

# Fraunhofer

magazine

3/20

## Perspectives H<sub>2</sub>

How to  
stay mobile:  
**Hydrogen** –  
a source of  
energy and a  
source of hope

Sebastian  
Porstmann,  
Fraunhofer  
IWU



**Hildegard Müller:** "Individual mobility must remain affordable!"



**Prof. Reimund Neugebauer:** "Change is no longer a vision. It is a reality."

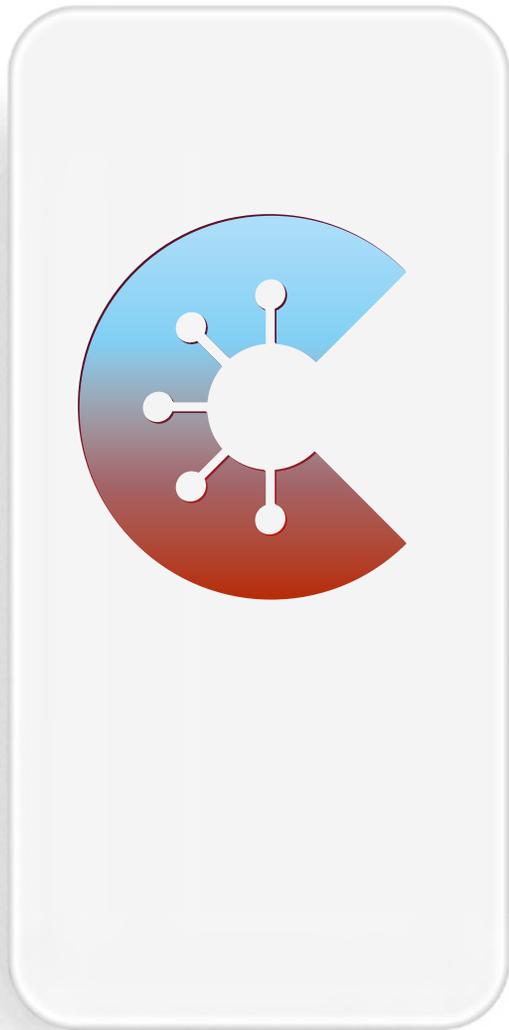


**Robert Habeck:** "As a society, we are outgrowing the car."

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2020

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# The spirit of Fraunhofer: driving innovation in a time of change



Prof. Reimund Neugebauer  
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The European Commission has just unveiled its new climate target plan. Over the space of 23 pages, this document maps out how Europe intends to mark a 55 percent reduction in CO2 emissions over the period from 1990 to 2030.

German politician Ursula von der Leyen, president of the European Commission, is seeking to turn Europe into the world's first climate-neutral continent by 2050. The UK oil company BP has already taken a lead and reduced its oil and gas production by 40 percent.

"In less than 30 years from now, we will no longer be flying with aircraft that consume less and less aviation fuel; we will be flying with aircraft that have dispensed with fossil fuels altogether," states Peter Altmaier. When asked how we can meet these increasingly ambitious targets, Germany's Federal Minister for Economic Affairs and Energy replies: "I have every confidence in the ingenuity of our engineers."

**Change is no longer a vision. It is a reality.** If we wish to remain spatially mobile in the future, then we need to show mental mobility today.

As a matter of fact, the German economy has already returned to growth in the third quarter of the year. Meanwhile, German automakers are doubling their range of electric vehicles. As the "voice of industry" in this edition of Fraunhofer magazine, Hildegard Müller, president of the German Association of the Automotive Industry (VDA), calls on industry "to make climate-friendly technologies a European export success." Let us rise to meet this challenge.

Hydrogen offers a key source of energy and a key source of hope for the future. Fraunhofer experts from many different institutes are now busy charting the route to a workable hydrogen economy. Meanwhile, the German federal government has presented its National Hydrogen Strategy and established a National Hydrogen Council, members of which include two proven experts from Fraunhofer, Karsten Pinkwart and Sylvia Schattauer. As the overarching organization for applied research in Germany and Europe, the Fraunhofer-Gesellschaft is ideally placed to provide industry and administrations, both in Germany and Europe, with strategic advice and comprehensive systems knowledge.

Let us combine the spirit of Fraunhofer with the current momentum for change and launch a new push for innovation. In a technology-based society, ensuring a secure, efficient, environmentally friendly and publicly accepted supply of energy remains a key – perhaps the key – task.

Yours sincerely,

Reimund Neugebauer  
President of the Fraunhofer-Gesellschaft

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It looks like history, but represents the future: Sören Scheffler, project leader at Fraunhofer IWU in Chemnitz, sits in his Silberhummel race car. The vehicle is based on drawings for a race car that was designed by Auto Union during the 1940s but never made – and is equipped with fuel-cell drives. How the future technology of hydrogen is creating mobility: the front-page story provides an overview.



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The European SeaClear initiative helps clean up plastic waste at the bottom of the ocean

Traveling hundreds of kilometers for a one-hour meeting – before the coronavirus pandemic, that was typical for many professionals. The pandemic forced a transition to digital meetings, and the results are in: it works! And it is environmentally friendly to boot. Going forward, **90 percent of companies** plan to reduce business trips, instead relying on conferences via telephone or video, as determined by a study of Fraunhofer Institute for Industrial Engineering IAO.

**90%**

## Coffee grounds: too good to throw away

Despite containing valuable substances, coffee grounds generally end up in the garbage can.

Researchers at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT are seeking to turn coffee grounds into valuable intermediates. These include bioplastics and additives for different types of paper.

The InKa project comprises a number of stages: separation of the coffee grounds into rational component groups, purification of these components, and, in particular, the investigation of high-grade uses for the resulting intermediates.

Although not suitable for consumption, coffee oil can be converted into a valuable chemical intermediate. Researchers are investigating whether such biobased building blocks might be used to synthesize polymer additives such as plasticizers.

Work is also underway to examine the use of deoiled coffee grounds as an alternative raw material for the paper and cardboard industry. After comminution, the coffee grounds are mixed with pulp for further processing. These steps are now being tested with partners from the paper industry. The recycling process can also be used to recoup and reuse glycerol, fatty acids, polysaccharides and flavorings. In addition, a material flow analysis is being conducted in order to identify any potential impact on the market supply of raw materials.



A popular beverage worldwide, coffee is consumed in enormous quantities. Germany alone accounts for some 400,000 metric tons of roasted coffee a year.  
© istockphoto

## A mobile cleaning robot for industry

Hygiene is vital in the food, pharmaceutical and cosmetic industries, where production facilities and other workspaces are still cleaned largely by hand. This is a time-consuming process and also prone to mistakes. Now, however, an autonomous cleaning robot with self-learning capability could soon be taking on this task.



With its telescopic arm, the robot is able to reach higher areas without difficulty.  
© Fraunhofer IVV

Known as the Mobile Cleaning Device 4.0 (MCD), this robot has been developed at the Fraunhofer Institute for Process Engineering and Packaging IVV in Dresden. It is currently available in two variants: one rides a conveyor belt down the production line and cleans the processing machinery from the inside; the other cleans the floor, walls and ceiling of workrooms and the outer surface of machinery. The robot moves autonomously and has a telescopic arm fitted with a jet cleaner. It is supplied with cleaning agent via a hose from a docking station and controlled via Wi-Fi.

The robot is equipped with a range of sensors that determine its position in the room and identify the type and degree of dirt. As Max Hesse, head of the Hygienic Production, System Development and Simulation team,

explains: "Using UV light, a detector is able to spot fluorescing particles of dirt such as fats, vitamins and proteins. It then determines parameters such as the thickness and dryness of the dirt and adjusts the amount of detergent and water accordingly. This is enabled by an AI-based self-learning system, which selects the right cleaning parameters and specifies the individual process steps."

**The robot monitors the success of the cleaning operation on the fly** and supplies these results to a digital twin. Thanks to its AI-based self-learning capability, the robot is able to continuously improve the cleaning process. This means, for example, that it only ever uses as much detergent as is actually required. "Our tests have shown that this can lead to savings of up to 50 percent," says Fraunhofer IVV.

# Eyes peeled!

## Responding rapidly to vineyard pests

Extreme weather and increasingly frequent attacks by known and unknown pests: climate change is creating new challenges for winegrowers. EyesOnTraps from the Fraunhofer Center for Assistive Information and Communication Solutions AICOS in Portugal is a mobile system for insect detection that leverages artificial intelligence and crowdsensing.



Phylloxera, vine moth and other pests are on the increase in wine-growing areas.  
© Stocksy/F1online



Alto Douro in Portugal is the world's oldest wine-growing region. Plagues of insects now pose a serious threat to grape quality and grape yields in this area. Meanwhile, rising temperatures mean that such pests are now increasingly found in German wine-growing areas.

The difficulty facing growers is to determine which type of insect has infested vines and to what degree. Traps are used to monitor the vineyards, but it takes a trained human eye to identify which insects are in a trap. Taxonomy experts on hand help to scientifically classify the findings. Yet this type of risk monitoring is time-consuming and costly, and it also fails to generate any geographical data on the spread of the infestation.

**Fraunhofer researchers have now developed a system** that enables automatic identification of the various insects. EyesOnTraps also records local temperature data and offers concrete recommendations on how to treat any identified diseases. This reduces human error and improves the quality of analysis.

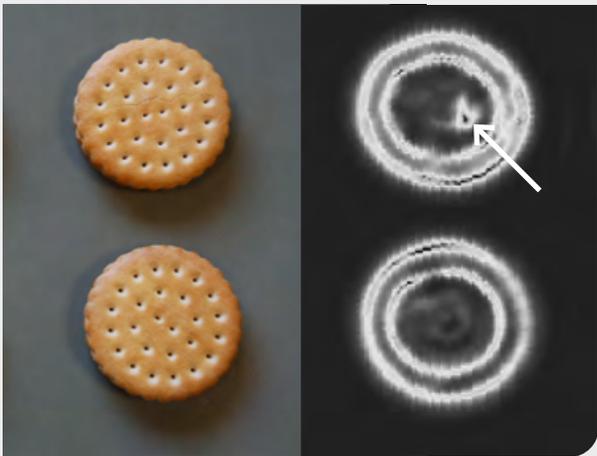
EyesOnTraps comprises three modules: (1) a mobile application enables the winegrower to enter and identify trap contents via smartphone, to register local temperature trends and to record the phenological status; (2) a central web module stores the information entered via the app and provides recommendations; (3) a web portal, which can also be used by other taxonomy specialists, enables automatic monitoring of different parcels and regions. EyesOnTraps is to be continually updated, so that it will also be able to recognize new types of insects.



## Detecting glass fragments in food

Foreign matter in food poses a real hazard. In particular, nonmetallic contamination can be difficult to spot. A new prototype by the name of SAMMI® remedies this problem.

Time and again, foodstuffs get recalled because they have been accidentally contaminated, during production, with fragments of plastic, glass, metal or wood. Although many manufacturers now use X-ray scanners to monitor their products, this type of system often has difficulty identifying small pieces of plastic, wood or glass.



A radar image clearly reveals the presence of glass splinters in the filling of a chocolate cream cookie. © Fraunhofer FHR

Technology based on millimeter waves can remedy this problem. SAMMI® is a prototype developed by a team of researchers at the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR. Using electromagnetic radiation in the 90 GHz range, this system can reliably detect splinters of glass placed in the filling of a chocolate cream cookie.

**SAMMI® is very easy to use:** simply place the foodstuff on the conveyor belt for automatic scanning. A transmitter antenna positioned above the belt emits millimeter waves that penetrate the food and are picked up by a receiver antenna. Glass splinters affect the signal in a different way than the chocolate filling and are therefore easily detected. At 40 × 40 × 30 centimeters, the prototype is highly compact, yet it can still handle foodstuffs up to a dimension of 30 × 30 × 5 centimeters. Should concrete applications so require, it would also be possible to produce larger devices.

## A patch to track fitness

A small patch delivers real-time monitoring of the cardiovascular system during physical activity.

In addition to regulating body temperature, perspiration also contains important biochemical information regarding an athlete's fitness. Working with partners from abroad, researchers at the Fraunhofer Institute for Reliability and Microintegration IZM have now developed a pliable sensor system in the form of a plaster, which captures and analyzes this information in real time and then displays it on a digital device.

The XPatch incorporates an antenna along with integrated circuitry for wireless communications with a Bluetooth-capable device, a pliable microbattery providing an independent power supply, a sensor chip and power management controls. Microelectronics experts at Fraunhofer IZM have also devised a sophisticated assembly technique in order to create a flexible patch that incorporates ultrathin biosensors and other



XPatch, a new electronic plaster, tells athletes how effectively they are training. © Fraunhofer IZM/Stocksy/F1online

electronic components. This delivers an application suitable for use by athletes. Ultimately, researchers are aiming to make the entire system, including all integrated components and functions, substantially thinner than one millimeter. Meanwhile, fully functional prototypes are to undergo testing under real conditions this year.

### Editorial notes

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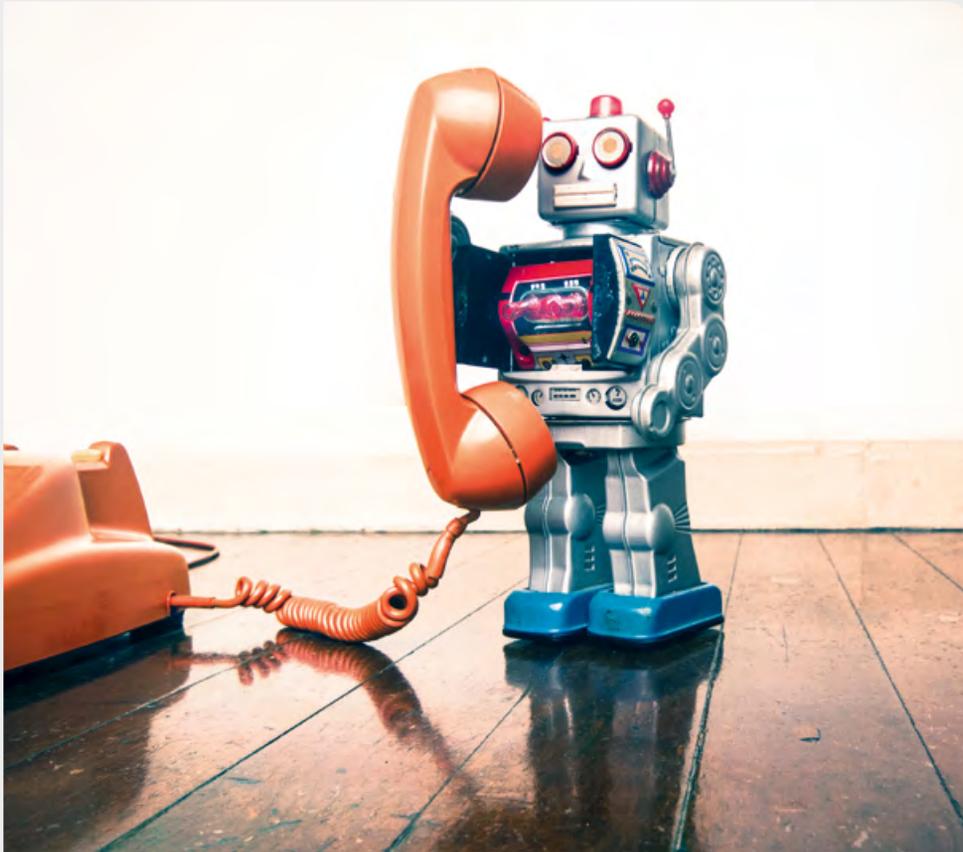
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# Chatbots on the line

Users are happy to use automated services when shopping or banking online. For online inquiries, acceptance is not as high.



For standard inquiries, users are more likely to encounter an automated system than a human voice at the end of the line.  
© AdobeStock

## Automated inquiries

A survey by the Fraunhofer Institute for Industrial Engineering IAO looked at whether the use of artificial intelligence (AI) in online services is a risk or an opportunity for companies. The results showed that almost all respondents (94.1 percent) regularly make use of automated services when purchasing goods online. Usage was similarly high for online ticket purchases (93.3 percent) and online banking (91.9 percent). When it came to online inquiries, however, only 23.7 percent of respondents said they were prepared to interact with a chatbot.

To gain acceptance and encourage regular use, human-machine interaction has to function without any hiccups. This is especially important in environments where customers need to be able to handle online or telephone systems without human assistance. When online assistants such as Alexa or Siri are unable to understand users, or when callers have to

fight through a complicated interactive voice response system, such automated services defeat their own purpose and, in the worst case, frighten customers away.

**Flexibility and fast service are what users prize most in automated services.** In such cases, they believe that AI can significantly enhance communications between companies and their customers. User acceptance is particularly high for services that can be accessed from home or via smartphone when out and about. When it comes to complex inquiries at hotels or stores, however, respondents said they still prefer the personal touch.

“The trend is towards the best of both worlds,” explains Elisabeth Büllesfeld, who ran the study at Fraunhofer IAO. “The challenge is therefore to develop AI-based online services that meet the wishes and expectations of users.”

Of all respondents, only  
**23.7%**  
said they would interact with a chatbot

# Perspectives

# H<sub>2</sub>



By 2050, we will need 3000 times as much hydrogen as in 2015. Yet how will this be **produced**?

Will **ships** be powered by hydrogen?

How many **hydrogen stations** will Germany have three years from now?

Will **racing cars** run on hydrogen?





Will I be able to refuel my **motorbike** with hydrogen?

Will we be able to **fly** with hydrogen?

Will we see a **Silberhummel** on our roads?

Can hydrogen safeguard Germany's **future viability** as an industrial location?



© Daniela Leitner

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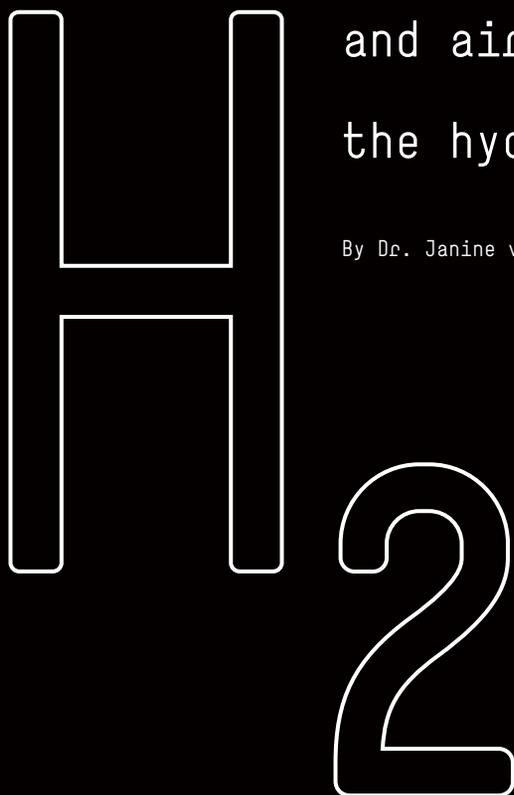
# HOW

Sören Scheffler, from Fraunhofer IWU, in his Silberhummel, which is based on design drawings for a racing car that was never built. It is fitted with a fuel cell drive.  
© Roger Hagmann

# we can stay mobile

Gasoline and diesel engines - powered, as they are, by fossil fuels - are about to reach the end of road. Instead, new propulsion systems are urgently required for road, rail, sea and air. Is this the dawn of the hydrogen age?

By Dr. Janine van Ackeren



## >> Germany already has one of the best networks of H<sub>2</sub> filling stations.

Prof. Christopher Hebling, division director of Hydrogen Technologies at Fraunhofer ISE and spokesperson of the Fraunhofer Hydrogen Network

As the HYRAZE League shows, the latest mobility trends have now reached the world of motorsport. Scheduled to launch in 2023, this new series will be contested by cars powered by hydrogen. Although equipped with 800-horsepower engines boasting an acceleration that can propel them from zero to 100 km/h in less than three seconds, these racing machines will produce practically no emissions.

Fraunhofer, meanwhile, is working to preserve a piece of history for the future. In a project known as Silberhummel – “Silver Bumblebee” – the Fraunhofer Institute for Machine Tools and Forming Technology IWU is seeking to bring together two branches of engineering: the low-cost development of prototype vehicles and fuel cell technology. The Silberhummel project is based on a racing car designed – but never produced – by the automaker Auto Union AG, back in 1940. Fraunhofer IWU has reconstructed the vehicle, including body parts, and fitted it with a fuel cell drive. “Our Silberhummel will remain at the cutting edge of fuel cell technology,” explains Sören Scheffler from Fraunhofer IWU, “because we are going to successively replace components as newer and improved ones become available.”

**Yet hydrogen can do more.** And more is expected of hydrogen. Indeed, hydrogen can provide the key to achieving the world’s climate targets. This is the key message of the German federal government’s National Hydrogen Strategy, a plan of action that covers 38 measures designed to promote the production, transport and use of hydrogen – and which thereby maps out the necessary steps required to achieve key climate goals. These include, for example, the creation of between 1.5 and 2 gigawatts of installed capacity for the

electrolysis of green hydrogen by 2023 and a 20 percent increase in the share of renewable energy in the transport sector by 2030. In short, the promotion of technologies based on green hydrogen is vital for Germany’s future viability as an industrial location. Federal government is supported in this task by the National Hydrogen Council, members of which include Dr. Karsten Pinkwart from the Fraunhofer Institute for Chemical Technology ICT and Dr. Sylvia Schattauer from the Fraunhofer Institute for Microstructure of Materials and Systems IMWS.

### What can hydrogen bring to future transport?

Hydrogen still plays a minor role in the transport sector. There are still only a couple of hundred H<sub>2</sub>-powered cars on German roads, but this will have to change fast if federal government is to meet its climate targets. Despite the low number of hydrogen cars, Germany’s position regarding hydrogen technology is not too bad. “We already have one of the best networks of hydrogen stations,” explains Prof. Christopher Hebling, division director of Hydrogen Technologies at the Fraunhofer Institute for Solar Energy Systems ISE and spokesperson of the Fraunhofer Hydrogen Network. “And there are plans to expand from 100 to 400 stations over the next three years.” It makes good sense primarily to use hydrogen where longer distances are involved – heavy goods transport, for example, inland shipping, and rail transport on branch lines that have not yet been electrified. As with electric vehicles, green electricity – in other words, electricity generated from renewable energy sources such as wind and sun – can be used to produce hydrogen that is then utilized to power vehicles on a local and carbon-free basis. ►

There are still only a couple of hundred H<sub>2</sub>-powered cars on German roads, but this will have to change fast if federal government is to meet its climate targets.

H<sub>2</sub>

Production of green hydrogen is a key task: Dr. Sylvia Schattauer inspects a mini electrolyzer installed in the lab of Fraunhofer IMWS.  
© Roger Hagmann

► If future transport is to be run largely on hydrogen, then certain preparations must be made now. This means enhancing the technology, especially fuel cells and electrolyzers, establishing technical and industrial standards, and expanding the infrastructure for distribution and refueling. Fraunhofer researchers are currently involved in a host of projects to promote hydrogen technology and support the industry. At the same time, the Fraunhofer-Gesellschaft is providing government with expert consultation. For example, Fraunhofer has recently published *A Hydrogen Roadmap for Germany*, which sets out its own scientific position regarding hydrogen electrolysis and hydrogen use. This report has also been made available to the federal chancellery and to federal ministries that worked on the development of the National Hydrogen Strategy.

**The Fraunhofer H<sub>2</sub>D initiative creates an overarching strategy** that pulls together various institutes and specific expertise. H<sub>2</sub>D is also intended to provide inspiration for people in government, business and society. The Fraunhofer Hydrogen Network, meanwhile, was established to simplify the sharing of expertise in the field of hydrogen technology. All in all, a total of 28 Fraunhofer institutes are now using the network to swap information and coordinate collaboration. At the same time, a number of hydrogen alliances have formed on the regional level. These include the H<sub>2</sub>-Innovationslabor Heilbronn-Franken, a project which aims to turn the Heilbronn-Franken region into a pilot area for the development of hydrogen-related concepts – and which involves the participation of various scientific institutions as well as the Research and Innovation Center for Cognitive Service Systems KODIS, a branch of the Fraunhofer Institute for Industrial Engineering IAO. A further initiative is the HZwo innovation cluster, which aims to bolster, at three different locations, Saxony's research

expertise in fuel cell technology, high-temperature electrolysis and other areas of hydrogen technology.

### How can sufficient (green) hydrogen be produced?

One problem hindering the advent of hydrogen-powered transport is a bottleneck in H<sub>2</sub> production. This therefore requires substantial expansion. "In 2015, we had 21 megawatts of installed capacity for electrolysis," explains Prof. Ralf B. Wehrspohn, Executive Vice President, Technology Marketing and Business Models, at the Fraunhofer-Gesellschaft. "By 2050, we will need 3000 times that, though not all of it for transport. In other words, we need to have capacity growth of between 1 and 5 gigawatts a year by 2030." At present, the electrolyzers – which use electricity to generate hydrogen – are still produced largely by hand. To be able to produce this equipment in the requisite volume and with the requisite capacity, system reliability must be improved and suitable production technologies developed. This means automating the production of such equipment, upscaling production to an industrial level and thereby reducing production costs. Fraunhofer ISE, for example, is currently investigating how to reduce the costs of building electrolyzers. Here, researchers are developing new membrane materials, working to extend cell lifetime with an anticorrosion coating, and running endurance trials to test durability. Meanwhile, fellow researchers at the Fraunhofer Institute for Ceramic Technologies and Systems IKTS are combining high-temperature electrolysis with the Fischer-Tropsch Synthesis – an industrial process for coal liquefaction. This pilot plant is to be installed at a lime works belonging to the company Johann Bergmann. It will initially be upscaled to 10 kilowatts and then provide the basis for further upscaling. ►

» In 2015, we had 21 megawatts of installed capacity for electrolysis. By 2050, we will need 3000 times that, though not all of it for transport.

# H<sub>2</sub>D

Researchers from a range of Fraunhofer institutes are working to remove the bottleneck in hydrogen production.



Katharina Pautsch and Dr. Achim Schaadt from Fraunhofer ISE are designing mini plants for the conversion of renewable energy into liquid fuels and chemicals such as methanol and oxymethylene ethers.

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► All this development work to build larger electrolyzers must be accompanied by testing on an industrial scale. This will be possible at ELP, an electrolysis test and trial platform currently being built in Leuna by the Fraunhofer Institute for Microstructure of Materials and Systems IMWS and the Fraunhofer Center for Chemical-Biotechnological Processes CBP. This facility is scheduled to start operation at the beginning of 2021. “ELP will be the first test platform to provide technology-neutral system testing on this scale,” says Dr. Sylvia Schattauer, deputy director of Fraunhofer IMWS. “With a total connected load of 6 megawatts, the capacity of our four ELP sites will be significantly higher than the manufacturers’ own test capacity.” Moreover, the infrastructure is unique anywhere in Germany. The hydrogen produced at ELP – on the basis of a connected load of 6 megawatts, this can easily amount to several metric tons – will be fed into a 157-kilometer-long H<sub>2</sub> pipeline operated by the company Linde. In other words, not only will hydrogen be efficiently generated in Leuna, but it will also be efficiently transported, via this pipeline, for use in the chemical parks of Central Germany, and in hydrogen stations and other projects. At the same time, the installation of the Hy2Chem upscaling platform, which is to be connected to the ELP, will mean that hydrogen generated on an industrial scale can be used for the sustainable production of basic chemicals and fuels.

**When driven by green hydrogen** – in other words, hydrogen generated by electrolyzers powered with renewable sources of energy – hydrogen-based transport makes sound ecological sense. This, however, leads to another problem: wind and solar energy fluctuate greatly, with the result that the electrolyzers often have to operate at different partial loads. What effect does this have on the electrolyzers? And how can they be best operated so that wind turbines no longer have to be shut down whenever there is an excess supply of electricity but can remain operational, with the surplus energy then being converted to hydrogen and stored in this form? Researchers from the Fraunhofer Institute for Wind Energy Systems IWES are currently investigating these

questions. They plan to construct a 2-megawatt electrolyzer unit that will be capable of generating up to one metric ton of hydrogen a day. As of 2022, this new testing site will offer customers from industry the opportunity to trial their own electrolyzers and complete systems within a variety of grid scenarios.

**A completely different approach** to the production of green hydrogen – without electrolyzers and without wind or photovoltaic systems – is the focus of HyPerFerMent, a development project conducted by the Fraunhofer Institute for Factory Operation and Automation IFF together with partners. “We use a biogas unit to produce hydrogen from biowaste,” explains Dr. Torsten Birth, group manager at Fraunhofer IFF. The basic concept is simple: microorganisms produce carbon dioxide and hydrogen from biowaste in a process known as dark fermentation. This hydrogen is then separated off. “In the long term, this means that the 9500 biogas units currently active in Germany could not only contribute towards hydrogen production but also become more efficient and operate more economically than before,” Birth says. At present, researchers are investigating the process at the lab and pilot scale. In 2021 a pilot plant is to be connected directly to a biogas unit.

### Has the fuel cell drive achieved technological maturity?

Among hydrogen-powered drive systems, the fuel cell is the most familiar. All of the H<sub>2</sub>-powered cars currently on the market are equipped with this type of drive: the Toyota Mirai, Hyundai NEXO, Hyundai ix35 FCEV and Mercedes-Benz GLC. Technologically speaking, the fuel cell reverses the process of electrolysis: hydrogen reacts with oxygen to form water, thereby producing electrical energy, which is then used to drive an electric motor. As in the case of electrolyzers, fuel cells are still largely manufactured by hand. However, if fuel cells are to become a standard feature of automotive engineering, an inexpensive method of production is required. ►



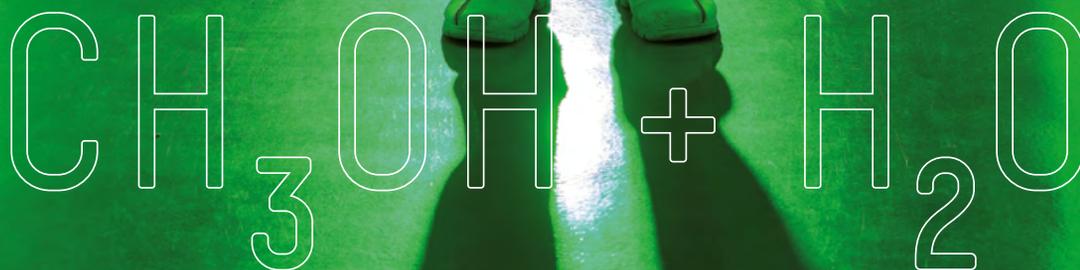
We use a biogas unit to produce hydrogen from biowaste.

Dr. Torsten Birth, group manager at Fraunhofer IFF

In the long term, the 9500 biogas units in Germany could contribute to hydrogen production and thereby operate more efficiently and economically.

>> Our method can reduce emissions from shipping by as much as 97 percent.

Dr. Benjamin Jäger, research associate at Fraunhofer IKTS



When it comes to marine propulsion systems, methanol has magical properties for Dr. Benjamin Jäger from Fraunhofer IKTS. He is working on HyMethShip, a project to use methanol as a marine fuel that produces practically no emissions.  
© Roger Hagmann

► Each car requires much more than just a single fuel cell. A 100-kilowatt vehicle, for example, is equipped with a stack of 400 fuel cells. Given that each day, anything between 1000 and 1500 cars roll off the assembly line in a single automobile plant, it is evident that the scale of fuel cell production must enter a whole new dimension. In terms of cost, too, mass production is vital, as it is only in excess of around 100,000 stacks a year that production for a high-volume use in automobile manufacture will become cost-effective. For this, however, a large number of unresolved production issues must still be determined. This is one of the tasks currently facing the Fraunhofer Institute for Production Technology IPT. “We are creating a research infrastructure that will enable us to run through the entire production process on an industrial level,” says Dr. Christoph Baum, managing chief engineer of Fraunhofer IPT. This will replicate the production process in such a way as to eliminate upscaling risks at each of the individual stages of production.”

**The EU project Fit-4-AMandA** – “Fit for Automatic Manufacturing and Assembly” – illustrates the extent to which – and, above all, the speed at which – it is possible to enhance the production of fuel cell stacks. It took just two years for an international project team, including Fraunhofer IWU, to develop an automated assembly line for PEM stacks on behalf of the company Proton Motor Fuel Cell. “This boosts production capacity from currently 300 to as many as 5000 stacks a year, depending on stack size,” explains Sebastian Porstmann from Fraunhofer IWU. “At the same time, it reduces assembly times by as much as 95 percent and assembly costs by as much as 90 percent.” Indeed, with slight adjustments to machinery layout, it may be possible to increase production volumes to as high as 30,000 stacks a year. The automated assembly line was jointly developed by the six project partners and delivered to Proton Motor Fuel Cell at the end of May 2019. The Fraunhofer research team was responsible for a number of aspects, including a profitability study, an analysis of the manufacturing process

for bipolar plates and a risk assessment to determine the risks involved in supplying bipolar plates to a market that is only just emerging.

In HOKOME, another Fraunhofer project, five institutes – IWU, ISE, IWS, IKTS and IPT – are seeking to upscale production to an industrial level with technologies that enable the manufacture of between 50 and 60 stacks per minute. “What’s more, our production method can bring cost savings of up to 50 percent,” says Scheffler from Fraunhofer IWU. “We’re now using a roll-to-roll process to coat the MEA – the membrane electrode assembly – which is one of the two main components of the fuel cell.” The second of these components, the bipolar plate, is manufactured from a sheet of stainless steel only 0.05 to 0.1 millimeters in thickness – about as thin as kitchen tinfoil. As the sheet unwinds from a roll, the anode and cathode are produced in parallel by means of a forming process and then directly joined together to form the bipolar plate. In spring 2021, this method will transfer from the laboratory to an environment with conditions close to those of mass production.

When it comes to solid oxide fuel cells, there are various cost drivers. These include manual fabrication and the use of parts made of expensive materials, such as ceramic components in the supply lines. However, researchers at the Fraunhofer Institute for Mechanics of Materials IWM have now discovered a way of coating steel that increases its resistance to hydrogen, compared to noncoated steel, by a factor of around 3500.

### What are the alternative H<sub>2</sub>-powered drives for vehicles?

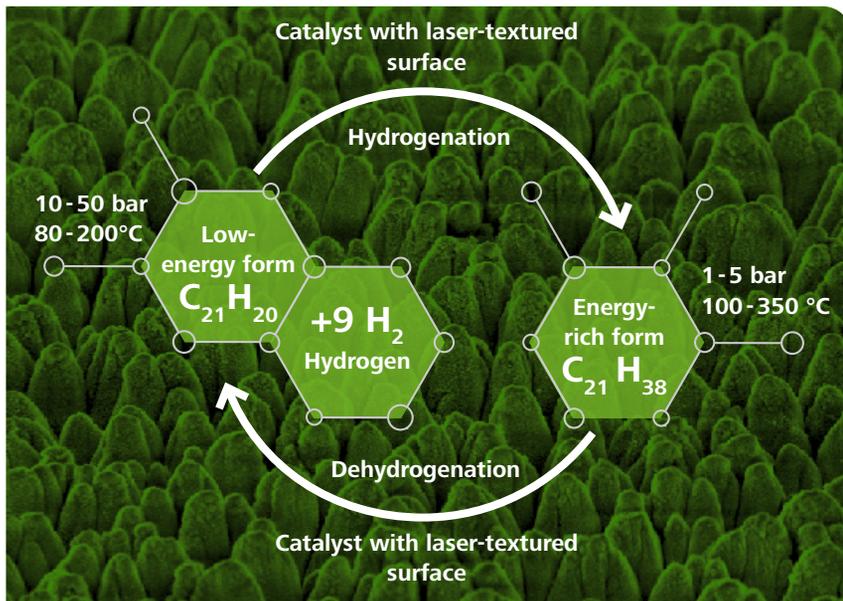
Although the fuel cell offers the most familiar way of exploiting the chemical energy stored in hydrogen, it also has some fairly serious competitors. One of these is the combustion engine, which offers great flexibility in terms of the fuel on which it can run. ►

# Fit-4-AMandA



Dr. Marcus Vogt from Fraunhofer IFAM: PowerPaste means that hydrogen vehicles can refuel in areas lacking in infrastructure.  
© Roger Hagmann

It took just two years for an international project team, including Fraunhofer IWU, to develop an automated assembly line for PEM stacks.



Laser texturing to the surface of a metal catalyst enlarges its area, thereby enhancing the efficiency of the reaction to produce liquid organic hydrogen carriers (LOHCs). When bound in this form, hydrogen can be stored without hazard. Source: Fraunhofer HHI © Graphics: Vierthaler & Braun

► For example, a hydrogen-powered combustion engine burns an ignitable mixture of hydrogen and air in the combustion chamber. What makes this type of engine interesting is not least the fact that it can be modified – by adapting the relevant components – to operate as a bivalent engine that can be run on either hydrogen or a carbon-neutral gasoline fuel. The direct combustion of hydrogen is one of the areas of interest at Fraunhofer ICT. Here, researchers are developing and refining combustion processes and related technology in a program that combines computer simulation and concrete experimentation with single-cylinder research engines. Hydrogen has superb combustion properties, meaning that an internal combustion engine can be run on a very lean mixture of hydrogen and air. As a result, only low levels of nitrogen

oxides are produced within the engine, and these can be reduced to almost zero by means of simplified exhaust gas treatment. Furthermore, unlike conventional combustion engines, hydrogen engines do not produce any carbon-based emissions, which otherwise necessitate the use of increasingly sophisticated methods of exhaust gas treatment.

**The key question regarding the direct combustion of hydrogen is what if something happens to the vehicle.** After all, hydrogen is not only a powerful energy carrier but also highly explosive. A research team at Fraunhofer ICT is currently investigating a range of scenarios, including the worst case. Under what conditions might a critical event occur? Are there cavities in the vehicle where escaped hydrogen might accumulate? In the worst instance, how much pressure would build up there? The researchers calculate potential failures on the basis of key system data, identify and model likely scenarios and then verify the results on the basis of real tests. This means calculating the theoretical impact of possible failures and then, on this basis, pumping hydrogen into vehicle cavities and generating an explosion under controlled conditions. Fraunhofer ICT has its own test site for this purpose. It is designed to withstand a detonation force equivalent to that of 3 kilograms of TNT.

Hydrogen-based liquid fuels are also in competition with the fuel cell. The basic concept is simple: green hydrogen generated via electrolysis is combined with carbon dioxide or nitrogen – rather than being turned back into electricity via a fuel cell. The result is methanol ( $CH_3OH$ ), which in turn can be used to produce highly synthesized fuels – more precisely, oxymethylene ethers, which, similar to E10 in gasoline, can be used directly as a diesel substitute. This type of power-to-liquid (PtL) process makes sense primarily in areas where a rapid renewal of vehicle fleets is impracticable or where the conversion of existing infrastructure is prohibitively expensive. Indeed, one of the key advantages of this type of drive is that, in ideal circumstances, no changes must be made to the engine technology – and yet, compared to fossil

» Everyone knows we need to move to a sustainable energy economy, and hydrogen is an indispensable part of that process.

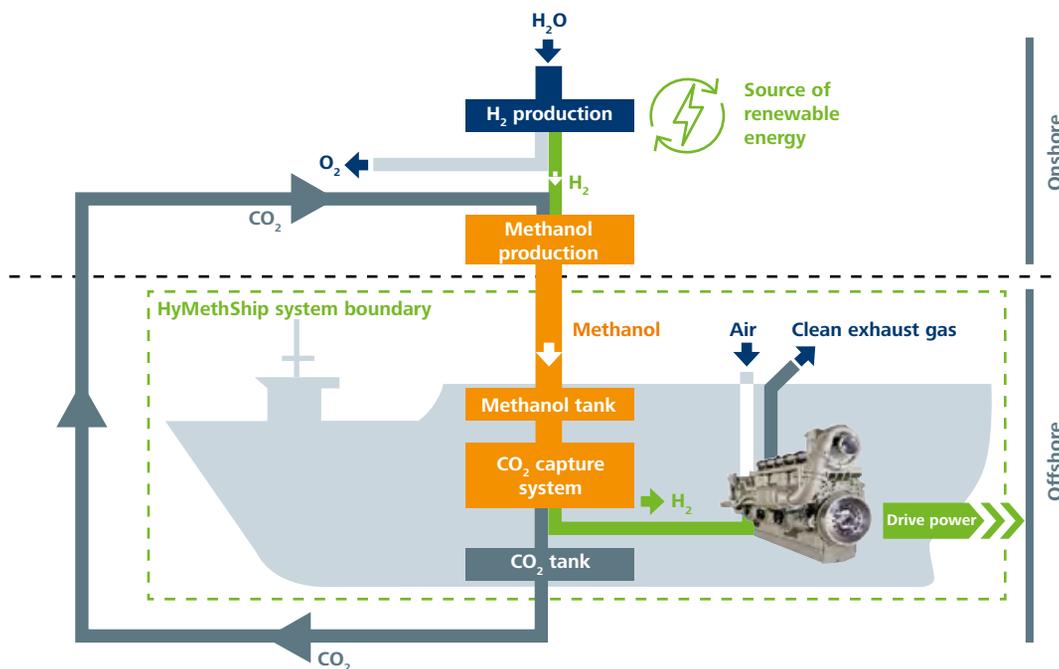
fuels, greenhouse gas emissions are reduced by as much as 90 percent over the entire functional chain. Moreover, due to their specific chemical structure, which does not include any C-C bonds, OMEs also produce very low emissions when combusted, which greatly reduces the local emission of pollutants. Similarly, in combination with CatVap®, a process developed at Fraunhofer ISE, power-to-liquid fuels could help to significantly reduce emissions of combustion engines. Fraunhofer ISE is currently investigating this potential in a number of projects, including Sylink and C3-Mobility. “In terms of efficiency, there’s not much to choose between fuel cells and oxymethylene ethers,” Schattauer says. “As far as cars are concerned, it’s really more a question of ideology.”

### Is hydrogen also suitable for powering trucks, ships, trains and aircrafts?

Far less ideological is the question as to whether fuel cells or liquid fuels are better for propelling ships, trucks and aircrafts. In this instance, liquid fuels have clear advantages, thanks to their high energy density. After all, every ounce of weight counts, especially in aviation, where high performance over long operating times is a necessity. In NAMOSYN, a project to develop synthetic fuels for sustainable transport, Fraunhofer

ISE has teamed up with a host of partners. Tasks include the race to devise a cost-effective method of producing OMEs. This covers the entire value chain, starting with the feedstocks, CO<sub>2</sub> and H<sub>2</sub>, and progressing to the development – including all the catalytic and separation processes – of a fuel that complies with current standards. In addition, the research consortium is investigating the in-engine use phase of OMEs, the compatibility of refueling infrastructure, the life cycle over the entire value chain and integration of these new fuels. “At Fraunhofer ISE, we’re looking at six alternative processes and evaluating them in terms of, for example, cost and carbon footprint,” says Dr. Achim Schaadt, head of department at Fraunhofer ISE. Vital to this work is a process simulation platform developed by the research team. This helps to identify the kind of process that would be required to produce a million metric tons of fuel a year. “There’s an interplay here between simulation and experimentation: we learn from the results achieved with small-scale plants and then feed these results into our simulation model,” explains Dr. Ouda Salem, head of the Power-to-Liquids group at Fraunhofer ISE. Another project partner is constructing a modular system with an output of 1 kilogram of OME an hour, while others are busy running engine tests. Incidentally, OMEs can be used not only as fuels but also as highly selective green solvents and CO<sub>2</sub> sorbents. ▶

With their high energy density, liquid fuels produced from hydrogen have clear advantages for the propulsion of ships, trucks and aircrafts.



Onshore, the ship refuels with methanol; onboard, this is reformed with water to produce hydrogen, which is directly combusted to power the ship. The resulting CO<sub>2</sub> is stored in tanks until the ship docks. It is then pumped into onshore tanks and reused for methanol production. © LEC GmbH



Samples of materials used to make the tank are placed in a pressure chamber filled with gaseous hydrogen, which is pressurized to the same level that will obtain in the actual tank.

Ken Wackeremann, research associate at Fraunhofer IWM

A demonstration plant designed to supply 1.6 megawatts of hydrogen power is scheduled to begin trials in early 2021.

► Liquid organic hydrogen carriers (LOHCs) are another way of safely storing large amounts of hydrogen in a small volume. This technology is currently under development at Friedrich-Alexander-Universität Erlangen-Nürnberg and the Helmholtz Institute Erlangen-Nürnberg for Renewable Energy. LOHCs bind hydrogen in a minimally flammable and nonexplosive form. This means such liquids can be safely stored, transported and pumped into fuel tanks. To release the hydrogen for further use, a mini reactor is required. This removes the hydrogen from the LOHC, which is then stored in a second tank until required for reuse. Given that the system requires two tanks and a reactor, LOHCs are not ideal for use in small vehicles. In the case of rail locomotives, however, where space is not an issue, they have great potential. To ensure an efficient reaction, large reactor surfaces are required. At the same time, the challenge is to keep the reactor units as small as possible. A research team at the Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute (HHI), is currently developing a technique to increase the available surface area of reactor plates. “We work the metal surface with a laser,” explains Prof. Eike G. Hübner from Fraunhofer HHI. “This creates a porous texture with sharp ridges, which enlarges the surface area by a factor of almost 100.” This project has already returned impressive results, which have led to the development of a reactor with modules of approximately 20 × 20 × 10 centimeters in area. This produces hydrogen equivalent to a power output of up to 5 kilowatts. There are now plans to install a number of these LOHC power packs in an approved locomotive, where they will produce enough hydrogen to power the engine.

**Researchers at the Fraunhofer IKTS site in Hermsdorf, Thuringia,** are currently working on a pioneering propulsion system for ships. Partners on the EU project HyMethShip include the shipbuilding company Meyer Werft. “Our method can cut emissions from shipping by as much as 97 percent,” says Dr. Benjamin Jäger from Fraunhofer IKTS, which is coor-

inating a key part of the project – methanol reforming. Such cuts are significant, not least because ships on the open seas still run on heavy fuel oil, which produces emissions such as sulfur compounds. Closer to shore, vessels switch over to diesel, which in turn releases nitrogen oxides and CO<sub>2</sub> into the atmosphere. All this can be avoided with hydrogen-powered propulsion: sulfur compounds are eliminated, nitrogen oxides cut to almost zero, and any CO<sub>2</sub> is recycled rather than being emitted into the atmosphere along with other exhaust gases. The propulsion system functions as follows: when in dock, the ship refuels with methanol. Unlike hydrogen, methanol is easy to store and does not pose an environmental hazard – even if, in the worst case, the tank were to strike a leak and empty completely. Here, methanol serves as a hydrogen carrier. Onboard, it is reformed, together with water, in a reaction that produces both hydrogen and carbon dioxide. The hydrogen is separated off by means of a membrane and then combusted directly in the ship’s engines to provide propulsion. The reforming process yields more hydrogen than is stored in the methanol, since water also contains hydrogen. Meanwhile, the CO<sub>2</sub> produced in the reaction is stored in tanks until the ship docks. This is then pumped into onshore tanks and reused in methanol production. The heat required for the reforming process is provided by the ship’s engines, which further increases the overall efficiency of the propulsion system. Jäger’s team has been responsible for complete process and reactor design and has also developed the membranes for the system. At the same time, researchers at Graz University of Technology, another project partner, are currently constructing a demonstrator plant designed to supply upwards of 1.6 megawatts of hydrogen power. Initial trials are scheduled to begin early next year, with test operation to follow in the middle of 2021. In addition, the consortium plans to produce a design study for a Scandinavian ferry fitted with a 20-megawatt propulsion system based on this innovative principle. By way of comparison, an oil tanker is equipped with engines delivering an output of 50 to 80 megawatts.



© Daimler Truck AG

## 1000 kilometers on hydrogen

One of the key arguments in favor of the GenH<sub>2</sub> concept truck (pictured) is its operating range of up to 1000 kilometers. Daimler hopes to make it the centerpiece of its coming commercial vehicles portfolio. The start of customer trials is planned for 2023, with mass production to follow in 2025. Alternative drive systems are set to remain significantly more expensive than diesel engines. According to management consultants McKinsey, it will be 2027 before the total operating costs of hydrogen-powered semi-trailer trucks are lower than those of diesel equivalents.

## And what about small vehicles such as motorcycles?

When it comes to hydrogen, a special approach is required for small vehicles such as motorcycles. After all, they can't simply roll up to the hydrogen station and fill up with gas – the pressure on the fuel tank would be too great. Besides, it would be impossible to achieve the required storage density by means of a high-pressure tank small enough to be fitted on a motorcycle. Now, however, a new development from Fraunhofer IFAM in Dresden aims to cater to such applications. PowerPaste is a solid fuel based on magnesium hydride. Instead of heading to the filling station, motorcyclists simply have to replace an empty PowerPaste cartridge with a new one and then top up a tank with water. "PowerPaste stores hydrogen in a chemical form at room temperature and atmospheric pressure," explains Dr. Marcus Vogt, research associate at Fraunhofer IFAM. Were a motorcycle to stand for hours in the baking sun, there would still be no danger, since PowerPaste only begins to decompose at temperatures of around 250°C. In fact, PowerPaste would also be an option for larger vehicles, especially where there is a lack of infrastructure in the form of hydrogen stations. After the cartridge is inserted, a plunger forces out the PowerPaste in

the precise quantity required by the fuel cell. Water from an onboard tank is then added, and the ensuing reaction produces hydrogen. As with the HyMethShip propulsion system, half of the hydrogen produced comes from the added water. "PowerPaste has an enormous energy storage density," says Vogt. "It is substantially higher than that of a high-pressure tank designed to withstand 700 bar. And compared to batteries, it has ten times the energy storage density." Fraunhofer IFAM is currently building a production plant for PowerPaste at the Fraunhofer Project Center for Energy Storage and Management Systems ZESS. Scheduled to open in 2021, this new facility will be able to produce up to four metric tons of PowerPaste a year – not only for motorcycles.

## How can hydrogen be safely transported and supplied at filling stations?

There are now around 100 hydrogen filling stations in Germany. This has created a new situation. "Back in 2016, the key question was how to fit hydrogen tanks in vehicles," explains Armin Keßler from Fraunhofer ICT. "But in the HySafe project, we are now focusing on the safety of individual components and aspects of hydrogen stations." ►

Conventional wisdom says that hydrogen should be used to power larger vehicles. PowerPaste from Fraunhofer IFAM shows it is also an option for motorcycles.

► Questions here include: how best to prevent a buildup of excess pressure in a hydrogen tank. The solution from Fraunhofer ICT is to make a hole in the tank and then reseal this with epoxy resin. As the pressure rises in the tank, the temperature increases, causing the epoxy plug to melt and rupture within a couple of seconds, thereby releasing the entire tank contents. Fraunhofer researchers are also analyzing what happens in the event of an explosion and which measures are most effective in containing this.

Materials are tested for their properties in the hydrogen lab at Fraunhofer IWM, which has equipment to pressurize hydrogen up to 1000 bar.

**And then there is still the question of how best to store hydrogen at filling stations.** At present, the hydrogen is stored in pressurized tanks. Yet there are drawbacks with this method. For example, it requires the use of elaborate pressurizing and cooling systems. Here, too, an alternative is to use liquid organic hydrogen carriers. LOHCs make it possible to safely transport and store – at no loss – this otherwise highly explosive gas. Researchers at Fraunhofer IAO have integrated Europe’s first LOHC storage unit of the latest generation, with a storage capacity of 2000 kilowatt-hours, into the Micro Smart Grid at the Fraunhofer Institute Center in Stuttgart. As for the question of how to use LOHCs for refueling purposes, the requisite technology is currently being developed by researchers at Fraunhofer HHI, as part of the LOReley project. Funded by the German Federal Ministry for Economic Affairs and Energy, this focuses on the high-capacity production of hydrogen by LOHC reactors equipped with efficient surface catalysts. The key component of the project is the reactor, which is currently under development by researchers. Designed for vehicle-refueling purposes, this will efficiently extract hydrogen from a carrier oil at a continuous output – in terms of the amount of hydrogen produced – of at least 1 kilowatt and a peak output of 5 kilowatts. In other words, reactor modules should have a simple design, be of compact dimensions and combinable in modular fashion up to the required performance category, and yet still provide formerly unattainable space-time yields. This is enabled by laser-textured reactor plates, as developed by Fraunhofer HHI, which substantially enhance reaction efficiency. This kind of LOHC refueling station can also be designed as a mobile application. In this case, the LOHC will be stored and transported in a tank truck, along with a mobile reactor.

### A solar-powered filling station for hydrogen

Fraunhofer ISE produces its own green hydrogen at a solar-powered filling station, which the institute has been operating since March 2012. “We cover the entire process chain – from photon to traction,” says Dr. Tom Smolinka, head of the department for Chemical Energy Storage at Fraunhofer ISE. Using its own locally generated solar power, the institute operates an electrolyzer fitted with a modern

membrane technology and housed in a container. The resulting hydrogen is compressed to 900 bar and stored in a high-pressure tank. The refueling process takes place at a pressure of 700 bar, lasts between three and five minutes and is free of charge. “But we’re not really aiming to refuel hundreds of cars,” says Smolinka. “Our solar-powered filling station provides us with a research and technology platform. It has a lot of measurement systems for monitoring purposes and also has a control system that enables flexible operation.”

### Safe and recyclable vehicle tanks

Further research is required for the development of vehicle tanks, not least because hydrogen is highly explosive. Before tanks can be installed in vehicles, the materials to make them must first be tested for strength. This is the work undertaken by researchers from Fraunhofer IWM in the institute’s own hydrogen lab, which has equipment to pressurize hydrogen up to 1000 bar. “Samples of materials used to make the tank are placed in a pressure chamber filled with gaseous hydrogen,” explains Ken Wackeremann, research associate at Fraunhofer IWM. “This is pressurized to the same level that will obtain in the actual tank. Samples are then subjected to mechanical stress by means of a special machine that literally tears them apart.” The point is to discover how much strain a material can withstand under realistic conditions. The researchers describe the material’s properties and then apply this to the geometry of the tank as a whole by means of the finite element method, a form of computer simulation. On the basis of these results, the researchers are able to say how thick the tank must be – or decide that other materials are required. In addition, the results of the simulation are checked, together with partners, by pressurizing a complete tank until it bursts. This shows whether the hydrogen tanks can actually withstand as much pressure as was calculated. The hydrogen pressure chambers have only been in operation since the end of August and still look completely new.

Other questions as yet unresolved include how the hydrogen tanks can be recycled. At present, most hydrogen tanks for mobile use are made of thermosetting plastics, which can only be shredded at the end of their useful life. Fraunhofer IPT has therefore switched to thermoplastics: the liner – a hydrogen-proof tank – is wrapped in sections of carbon fiber embedded in a thermoplastic matrix and bonded together thermally. By reversing this process, these materials can then be recycled: the sections are simply separated by means of heat. Researchers are now working to develop a suitable process to produce such tanks. After all, there is so much more at stake than the new HYRAZE motorsport series. Together with battery-powered electric transport, hydrogen offers the greatest hope for a future propulsion system that will enable as many people as possible to remain as mobile as possible. ■

Turboprop		 <b>&lt;100</b> Passengers   Hydrogen Hybrid Turboprop Engines (x 2)	 <b>1,000+nm</b> Range   Liquid Hydrogen Storage & Distribution System
Blended-Wing Body		 <b>&lt;200</b> Passengers   Hydrogen Hybrid Turbofan Engines (x 2)	 <b>2,000+nm</b> Range   Liquid Hydrogen Storage & Distribution System
Turbofan		 Hydrogen Hybrid Turbofan Engines (x 2)	 Liquid Hydrogen Storage & Distribution System

**AIRBUS**

© Airbus

### The dream of clean flying

Airbus hopes to realize its vision of zero-emissions aviation by 2030. This September, the company unveiled three design studies: a propeller aircraft, a jet aircraft and a so-called blended wing body aircraft, where the wings merge with the fuselage. Planned operating ranges are as high as 3700 kilometers, with capacity for around 100 or 200 passengers, depending on the aircraft type. Although lighter than kerosene, hydrogen in liquid form occupies around four times as much volume in order to deliver the same amount of energy. Trials of an initial prototype aircraft are planned over the next few years, with mass production to follow in 2035.

»» We're not really aiming to refuel hundreds of cars; our solar-powered filling station provides us with a research and technology platform.

Dr. Tom Smolinka, head of the department for Chemical Energy Storage at Fraunhofer ISE

# “Cities need to be bolder in the face of change.”

Many were captivated by the images of empty metropolises during the lockdown of spring 2020. However, the hesitance to resume normal life in some cities is increasingly becoming an issue. Restaurants, shops and cultural institutions are suffering as collateral damage of remote working and infection control. We talked to Willi Wendt and Claudius Schaufler, urban designers at the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart, about how cities are changing.

Interview by Mandy Bartel

## Mr. Wendt, how do you envisage the perfect city?

**Wendt:** For me, it is first and foremost about the quality of life of the city's inhabitants. This may sound straightforward, but quality of life is in fact rather subjective. This makes matters harder. That being said, there are some key elements that are important to everyone and that make a city inhabitable: safety, nature, social spaces. In recent years, access to the Internet has been another major factor for younger city dwellers.

## What visions for our cities have been pushed into the distant future by the coronavirus? And what has been brought forward by the pandemic?

**Wendt:** The concept of cities as social spaces has suffered in recent months. We need to be confident in the safety of our cities for this to be a reality again. And of course, cities have also seen a surge in digitization. At Fraunhofer IAO, we have conducted studies into the concerns that have become more prominent in urban communities due to the coronavirus. Digitization and agile administrative processes were top of the list. Interestingly, climate protection came in last. The reason for this is that cities now have so many other issues to focus on, which has caused climate protection measures to lag behind. It is also true that the trend towards remote working and fewer business trips has had a positive impact on city climates.

## Mobility is the word of the moment. Have people become less mobile or mobile in a different way? And what does this mean for cities?

**Schaufler:** People are physically moving from A to B less frequently. However, in the modern sense of urban design, they have become even more mobile. Ultimately, more options

are available. You can work remotely or travel to the office, and digitization means you can consider opportunities that are further afield.

**Wendt:** Most importantly, this has given more freedom to those with restricted mobility. At the same time, it is likely that public transport networks will find it increasingly difficult to maintain their services with fewer passengers.

**Schaufler:** We are also seeing this trend in urban communities. This requires new concepts. Many people switched to cycling, especially in late summer. Some cities reacted quickly to this, for example, with pop-up cycle paths. But it will be interesting to see what happens in winter. This is when we expect to see an increased use of cars again – contrary to the trend in recent years. Cities need to find a solution for this, too.

## Empty office buildings, a dying restaurant trade, ailing retailers – is the future of post-coronavirus cities really this bleak? Or is there some light at the end of the tunnel?

**Schaufler:** Change always brings opportunities. Repurposing is an important concept. Office blocks can be converted into highly sought-after living space, especially in major cities. It is likely that alternative uses will be considered during the planning of buildings in the future. Monofunctionality will give way to more flexibility. This also applies to municipal administrations. They have certainly become much more flexible as they have had to react quickly to current demands in recent months.

**Wendt:** Agility is important; cities are not static. This is why we need to rethink typical urban planning horizons that span 20 to 30 years. One example of this is Stuttgart train station, which



“Agility is important; cities are not static.”

Willi Wendt



“Ultimately, it is a matter of reinterpreting public space. People need to be reminded that cities are malleable.”

Claudius Schaufler

### City centers partnership initiative

The aim of the “City Centers 2030+ | Future Public Space” innovation partnership is to develop long-lasting solutions and concepts to make city centers more resilient, a better place to live and more flexible. Researchers at Fraunhofer IAO are testing concepts using strategic future scenarios as well as specific demonstrators and prototypes in real-world settings.

[www.iao.fraunhofer.de](http://www.iao.fraunhofer.de)

was being planned for decades and has now been outstripped by the demands of the current times in just a matter of months.

#### The IAO has recently launched an innovation partnership to help cities. What beneficial measures are being put forward?

**Schaufler:** Yes, we recently founded the “City Centers 2030+ | Future Public Space” initiative together with the “City Rescuers” association, which currently comprises 250 municipalities. Learning from one another and exchanging ideas is more important for cities now than ever before. Transferring knowledge of best practices – with regard to conversion measures, new administrative processes or the establishment of post-coronavirus action teams – is a novel concept. Living labs are another important element. Cities need to be bolder in the face of change. That is why we are planning a number of temporary experiments in public urban spaces over the next year: new mobility schemes, alternative space utilization, modified traffic routes and increasing citizen involvement. Ultimately, it is a matter of reinterpreting public space. People need to be reminded that cities are malleable. Another focus will be urban data to enable cities to make more evidence-based and fact-driven decisions in the future.

#### In all honesty, are our cities well equipped for the future?

**Wendt:** They are certainly better equipped now than they were before. This is because cities have had to learn how to handle unpredictable events flexibly. This situation has unveiled approaches that were previously hidden. This has also changed the way that urban leaders think. If this new way of thinking can be translated into structures, new processes and experimental spaces, our cities will be well equipped for the future. ■



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# Individual mobility must remain affordable

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The way forward in transforming mobility: an ecological, economical approach combining climate protection and economic growth

A guest contribution from Hildegard Müller, president of the German Association of the Automotive Industry (VDA)

“The coronavirus pandemic has shown us how important individual mobility is for the social involvement of many people and for a functioning economy.”

The coronavirus pandemic has presented us with a set of unprecedented challenges. We are currently experiencing the greatest economic crisis since the end of the war. During the first half of 2020, passenger car markets around the world collapsed. Moderate stabilization is now in sight, but it is unlikely that there will be a return to pre-crisis levels until 2022. The effects of a second wave are anyone’s guess as another shutdown of the economy would have disastrous consequences – and not just for the automotive industry. This situation, which has been exacerbated by the coronavirus, shows that we need to take a resolute approach to the transformation of the industry with regard to new drive systems and digitization. This transformation also needs to be socially, economically and ecologically sustainable.

Climate protection is one of the most pressing challenges of our time. We support the Paris climate protection objectives and are making climate neutrality in the transport sector a top priority. However, all of this means nothing if the European industry is weakened in competition with other markets in the name of climate protection. We have to think about economic success and climate protection alongside one another – intelligent regulation should make this possible. This is because the only way we can continue to invest so heavily in the restructuring of our economy and in solutions for climate-friendly mobility is with a sound economic foundation. That is why our efforts need to be

geared toward making technologies that protect the climate a European export success: modern industrial policy and climate protection made in Europe.

The coronavirus pandemic has shown us more than ever before how important individual mobility is for the social involvement of many people and for a functioning economy. All forms of mobility must also be affordable in the future. For this reason, all perspectives should be taken into account and the needs of people in both urban and rural areas have to be met with carefully considered mobility concepts that are open to all types of technology. Unilateral bans are the wrong approach because they jeopardize the acceptance of climate protection and delay the development of intelligent concepts that are needed to combine climate protection and economic growth.

## A socially sustainable transformation

As an industry with over 800,000 people directly employed in the automotive sector in Germany, and many other jobs indirectly linked to us, we not only have a responsibility when it comes to climate protection, but it is also our task to safeguard high-quality jobs in Germany and Europe throughout this transformation. As demonstrated in a VDA survey, six out of ten companies in the supply industry are having



Hildegard Müller was unanimously elected as president of the German Association of the Automotive Industry (VDA) in November last year. She took office in February. © Roland Horn

## Hildegard Müller

... Hildegard Müller has been president of the German Association of the Automotive Industry (VDA) since February 1, 2020.

... Müller was the first female chair of the Young Union of Germany from 1998 to 2002. In 2005, she was appointed by Angela Merkel as Minister of State to the Federal Chancellor and was responsible for federal/state coordination.

... After training as an employee of Dresdner Bank, Hildegard Müller studied business economics before returning to the Dresdner Bank as a head of department.

to make significant staff cuts due to the coronavirus crisis and cost pressure in Germany. Just a quarter of companies cite the transformation process involving digitization and alternative drive systems as a significant factor. This is why this crisis should act as an impetus for reforms that unburden companies and consequently strengthen Germany as a location. In Germany and in Europe, we need an aggressive industrial policy dedicated to climate protection.

### German car manufacturers are doubling their electric range

The synthesis of these challenges and the aim of making European transport greenhouse gas neutral by 2050 make it clear that we now need to increase the market share of vehicles with alternative drive systems with more commitment than ever before. Electromobility is at the forefront of this – whether that is in the form of a purely battery-powered drive system (BEV) or a plug-in hybrid. German manufacturers will be investing approximately 50 billion euros in this field by 2024 and doubling their range of electric models from 70 to 150 by 2023. In line with this, we need to work consistently at expanding the charging infrastructure across Europe.

However, we can only achieve the EU's ambitious climate protection objectives when sustainable, renewable fuels are

used in addition to electromobility, particularly when it comes to heavy-duty and long-distance transport. Renewable fuels can also be used in vehicles that are already on the road and therefore help to rapidly reduce considerable amounts of CO<sub>2</sub> produced by road traffic. E-fuels can gradually be added to fossil fuels.

Germany's National Hydrogen Strategy proposed by the federal government is an important step. Now it is just a matter of implementing it quickly and ensuring there is a focus on transport in the deliberations. A targeted market launch program is required to establish these new technologies on the market. This program is expected to stipulate, for example, minimum quotas of 23 percent for renewable fuels and 5 percent for e-fuels (including hydrogen) by 2030. Energy tax relief for renewable fuels would be another simple way of ramping up acceptance.

Tackling the coronavirus crisis and transforming the sector require a great deal of effort from the automotive industry. Politicians need to recognize that they should not be burdening companies with additional requirements during this critical time, and instead set the course for innovation and growth. This is because there are two objectives on the agenda: establishing sustainable business operations dedicated to climate protection and safeguarding prosperity, growth and employment. ■

“Germany’s National Hydrogen Strategy is an important step. Now it is just a matter of implementing it quickly.”



Robert Habeck, chairman  
of Alliance 90/The Greens  
© *Andreas Chudowski*

# “The purpose of taxes is to shape behavior”

Robert Habeck believes that the future of mobility is one of the most important issues in politics. In this interview, the leader of Germany's Green Party tells us what he has learned from the Tour de France to help him pedal his way into the next German federal government with his own political Tour d'Allemagne in 2021.

Interview by Josef Oskar Seitz

**Mr. Habeck, you are a self-proclaimed fan of handball. What do you love about the game?**

**Habeck:** It is a fast, hands-on sport. It remains anyone's game right up to the last 30 seconds. Anything is possible.

**The aim in handball is to put all your energy into penetrating an inner circle, which your opponents defend with everything they have. Would it going too far if I drew a parallel between this and your current attempt to get into government and the chancellery?**

Handball often looks like the work of an individual, but it requires teamwork. The art of the game is to pass for as long as possible and rotate as fast as possible until someone has a clear shot. It is not automatically the goal scorers who do the most important work. Or take cycling, for instance. Modern teams have two captains, if only to throw off the other teams.

**That reminds me, have I already asked whether it will be you or the party's second captain Annalena Baerbock running for Chancellor?**

I have just answered your question. Operating on the principle that there can only be one captain will not win you a game of handball or a Tour de France these days.

**And the political Tour d'Allemagne in fall 2021?**

Annalena and I work together and will make the decision of who will pull ahead at the end over the coming year. We have a pretty good head start – not as the favorite, but we have a healthy dose of self-confidence and a great deal of passion. We want to see what we can do – and do it with the knowledge that we can use our strength to turn around difficult situations, like we have seen with the coronavirus crisis, which has put all future issues on hold and forced us to focus only on the present.

**Does the will to power exist?**

Yes.

**Why?**

With all due respect to opposition, it lies at the heart of a democracy – opportunities for influence are far greater when you are in government. And of course, we want to be in a position of influence to change our reality. I want us to lead the Greens into government.

**I was particularly interested in this sentence in the preamble to the draft of your manifesto: “Our arms are open to participation, to forging alliances.” Does that mean it is better to govern badly than not to govern at all?**

Our arms are open because we invite allies to get involved. This is how we develop our strengths. This is how we will define what we want to achieve. I have been a minister in two different governments, in the Jamaican coalition and in the Red-Green coalition. They were very different experiences, but both were examples of good governance.

**We are sitting here in Berlin in front of your party headquarters in a lovely square ...**

It could be worse.

**We are surrounded by cars – parked, moving, honking cars. In the draft of the Green Party's new manifesto, there is a commitment to individual mobility. But there is also a clear rejection of the car.**

For most city centers, this is the right way to go. In rural areas, many people will still rely on cars. I'm aware of that; I'm from the countryside. Mobility is the realization of freedom. But the car is a false promise of freedom in many ways. Quite frankly, people who end up sitting in traffic jams for hours on their way to work are generally more frustrated than free. In cities at least, we can engineer mobility to make it more relaxed, faster and more environmentally friendly. Taking away the cars would breathe new life into this very square, for example. We should think of cities in terms of people, not cars. As a society, we are outgrowing the car. ►

“The combustion engine is no longer considered cool.”

Robert Habeck

“We need research and maximum creativity to find the best route to technical innovation.”

Robert Habeck

► **A nice promise, but who pays for it? Your manifesto stipulates an abolition of the diesel tax privilege, higher taxation for fossil fuels...**

These taxes are not intended to fill holes in the budget, but rather to shape behavior. This will allow per-capita income to be paid back to the people.

**You want to introduce speed limits as an initial measure as soon as you enter government – 130 km/h on highways, 30 km/h in cities.**

We have lots of plans, and the speed limit is just one issue that can be implemented relatively quickly. We are the last country in Europe not to have a speed limit. Perhaps the only country doing things differently could be the one in the wrong here. In the coronavirus era, we are working so hard to protect human lives, and yet hundreds of people die on highways every year. We could easily reduce this number.

**If the Green Party is positioned in government, you want to tax kerosene. This means flying will become more expensive. Is this a farewell to affordable flights for everyone?**

We will never prohibit anyone from flying. But cheap city flights, like those to Lisbon for 23 euros, have to stop. It is wrong to encourage this kind of climate-damaging behavior with subsidies.

**As an author, not all of the characters in your children’s books would probably support green policies. Like Greta, for example, who wins a competition for a cruise with the slogan: “I want to see the sea”!**

I wrote that story for the radio over 20 years ago, which has now been dug up by a publisher. At the time, I still had a very romantic view of cruises. I would not write this story today.

**Back to Habeck the politician. How can we achieve defossilization without deindustrialization?**

The automotive industry will gradually transform from a provider of cars to a provider of mobility. The question is no

longer whether or not we want this from a political stance. The change began a long time ago. California is banning the combustion engine from 2035. People are waiting for more climate-friendly developments. Delivery times for electric vehicles will soon be a year. The combustion engine is no longer considered cool. Now it is a matter of driving forward technological developments – in the automotive industry, in drive systems, in the chemical industry, in the steel industry. If we are politically astute, we will have a hand in shaping this transformation and supporting the sector in reaching the next stage towards a decarbonized, fossil-free industry. It will be a hard road. It will certainly involve structural overhauls and changes to jobs. But new jobs will be created, new supply chains will be created, new services will be created.

**Is electromobility the future?**

For short routine routes, yes. This is because it is more efficient than hydrogen in everyday car consumption. For heavy-duty transport – trucks, trains or even ships – hydrogen may be the answer.

**How crucial will research be for Germany as a business location?**

Very crucial. It is an objective defined by the Paris Agreement. But there are many different ways to achieve it. We need research and maximum creativity to find the best route to technical innovation. This is called competition. This is a market economy.

**What can politicians do to promote this kind of scientific creativity?**

In the first instance, it is important not to stifle innovation. Last year alone, for example, almost 6500 gigawatt hours of electricity from renewable sources were restricted to an equivalent value of 700 million euros because the networks were already full of power generated by fossil fuels. The grand coalition has been impeding the use of electricity for years because the cost components are too high. But clearly, politicians also need to systematically support basic and

1969

A young Robert, born on September 2, 1969, was already trying to overcome barriers at a young age. © Instagram



2004

As a latecomer to politics, Habeck was selected as the spokesperson for the Flensburg Green Party executive at the age of 35. © dpa



2012

Robert Habeck worked as a chimney sweep as he rose to become his party’s top candidate in Schleswig-Holstein. © dpa



Robert Habeck, 51, during his interview with the Fraunhofer magazine at Platz vor dem Neuen Tor in Berlin.  
© Andreas Chudowski

applied research. Research spending needs to be high, and preferably European. A small-state mentality can no longer compete with the United States and China. But we can make a difference as a united Europe.

**The working group for tax estimation has just calculated that 19.6 billion euros will be missing in 2021 due to the coronavirus. Where does the money you want to spend come from?**

Let me differentiate. In the coming years, we will have to use loans to finance the urgent need for investments in infrastructure, the expansion of broadband, the conversion of the gas network into a hydrogen-capable network where necessary, and the development of charging point infrastructures. If we do not make sound investments now, we will be indebted to the future. So-called consumption expenditure – for social welfare, education, research and science – needs to be covered by higher government revenue.

**In other words, through tax increases.**

The first thing to do is to take decisive action against tax fraud and the shifting of profits into “tax swamps”. If that is not enough, I think it is right and reasonable that people with really high incomes should contribute more to financing education, health and research than they do now.

**Wealth tax?**

The wealth tax is a state tax. This means that the money would be available to the states for their expenditures, for example, for education. At the federal level, we will have to wait and see how the budget situation develops after the coronavirus. Only then can we make a realistic recommendation. We need to remember, however, that billions are taken away from the people every year through tax avoidance. The German federal government needs to take much more decisive action on this, for example, through a comprehensive and national duty of disclosure for tax structures. And through tax transparency for international corporations. The latter is being blocked by the German federal government at European level.



**What has potential chancellor candidate Habeck learned from Chancellor Merkel?**

Despite all that I could criticize her for in terms of policy, she has clear moral principles and a backbone. She has never been corruptible by populism. The most powerful woman in the world has always radiated human compassion. Her modesty, her accessibility and her straightforward character should be the legacy of her time in office.

**Does being in office still require a strong moral compass?**

The real major events in politics – German Unity, 9/11, the coronavirus crisis – were not part of any coalition agreement. Nobody knows beforehand how they will rise to the challenge. But you need to have established your own set of principles with regard to politics and society – and have developed a solid core to consult when making decisions. ■

“The real major events in politics were not part of any coalition agreement. Nobody knows beforehand how they will rise to the challenge.”

Robert Habeck



**2018**

Handball fan Habeck cheers on his team SG Flensburg-Handewitt at the German Championship in 2018.  
© Instagram



**2018**

Time to party! A somewhat introverted Robert Habeck celebrates his party's success in the Bavarian state elections alongside a gregarious Anton Hofreiter. © dpa



**2021**

Who will be the chancellorship candidate? Co-chairs Annalena Baerbock and Habeck are yet to decide. © dpa



© istockphoto

# The burger with a clear conscience

At the Fraunhofer Institute for Process Engineering and Packaging IVV, researchers are experimenting with food that looks, smells and even tastes like meat and fish. What's more, no animals have had to die in the process. By Beate Strobel

**T**he road leading to the Fraunhofer Institute for Process Engineering and Packaging IVV shines a light on the current state of human nutrition. In the village of Gigenhausen next to Freising, a sign directs road users to the fishmongers. Cows graze in the meadow behind the Grill Express food truck at the roadside. A delivery van makes its way up to the Butcher's Inn guesthouse. People like animals. Especially on their plates.

**Even Fraunhofer IVV's test kitchen smells of fried meat.** Food technologist and head of the Food Process Development department Raffael Osen balances a hot burger patty from a Teflon pan on a fork, slowly tears it apart and gently squeezes it between his index finger and thumb. Glistening juices drip from the pink center of the patty. "I am amazed by how much it looks like meat every time," he says with satisfaction. "It's really fantastic!"

The IVV burger not only looks like meat but also smells like meat and reacts similarly in a hot pan. And yet, the main ingredient is peas, a result of years of research at Fraunhofer IVV. Here on the

outskirts of Freising, Fraunhofer food technologists are working on national and international projects and on behalf of external companies to create the perfect illusion of meat and help save the world a little bit in the bargain.

There are plenty of arguments against eating steak, pork chops and sausages. The production of just one kilo of ready-to-eat beef requires over 15,000 liters of water and produces around 12 kilograms of the climate-damaging greenhouse gas carbon dioxide. The ecological footprint is smaller for pork and poultry at around 4 kilograms of the greenhouse gas – but it is still ten times higher than the CO<sub>2</sub> pollution caused by the production of 1 kilogram of plant protein (e.g. potatoe or pea protein).

The use of antibiotics and hormones in factory farming has also turned meat from a gourmet product into a health risk for many people. The liquid manure – a waste product of livestock farming, which is generously spread across fields – pollutes drinking water. The living conditions of animals for slaughter make a bolt

shot look like an act of mercy. Recent reports from the meat industry have also revealed that the working conditions for employees can range from abysmal to illegal.

## The meat is juicier than the mind is willing

The enlightened consumer knows all this. Despite this, experts in the US Department of Agriculture (USDA) forecast an annual production of 256.4 million metric tons of meat for 2020. This is because the meat is juicier than the mind is willing. While our brains may know the facts, our bellies have already placed their order: "Rump steak cooked medium rare for me, please." Our inner beast and the most loyal friend to man is, unfortunately, a carnivore. This is why the food experts at Fraunhofer IVV do not have their sights set on vegetarians and vegans in their endeavor to make real ecological and social change. Instead, they are hoping to reach those who see vegetables as a side dish at best and who cannot eat a meal if it does not contain some meat. Taking a steak away from a



Germans consumed 59.5 kilograms of meat per capita in 2019. More than half of this was pork. This was followed by poultry at 13.8 kilograms and beef at around 10 kilograms.

meat eater and simply replacing it with a green spelt patty is clearly not going to work.

“Our goal is to develop plant-based meat alternatives that are real alternatives for non-vegetarians as well,” says Christian Zacherl, food technologist and head of the Food business unit at Fraunhofer IVV. Meat alternatives that not only satisfy the mind but also the stomach. The hope is that this will help to transform meat-free days from a threat into a good idea.

**The Fraunhofer Institute for Process Engineering and Packaging IVV is one of the pioneers** in this field. Plant-based meat alternatives have been the subject of research here for more than a decade. Now they have current trends on their side. Delicious food with a clear conscience: consumers have acquired a taste for it. Rügenwalder Mühle, a sausage manufacturer that has been in operation since 1834, has put its own range of vegetarian and vegan sausages on the market. Vegan burgers, usually made from vegetable proteins derived from the soybean, can be found in deep freezers at discount stores. Even fast-food giant Burger King is promoting plant-based products, like its chicken nuggets based on soy proteins, which, according to Burger King’s own advertising campaign, can even fool carnivorous plants.

Fraunhofer IVV, on the other hand, is focusing on peas. “This is due to the sustainability aspect,” explains Raffael Osen: “Unlike soy, peas are a traditional component of German cuisine and are regionally available in sufficient quantities.” Protein extraction follows on from the production of the pea starch. This is also an advantage in terms of zero-waste utilization of

raw materials and sustainability. Furthermore, soy – just like wheat – has allergenic potential, meaning it is not tolerated by everyone. But Fraunhofer IVV is also experimenting with plant protein sources such as chickpeas, lentils, broad beans and lupins.

Real meat is a multisensory experience, which means that plant-based alternatives need to emulate meat on multiple levels. The look and smell need to be right as well as the taste. You want to be able to smell the typical roasting aromas as you place a meat-free patty in hot oil. The way the burger feels in your mouth as you eat it is the most important sensation. Food that looks and smells like meat also needs to have the right texture. The most important breakthrough in this regard was provided by extrusion technology – more specifically, the processing of plant-based proteins in a screw conveyor using pressure and heat. While dry-extruded protein texturates have a harder, porous structure, wet extrudates develop a texture, which is satisfyingly similar to muscle fiber. This makes them barely distinguishable from poultry, pork or beef depending on the colors and flavors added.

### **Red beet creates the blood-like appearance**

The IVV burger, which Zacherl – himself a vegetarian for the most part – proudly serves up in the kitchen, contains rapeseed oil and coconut oil instead of animal fats, which also reduces the amount of saturated fats and cholesterol. The thickening agent methylcellulose is used to bind the patty together. This replaces the binding function of the muscle protein in meat burgers. Red beet extract creates the blood-like coloring.

However, the most important ingredient of the plant-based burger is the pea, or more specifically the dry-extruded protein texturate of this legume. After being extracted from the pea in several steps, this protein texturate is transformed into a crumbly dry extrudate using extrusion technology. When mixed with water and the other ingredients listed above, it creates a rather tasty burger.

### **Deceptively real or just an illusion?**

**Zacherl pulls a face** at the expression – after all, meat-free products are always labeled as such – “we work with an open mind”. And yet, food designers latch on to meat dishes that frequently appear on menus in various cultures like culinary freeloaders: Doner kebabs. Gyros. Schnitzel. Hot dogs. As Christian Zacherl explains, you have to meet the consumer in their comfort zone – preferably at their own table. In other words, you need to tempt them with food that they are used to and already enjoy. And food they know how to cook. This is why all the plant-based alternatives developed by the experts at Fraunhofer IVV are as close to the original as possible in terms of how they are manufactured. Why mold sausage meat into a new shape when round sausages have worked perfectly well in a pan, on a plate and in a bread bun for centuries?

Fraunhofer IVV’s food inventors are currently turning their attention toward the secondary plant substances that are separated out during the extraction of the protein from the raw material. To what extent can the positive properties of these elements – for example, anti-inflammatory, cholesterol-lowering, antibacterial – enhance the final plant-based product and ►

Over half, or 55 percent of Germans class themselves as flexitarians – they do eat meat, but consciously avoid it on occasion. Further results from the 2020 nutrition report: food should “taste good” (98 percent) and “be healthy” (90 percent).



Take the raw ingredients of sunflower seeds, lupins and peas (bottom row), extrude them, and then create a burger patty from the rehydrated TVP (textured vegetable protein). The appetizing finished burger can be seen on the plate above. © Fraunhofer IVV



► make veggie ground meat or veggie sausages not just ecologically superior but also healthier than their meat-based counterparts?

The aim of Fraunhofer IVV’s meat-free inventions is to win over as many people as possible in the kitchen, on the plate and on the taste buds. This is why the amidori Food Company was founded in Bamberg, Germany in 2015 – with support from staff at Fraunhofer IVV. Its products – such as veggie koftas, veggie ground meat steaks and veggie burgers – are based on Fraunhofer patents and can now be found in the refrigerator aisles of the German supermarket chain Rewe. The ground meat alternative made of mushrooms and pea and wheat protein has a fat content of 12 percent and 18 percent protein, and contains 211 kilocalories per 100 grams, making it in no way inferior to its meaty cousin “all-purpose ground meat” (234 calories, 18 percent fat content, 18 percent protein).

### Plant-based fish and shrimp grown in a field? “Soon!”

The range of products is set to grow further now that consumers are slowly becoming more daring when it comes to trying new food. Plant-based fish? “We’re already working on that,” says Raffael Osen, even though there is a much wider range of meat from fish than from mammals. Salmon and herring are worlds apart in terms of taste and appearance. But in view of the overfishing of the oceans and the heavy metals and microplastics found in fish, it is good to hear that the first plant-based fish sticks are already on sale. Shrimp grown in a field? “Soon,” promises Osen. He and his team are currently researching plant-based seafood as part of the Smart Protein EU project.

**Whether research into the development of plant-based meat is still stuck in the Stone Age** or whether the products currently available today are similar to the first-generation iPhone is something that colleagues Christian Zacherl and Raffael Osen cannot quite agree upon. After all, eating meat is a centuries-old tradition that cannot be changed overnight. “We are taking it one step at a time,” says Zacherl. This being said, the development of imitation food products has already come a long way. As you leave the Fraunhofer IVV building and catch yourself picking a bit of meat-free burger out of your teeth, you realize that it does not get much more authentic than this. ■

# A new dress fashioned out of old jeans

Recycling cotton was not technically feasible until now. A team of researchers at Fraunhofer IAP has managed to produce a viscose filament yarn from recycled cotton for the first time.

By Britta Widmann

Cotton clothing is generally burned, turned into rags or ends up in landfill. "Now it can be recycled multiple times. It will be possible to manufacture new clothes from used shirts, trousers and skirts," says Dr. André Lehmann, a researcher at the Fraunhofer Institute for Applied Polymer Research IAP in Potsdam. Working on behalf of the Swedish company re:newcell, this chemist and his team succeeded in converting the pulp from recycled cotton into viscose rayon fibers made of pure cellulose – a step toward greater sustainability in fashion.

## Separating blended fabrics – an impossible task

Although Germany does recycle old clothes, they end up as inferior products, such as cleaning cloths, rather than new garments. This is because trousers, shirts and the like are rarely made of a single type of fabric. To date, it has been impossible to separate these blended fabrics made of intertwined fibers.

The textile industry usually uses pulp as the starter material for producing regenerated cellulosic fibers such as viscose rayon, modal and lyocell. The feedstock for this pulp is usually wood. "However, re:newcell sent us cellulose sheets made of recycled cotton and asked us to find out if they could be converted into viscose rayon fibers. We were able to extract the foreign fibers from the pulp by setting the right parameters for both the dissolving and spinning processes and by using effective filtration stages," explains the researcher. This yielded a filament yarn – that is, a continuous strand of fiber several kilometers long consisting of 100 percent cellulose, the quality of which is comparable to that of wood-based regenerated cellulosic fiber.

Compatible with the standard industrial process for making viscose rayon, the new fibers spun from this cotton pulp are suitable for mass manufacturing. "We were able to meet re:newcell's high purity standards for the new fiber," says Lehmann. This was no easy task. Producing viscose rayon is a complex process: the pulp is first activated with lye and then chemically derivatized. This yields a very pure alkaline viscose solution. Spinnerets riddled with several thousand holes with diameters of 55 micrometers then spin this solution in an acidic bath. The thousands of liquid filaments emerging from the polymeric solution enable the derivatized cellulose to regenerate and continuously precipitate in the spinning bath to form a filament.

## Eco-friendly cellulose

The next step is to steadily reverse the chemical derivatization, and then wash and dry the filament for it to be wound onto a spool. Made of pure cellulose, this filament is eco-friendly. Rather than adding to the mountains of microplastics that pollute the oceans, it readily decomposes. This is a huge advantage over petroleum-based polyester fibers, which still dominate the global market with a share of some 60 percent. ■

"We were able to meet the high purity standards for the new fiber."

Dr. André Lehmann, head of the Fiber Technology department at Fraunhofer IAP

The new yarn has already been used in this year's H&M Conscious Exclusive summer collection.  
© H&M



“Everything in our homes that is networked can be reached via the router.”

Johannes vom Dorp,  
research employee at  
Fraunhofer FKIE



# My smart home is my castle

Controlling your heating system remotely or having a quick look in your fridge via an app while you are out shopping for groceries - smart technology is meant to make our home lives easier. But it is not without risks.

By Sabine Spinnacke

In days gone by, defense towers and heavy gates provided protection against attackers, but these days cyber criminals can easily gain access to our private property via home routers.  
© *unsplash*

**M**y home is my castle – this famous remark made by English barrister Sir Edward Coke describes the profoundly human need for protection and security within our own four walls. During Coke’s lifetime some 400 years ago, locks on doors and windows were enough to protect the occupants against intruders. Nowadays, an army of hard-to-catch cyber criminals has joined the swarms of conventional intruders. These criminals use an inconspicuous device as a gateway to your private property: “Home routers are a common and frequent target,” explains Johannes vom Dorp, an employee at the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE. Over the past five years, he has been working intensively to address questions involving security issues.

“Everything in our homes that is networked can be reached via the router,” says vom Dorp. A hacked robotic vacuum cleaner could be sending images of our living room to criminals while we are at home; the children’s game console, the PC or TV could be used in a blackmail attempt. “There is also a major risk posed by misuse of the router as part of a botnet,” adds Adil Aden from the infrastructure security unit at Germany’s Federal Office for Information Security (BSI). The user rarely notices that anything is wrong. DDoS attacks can be launched by hijacking and combining hundreds or thousands of routers and smart devices to form botnets. BSI registers up to 110,000 bot infections in German systems daily. A BSI survey from 2019 indicated that almost one in four (24 percent) has already been a victim of cyber criminals.

## All devices tested have security flaws

With this in mind, it is hardly surprising that the results of the Fraunhofer FKIE Home Router Security Report 2020 caused a big stir and that numerous media outlets reported on it. The tests at Fraunhofer FKIE showed that the

firmware of almost all of the 127 models tested had significant security flaws.

Unlike an app or software that the user buys and then installs, firmware is embedded in the respective hardware of the device. Without firmware, the washing machine would not know which wash cycle has been selected; the vacuum cleaner would not know when it needs to be emptied; the smart light bulb would not know how bright it needs to glow. And of course, firmware is also the operating software of every home router. Fraunhofer FKIE has developed the FACT tool to check firmware for security vulnerabilities. It is intended to make the security status more transparent for manufacturers and users and to make problems easier to solve.

**“FACT is an automated tool that you can use to easily examine firmware,”** says vom Dorp. Tools like this have not existed until now, even though the number of Internet-enabled devices has been growing rapidly for years. According to Statista, there are currently more than 20 billion networked devices, almost two thirds of which are owned by private individuals.

The first thing FACT does is unpack the firmware. Since it can contain any number of components, which are grouped and packed differently, this is not a trivial matter. “The outer container can easily hold up to 20,000 or 30,000 files,” says vom Dorp. The files include the operating system, drivers and function blocks as well as stand-alone programs and perhaps a web server. Content and structure vary depending on the model and device. Furthermore, not all containers are the same. Each manufacturer designs the outer container differently, depending on the intended installation routine, for example. “There are lots of creative approaches,” says vom Dorp. The extraction process is a challenging undertaking and FACT programmers need to adapt it regularly to new file types and manufacturers.

Once the firmware has been unpacked, it is time to take stock: “There are small independent programs for moving, copying and deleting files, configuration files, stored IP addresses, URLs, processor architectures, passwords and cryptographic keys,” lists vom Dorp.

## Comparison with known security vulnerabilities

The actual analysis can only start once stocktaking is complete. This involves the tool comparing all security vulnerabilities stored in the CVE open source database with the available material. CVE stands for Common Vulnerabilities and Exposures and is a collection of publicly known security vulnerabilities. The database has existed since 1999 and is used by hackers, developers and institutions alike. After performing a comparison with the CVE, an overview of all weaknesses identified in the existing firmware is displayed. However, not every vulnerability is necessarily found on every device. The result can vary depending on the software variant installed.

**The popular routers from AVM GmbH performed best in the test.** Regular updates on these routers ensure the closure of many, but not all gaps in security. Other manufacturers often wait years to update their software – an unnecessary failing, according to vom Dorp, since the Linux operating system, which is used 90 percent of the time, is constantly providing updates.

In order to make devices more secure in the future, BSI advises manufacturers to consult the Secure Broadband Router technical guidelines during development. These guidelines describe the current security requirements and are used by Fraunhofer FKIE, which works closely with BSI, for the further development of FACT. This may result in smart homes truly becoming as secure as castles in the future. ■

Work  
2020:  
every-  
thing  
has  
changed.





20-year-old Turkish ballerina Lagun Sengelen stays disciplined during the coronavirus lockdown. Her house becomes a dance studio during her daily online training sessions – chests of drawers and chairs have to be used as ballet bars.

# Ballett office



## Hotel office

Pratap Pillai, a businessman from India, works on his laptop in a room at the Hotel Europäischer Hof in Hamburg. The ship manager from India was stranded in the hotel for two months due to the coronavirus pandemic travel bans. At times he was the only guest.



A total of **90 percent** of managers asked reported that working from home had not had any disadvantages for their business.

“Working during the coronavirus pandemic” study, Fraunhofer IAO

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# Music office

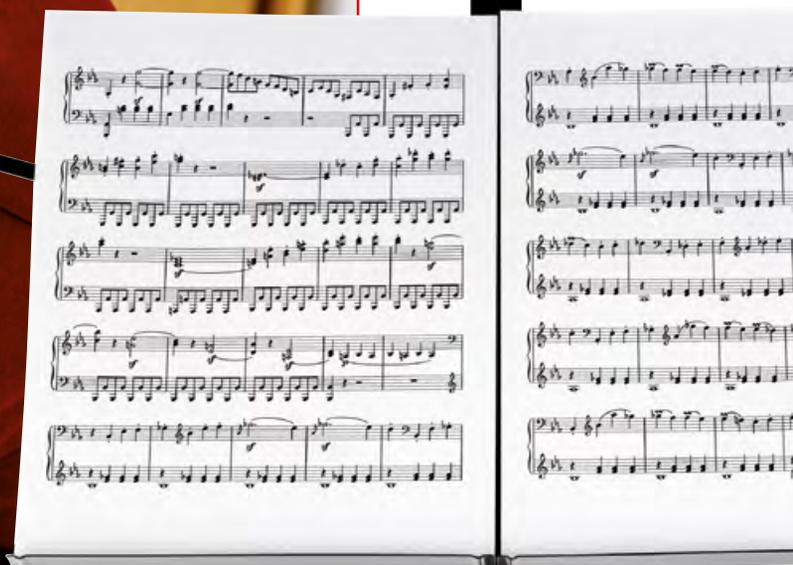
Viola teacher Felix Schreer from Karlsruhe working in his home office. Correct bowing techniques can also be demonstrated online and without an instrument.





“The coronavirus crisis has pushed the digitization of our working relationships forward by at least 15 years.”

Dr. Stefan Rief, head of the Organizational Development and Work Design research division, Fraunhofer IAO



© istockphoto

# Working from home

## There is no going back

Germany can work from home. Professional support is required to ensure that the successfully improvised present day leads a solid future.

By Dr. Sonja Endres

The study by Fraunhofer FIT found that 82 percent of survey participants are happy to work from home.

Working from home spread rapidly across Germany – and it was surprisingly successful. This success is indicated by the initial results of a survey conducted by the Fraunhofer Institute for Applied Information Technology FIT, which started at the beginning of April and is still ongoing. More flexibility and autonomy, a better balance between work and family life, no long commutes, better concentration and higher productivity – these are some of the compelling arguments made for working from home. On a scale of one to six, with six being the best, satisfaction initially averaged at 4.3 and rose to around 5.0 after ten weeks. “Employees getting used to the new processes, technical tools and communication channels certainly played a role in this,” states Prof. Wolfgang Prinz. The deputy director of Fraunhofer FIT also suspects another reason for the increase: “By this time, schools were gradually being reopened.”

### The coronavirus turned the world of work upside down at record speed

Before the coronavirus crisis, working from home was seen as a perk at most companies, similar to taking a sabbatical, getting a gym subsidy or a company car – it was allowed but not encouraged. In mid-March, companies sent their employees home in droves because of the virus, turning the world of work upside down. Since then, VPN connections, video conferences and online chats have been part of everyday office life at home – exciting times for occupational scientists.

“We are in the middle of a large-scale experiment into the digitization of work and collaboration. The speed of this change would have been unthinkable until recently,” says an enthralled Dr. Josephine Hofmann. She heads the Cooperation and Leadership team at the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart. Together with the German Association for Human Resource Management, researchers asked decision-makers at nearly 500 companies

throughout Germany about their experiences of remote working and their plans for the future.

**During lockdown, 70 percent of employees were working entirely from home** and 21 percent were working from home at least half the time. At the time of the survey in May, 42 percent of companies had already made the decision that opportunities to work from home should continue after the coronavirus crisis. An equally large proportion were still undecided. Hardly anyone wanted to see a full return to office-based working.

“It is incredible what the companies and their employees have achieved in such a short space of time, and they are rightly proud of it. It came as a surprise to everyone that it was even possible to switch to virtual working on this scale without any serious setbacks,” says Hofmann. For years, many bosses had little to gain from allowing employees to work from home. They worried about technical issues, a decline in productivity and a loss of control. Now around half of managers stated that they had overcome their reservations. Nine out of ten are certain that working from home can be implemented on a larger scale in the future without disadvantaging the company – quite the opposite. “Now is the time to mold this new world of work that has arisen from adversity,” appeals Hofmann. Many companies are seeking professional support to help with this, meaning Hofmann and her team from Fraunhofer IAO are in high demand: “We barely get a break from inquiries at the moment.”

### Making the most of the state of emergency

The researchers start by assessing the situation. What has worked well, where is there still some catching up to do? Hofmann stresses: “The learning experiences of recent months are too valuable not to be systematically leveraged.”

The wax figures from Madame Tussauds in Berlin are also working from home: instead of appearing in the normal exhibition, George Clooney and friends are shown quarantining at home. © dpa

The survey shows that technology has generally worked well from the start. Technical requirements for remote working, such as VPN access and shared document storage, were already in place at many companies before the crisis. There is a need for training, especially with regard to remote management, but also for self-management and media and communication skills. "Leadership and communication behavior is often based on immediate proximity. Of course, this is no longer the case. You have to call employees more often to find out how they are doing and where they are having difficulties," Hofmann recommends. However, the success of the new work conditions is not solely the responsibility of managers and requires support from the entire team. "Everyone gets something out of it, and everyone also needs to put in some effort to make it work. This requires everyone to have a certain level of discipline, consideration and the ability to compromise."

**What almost everyone misses when working from home** is face-to-face, informal interaction with colleagues. "Talking about our personal lives is important because it can help to establish social cohesion and solidarity within a team." Chat groups, regular coffee catch-ups and team lunches via video conference can help colleagues to stay in touch.

Spontaneity falls by the wayside. "Social communication has to be triggered. For example, I may walk down a corridor and hear some colleagues laughing in an office. Of course, I go in to ask them what's going on," says Prof. Wolfgang Prinz. He and his team at Fraunhofer FIT are already thinking about how existing collaboration systems such as Microsoft Teams could be enhanced to provide more communication stimuli. "This might involve daily situation reports, for example, which provide information about what is happening in my digital collaboration environment and what my colleagues are currently working on," explains Prinz.

Hofmann is also convinced that "People will use the time that they actually spend in the office differently in the future. We believe that new hybrid, flexible work environments will require activity-based workplace design." Fixed workstations will largely become a thing of the past. Instead, offices should offer more space for meeting, communication, creativity and coordination, as well as quiet areas to retreat to for phone calls or for confidential conversations with



colleagues. It is important to be able to access rooms quickly and flexibly when needed and not have to reserve them about five weeks in advance.

### The commercial property market is set to change

It is not just offices that need to be redesigned for the "new normal": workstations at home need an upgrade, too. Many still do not have ergonomic chairs and desks or a second, larger screen, not to mention the lack of space. Responsibility for purchasing and financing also needs to be clarified. Expanding remote working will allow companies to save on office space, resulting in a considerable reduction in costs. "The commercial property market is set to change," says Hofmann. However, she warns companies against making hasty cuts: "Assuming that 50 percent of people working at home means renting 50 percent less space does not add up."

Despite all the unanswered questions and teething problems, the new world of work offers lots of opportunities for employees and employers. Digital cooperation tools are tearing down spatial boundaries and bringing colleagues from different branches or from different countries closer together. Shared document storage and editing, being able to start a video conference with a click of the mouse – "all this provides an incredible boost and facilitates close-knit, effective communication," Hofmann believes. It is important that this concept works because there will be no return to the former culture of presenteeism in German offices after the coronavirus crisis. ■

Before the coronavirus crisis, 54 percent of companies had no or only a few employees who were permitted to work from home.

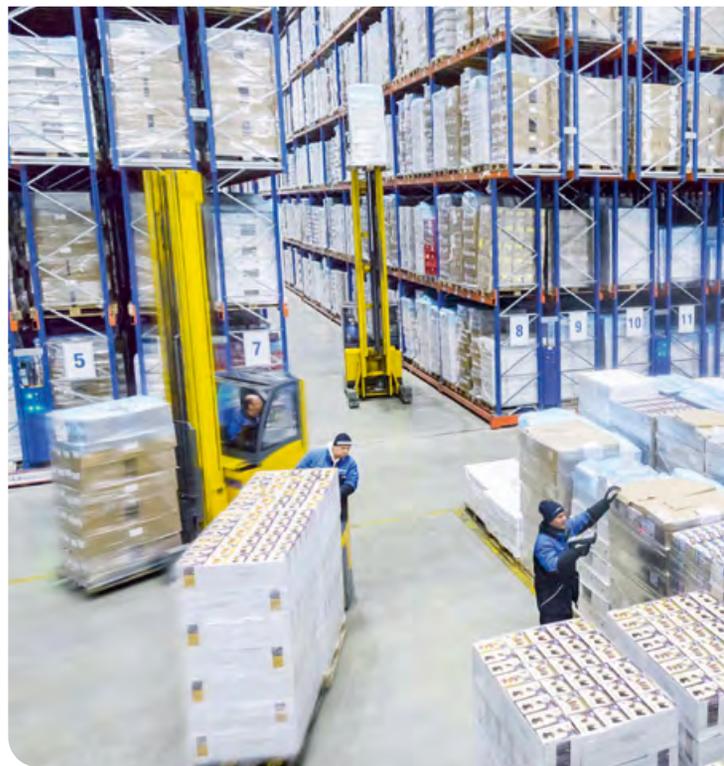
"Working during the coronavirus pandemic" study, Fraunhofer IAO

# Energy on ice

Nearly one-fifth of energy consumption goes towards refrigeration and cooling. But it does more than just use up energy - it can also be used for energy storage purposes. Fraunhofer researchers are using flexible network management, natural refrigerants and efficient cooling technology to lay the foundation for a more environmentally friendly future.

By Sabine Spinnacke

Nordfrost warehouse in Fürth.  
© Harry Köster



The temperature is -22 degrees. Dressed for the elements in thick jackets and wool hats on their heads, employees of the Nordfrost logistics company maneuver their forklifts around the high-rise stacks of the 9,000-square-meter frozen-food warehouse. In a matter of minutes, the piles of frozen food come together to be shipped to supermarkets, wholesalers and restaurants. The summery-warm outside temperature is held off by three refrigeration units, supplied by two combined heat and power plants that generate 1,100 kilowatts each hour.

**“Around 18 percent of total energy consumption goes towards cooling and refrigeration.** The largest consumer is the food industry, followed by the building sector,” explains Dr. Lena Schnabel from the Fraunhofer Institute for Solar Energy Systems ISE. But refrigeration technology can do more than just cool – it has the potential to play an important role in the decentralized load management for intelligent electricity grids: “With an increasing proportion of renewable energies, the grid has to become more flexible. After all, the amount of energy fed into the grid fluctuates significantly depending on the levels of wind and sunshine. Any excess power should thus be used or stored. Why not by refrigeration units or in cold-storage units?” says Dr. Clemens Pollerberg, head of the thermal storage group at the Fraunhofer Institute for Environmental,

Safety and Energy Technology UMSICHT. In May 2019, the researchers at Fraunhofer UMSICHT launched a project under the name FlexKaelte that investigates the contribution that the supply of cooling and refrigeration could make to the transformation of the energy system. “We already have power to heat. Power to cool is new and has a certain something to it,” Pollerberg says. There are some selective studies and individual, primarily large companies that are already taking a flexible approach to their refrigeration needs to save grid fees – but not on broader scale.

The first stage of the FlexKaelte project will involve gathering information on the existing supply. In their metastudy, the researchers ask “What types of applications already exist and precisely how is the demand for cooling and refrigeration met?” Fraunhofer UMSICHT then plans to establish measuring stations at ten locations to record the actual load profiles. The UMSICHT team first has to understand the actual load profiles in order to develop synthetic ones as well as use mathematical optimization models to investigate the potential for load transfer and how this can best be realized.

Fraunhofer UMSICHT held a workshop on the topic in September where representatives from the cooling and refrigeration industry presented their applications and discussed various scenarios that could contribute to flexible load management. Three of these scenarios proved

to be suitable: on the one hand, energy could be stored as refrigeration in cold storage units or in cold-water, ice or phase-change-material (PCM) storage units. PCM storage units make use of the characteristics of phase change materials and have a high storage density. Application examples can already be found in the industrial and building sectors.

## Grids becoming more flexible

On the other hand, existing storage options – such as refrigerated warehouses or even the refrigerators in private households – could be incorporated to make the grid more flexible. “The sheer masses are what makes this option intriguing,” says Kanngießer. Load transfers come into consideration if temperature fluctuations of 2.3 degrees for the type of products stored do not make a difference.

The third scenario involves production processes that can be carried out more flexibly with regard to time: “One participant in the workshop produces liquid nitrogen. Because the process runs under complete automation, the producer then operates at times when the electricity prices are low,” Kanngießer reports. It is quite conceivable to start industrial processes of this kind automatically, as soon as the wind blows or the sun shines. “For manpower-heavy processes, however, flexibilization is more difficult,” says Kanngießer.



Clemens Dankwerth from Fraunhofer ISE examines a propane refrigeration circuit for leaks in the test laboratory. The refrigeration circuit is one of the central components of the newly developed LC 150 heat pump, which works with propane as its environmentally friendly refrigerant. © Fraunhofer ISE / Marek Miara

At the end of the project, the team plans to make a recommendation that factors in both technical and economical aspects.

While the FlexKaelte project is investigating the contribution that cooling and refrigeration technology can make towards the incorporation of renewable energies, the researchers at Fraunhofer ISE hope to use the machines and refrigerants as a lever for saving energy and generating refrigeration in a more environmentally friendly way.

Nordfrost uses ammonia as its refrigerant. "Ammonia, as a natural refrigerant, is our first choice due to its relatively high level of energy efficiency," says Christian Wanke, location manager. In addition to ammonia, natural refrigerants also include butane, propane, carbon dioxide and water. Each substance comes with its own challenges: ammonia is toxic, butane and propane are explosive, carbon dioxide required high levels of pressure, "and water isn't the simplest substance to deal with," says Schnabel, who is fascinated by the history of refrigerants: "Natural refrigerants have been used for more than 150 years. Thanks to technological advances, they are now experiencing a sort of renaissance." Fraunhofer ISE develops components and equipment for cooling and refrigeration machinery.

In doing so, one focus is on reducing the use of refrigerants and the development of

state-of-the-art refrigeration circuits. Equal performance with minimal use of refrigerants – a high degree of expertise with regard to the machines is required to achieve this. The processes that take place during boiling and condensing are complex, as the thermal conductivity of a pipe varies depending on its geometry, material and flow rate. A broad experimental basis like that of Fraunhofer ISE is quite helpful in this regard. Schnabel and her team have already seen good results with propane, a natural refrigerant whose greenhouse gas potential is around 500 times lower than that of common refrigerants. For example, they developed a propane refrigeration circuit for LC 150 heat pumps that only needs one-fourth of the refrigerant compared to systems available on the market. That makes it the first pump of its kind in Germany that can be set up inside residential buildings without any additional safety measures.

**One refrigerant that also has intriguing qualities for energy storage** is a dispersion of paraffin and water. It is suitable for cooling car batteries, but also for storing refrigeration: when the dispersion developed at Fraunhofer UMSICHT takes on heat, the solid paraffin particles melt down to paraffin drops and store the warmth. When the solution cools, the drops become solid again. This is a good alternative to cold water in a temperature range of 5 to 20 degree Celsius, because it has an energy density that is two to three times higher.

If the temperatures in a frozen warehouse drop below –18 degrees, the food stored there can no longer be used – a catastrophe. For industrial processes, outages of the refrigeration technology often mean facility downtimes – which are to be avoided at all costs. The sector has therefore been rather slow to accept innovation in this regard, but things are changing. "I almost assume that the industrial sector will invest more heavily in innovative refrigeration technology in the coming years," Schnabel states. Because the development of cost-effective, recyclable and, at the same time, safe components and equipment – a major subject at Fraunhofer ISE – is making advances. Sensor prices are also dropping, which is a big plus for automated process monitoring. "Using sensors and artificial intelligence, a lot can be caught in terms of operations management," Schnabel says.

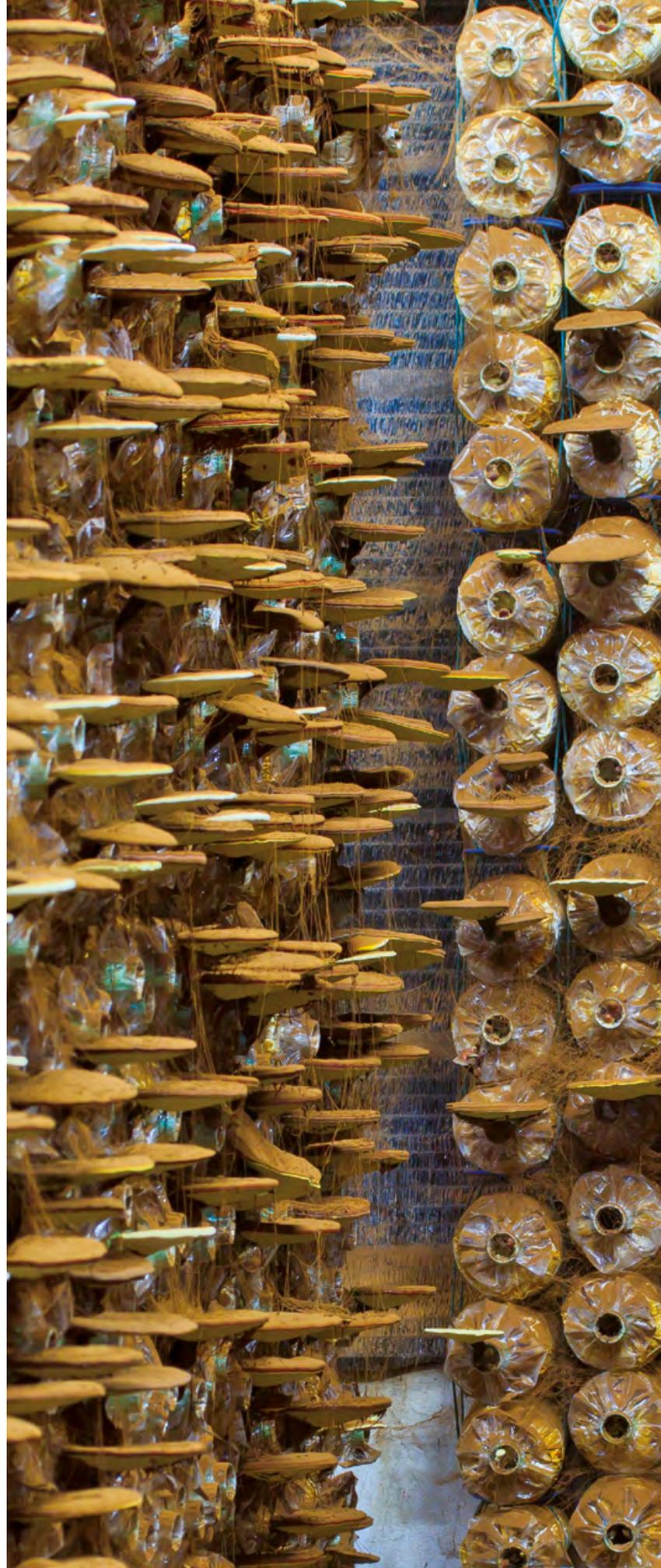
Software that helps increase performance, recognize errors early on and recording effects of degradation in the refrigeration circuit is more than welcome in the industrial sector. As are models that reduce electricity costs. For this reason, Kanngießner and Pollerberg have a positive outlook for the future acceptance of the planned web app that will calculate and evaluate the FlexKaelte options: "Economic advantages are always a motivation for our partners in the industrial sector." After a protracted "ice age," the sector is therefore warming to the ideas and developments of the Fraunhofer researchers. ■

# Sustainable acoustics, anyone? Sounds good

As healthy and tasty as mushrooms happen to be, they are good for much more than just the dinner plate. Fraunhofer Institute for Building Physics IBP and Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT are investigating fungal materials that they hope to turn into eco-friendly sound absorbers.

By Jacob Schmette

The researchers pursuing this project are working with relatives of the Polyporaceae family, including the lingzhi mushroom.  
© Shutterstock





The mycelium is the entire mass of filamentous cells of a fungus.  
© mauritius images

The incessant chatter of office coworkers who are always on the phone or the loud music of a noisy neighbor distresses many people. Ambient sound does indeed affect our well-being and health. Sound absorbers can improve a room's acoustics. Many soundproofing panels for walls and room fittings used in today's interior designs are made of mineral fibers or synthetic foams. Some of these materials are not particularly sustainable or easily recycled. In a bid to bring to market a more eco-friendly and more effective alternative, Fraunhofer UMSICHT is developing sound absorbers made of mushroom-based materials together with Fraunhofer IBP.

Julia Krayer, a project manager and research fellow at Fraunhofer UMSICHT in Oberhausen, came up with this idea. She has been working on biomaterials for many years: "The focus in material development is on vegetal substrates and mycelium," says Krayer. Mycelium consists of a finely spun web of filamentous hyphae. In their natural habitat, some species' underground mycelia may grow to span more than a square kilometer.

### Shaping up mycelial materials with a 3D printer

Mycelial strands for the Fraunhofer UMSICHT project are cultivated in the lab. Mycelium is first mixed with a vegetal substrate consisting of straw, wood and food production waste and then printed into any desired shape with a 3D printer. "The mycelial threads spread throughout the sub-

strate, growing to form a solid structure," says Krayer. Once these vein-like mycelial strands have permeated the granular substrate, the product is dried in a kiln to kill the fungus. The cell walls of the material produced in this fashion are open, enabling it to absorb sound. The open cells and printed porous structures make an excellent soundproofing panel.

**Remarkably effective, fair on the environment** and easy on resources, these sustainable fungal sound absorbers' benefits do not end there: "The structure permeated by mycelium is solid, so future sound absorbers could be made of much thinner layers," says Roman Wack of Fraunhofer IBP in Stuttgart, who is working with Julia Krayer on this project. The use of a 3D printer enables the researchers to predefine the absorber's internal porous structure. The printer then produces a structure designed to purpose that can be fine-tuned as the research progresses. These improvements benefit the developers' efforts to perfect their design. They expect this method to produce a sound absorber that is made of renewables yet outperforms the conventional products available today.

The potential applications for this mycelial material are not limited to acoustics: "The end products could probably be used as insulating material, but this would require more intensive research," says Krayer. Sound absorbers and insulating materials may be just the beginning. Mycelia could lend themselves to making "fungal" faux leather, fabric and plastic, so the prospects of fungus-based materials featuring prominently in apparel, furniture and encapsulation of electronic appliances look promising. Fraunhofer researchers are already looking into these possibilities. However, their first priority is currently producing sustainable sound absorbers. The project has been underway since the summer of 2019. Fraunhofer UMSICHT staff are currently producing various prototypes for Fraunhofer IBP to test. The aim is to develop sustainable, aesthetically pleasing products that improve the quality of life. That goal will also be pursued in a workshop with potential users, such as designers or interior designers, scheduled to take place soon. ■

The future looks fungi: mycelia could also serve to make "fungal" fabric, plastic or faux leather.

In their natural habitat, most relatives of the Polyporaceae (bracket fungus) family grow on dead wood. © Shutterstock



# How to avoid animal testing



**T**he number of test animals in Germany has been largely stable for years: tests were conducted in 2,825,066 animals in 2018. Animal studies are also necessary for examining the safety and toxicity of chemical substances. As the head of the Department of In-silico Toxicology at the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM, Dr. Sylvia Escher is looking for alternatives to animal testing.

“At our institute, we work with several groups on new concepts for chemical risk assessment,” the chemist explains. She mentions the EU-ToxRisk project as one example. Cultures of human cells and organ sections are meant to offer alternatives to animal testing. A total of 39 partners from 13 countries are working together in the EU-ToxRisk project, which has been ongoing since 2016 and has a budget of more than 30 million euros. In addition to universities, research institutes and companies, regulatory authorities are also taking part in the project – an important factor in the success of the undertaking. Because animal testing can only truly be replaced if the national and EU authorities approve the newly developed processes for determining toxicity.

**The objective is not only a more conservative alternative, but also one that is better.** The classic procedure is to expose animals to the substances to be tested. And the researchers observe: are there any inflammatory reactions? Are any organs damaged? Is there damage due to continuous long-term exposure to lower concentrations of a substance, for example in the amounts that could be breathed in on a daily basis? However, which mechanisms lead to the adverse changes observed usually remains unclear.

“As part of EU-ToxRisk, we investigate the cascade that a substance causes in the body,” Escher points out the advantages. It begins with first molecular interactions of the substance (for instance, with receptors on the cell), transitions to a

Mice are the most frequently used animals in research. Since the decoding of the mouse genome in 2002, the scientific community has known that mouse genes are 98 percent the same as those of humans. © Heidi and Hans-Jürgen Koch

Currently, we still require data from studies conducted in animals to evaluate the safety of a substance for humans. The EU-ToxRisk project is working towards a paradigm shift: away from animal testing and towards a deeper understanding of how chemical substances work.

By Christine Bröll

reaction of the cells and then leads to effects on organs, culminating in changes in the organism as a whole.

Multiple working groups from Fraunhofer ITEM are involved in three of the **nine case studies being conducted as part of EU-ToxRisk**. Dr. Tanja Hansen, head of the Working Group on In-vitro Test Systems, is currently investigating the toxicology of volatile compounds using diketones as an example. Diacetyl – a chemical compound that is a natural component of butter and whose industrially produced version serves as butter flavor, for example for popcorn – is the best-known representative of this substance group.

### Simulations with human tissue

What happens when people breathe in diacetyl? Can it be harmful to the lungs? To answer these questions, Sylvia Escher and Tanja Hansen use an apparatus that was developed at Fraunhofer ITEM: the P.R.I.T.<sup>®</sup> ExpoCube<sup>®</sup>, which enables them to simulate how volatile substances affect cells and tissue.

Human bronchial epithelial cells are cultivated on membranes at the air-liquid interface to simulate the situation in the lung. Using the P.R.I.T.<sup>®</sup> ExpoCube<sup>®</sup>, gaseous diacetyl is passed over the surface of the cells. Biochemical methods are then used to examine the effect on the cells. Thanks to comprehensive analyses of gene expression, the research team is able to recognize which genes the cells have activated and/or deactivated. They can then use this data to determine which signal pathways were activated within the cell. These could be signal pathways that lead to the production of messenger substances that cause inflammation, for instance.

**The investigation is taken to the organ level in the next step.** To this end, the researchers use living tissue sections cultured from human lungs that also have many of the lungs' functions. As with the cell cultures, the lung sections are exposed to diacetyl in the P.R.I.T.<sup>®</sup> ExpoCube<sup>®</sup> and then intensely scrutinized.

To simulate the behavior of diacetyl in the body, the project partners make use of complex calculation models, known

as "in silico methods." These computer-aided models reproduce to a high degree how an inhaled substance is absorbed, distributed and excreted in an organism. "The in vitro and in silico data result in a precise picture of how diacetyl damages the lungs," Escher reports. "They are consistent with the in vivo data from the tests carried out in animals."

### Using data from similar substances

The first step in avoiding animal testing with these alternative methods is the read-across approach. If you want to have a new chemical approved in accordance with this method, you seek out similar substances for which toxicological data from animal testing already exists. This data is then transferred to the new "sister" chemical as part of the read across. "In principle, this approach is already possible today. Practically, however, it has been difficult to demonstrate that two chemicals are so similar that they truly have the same toxicity," Escher emphasizes. "Which is why the read-across approaches have only seldom been accepted by the regulatory authorities thus far."

**In the case studies, the project teams investigated groups of closely related substances** and gathered comprehensive in vitro and in silico data to increase the level of acceptance. With these investigations, they were able to demonstrate that the methods are ideally suited to determine the toxicity of structurally related materials. In a detailed study, the cooperating partners presented how a read-across approach is made possible using data acquired without animal testing. "We sought out a close dialogue with the regulatory authorities from early on, continuously adapting the concept as we went along. In doing so, we have taken a major step forward towards acceptance," says Escher.

The EU-ToxRisk project partners already have the next objective in their sights: they hope to establish toxicity testing without the use of animals even for substances for which the read-across approach is not possible. The project timeline runs through the end of 2021. ■

"We sought out a close dialogue with the regulatory authorities from early on."

Sylvia Escher, head of the Department of In-silico Toxicology at Fraunhofer ITEM

# The factory of the future

The cognitive Internet makes its way into practice: three solutions that make production facilities more precise, lower maintenance costs and increase quality.

By Tobias Steinhäuber

**C**ognitive Internet that can recreate the abilities of humans: at first, this was a vision – then a buzzword for the business world. Now it is making its way into practice: little mobile units zip around factory floors – bringing workpieces to the robots or employees autonomously, picking them up again after processing and heading towards the next module in the production process. Prof. Claudia Eckert, spokeswoman of

the board of directors of the Fraunhofer Cluster of Cognitive Technologies CCIT, summarizes the objective, explaining: “The factory of the future is able to control itself and works hand in hand with the skilled employees. Individual stationary production steps can be flexibly adapted to short-term changes in the production plan.” At the moment, three solutions are about to make their debut in the industrial sector.

“Cognitive Internet technologies are the key to the competitiveness and the digital sovereignty of the German economy.”

Dr. Reinhold Achatz,  
Fraunhofer CCIT Advisory  
Board, Thyssenkrupp

In the factory of the future, machines control themselves – and precise down to the centimeter, so that collaboration between human and machine is reliable and safe.  
© Volkswagen AG



In the factory of the future, humans, machines, tools and components have to be able to be precisely located. Fraunhofer CCIT has developed a positioning system for industrial applications that is scalable in terms of precision and range.

## Positioning – precise down to ten centimeters

FlexLoc can locate objects with a precision down to ten centimeters. The technology is based on ultra-wideband (UWB) wireless technology and receives the necessary information from mobile sensor hubs distributed throughout the production hall or warehouse. “The wireless technology is comprised of commercially available components,” explains Marc Faßbinder, head of the industrial positioning group at the CCIT IoTCOMMs Research Center. It can, for example, determine the position of driverless transport vehicles to support skilled laborers in production processes or of warehouse cranes. This allows the autonomous units to interact with humans or to precisely determine the location of objects and things that are needed for the production process.

Order-picking example: a mobile self-driving vehicle helps employees distribute goods. “Using a sensor tag, we measure the distance between people and the vehicle and use this data to calculate their relative positions. In doing so, it’s important to occupy wireless channels efficiently to receive a high rate of precise positioning data. Additional data from the vehicle’s sensors are used to determine the position – down to the decimeter – of the driverless transport vehicle,” says Faßbinder. FlexLoc can be used as a mobile ad hoc positioning system for entire production facilities – for example for the positioning of mobile machines and workpieces. This involves the distribution of multiple battery-operated and wireless UWB hubs throughout a working area. An area of 100 square meters can be covered with four to five such hubs.

## Securely sharing sensitive data

Maintenance is expensive. In Germany, losses caused by production outages due to mainte-

nance amount to the double-digit billions each year. “Every second costs the company money,” says Frederik Möller, chief engineer of the Chair for Industrial Information Management (IIM) at TU Dortmund University. The more tailored the maintenance intervals, the lower the costs – but, to this end, facility operators and manufacturers have to exchange usage data. “The manufacturer can combine this data with their own knowledge of the machine and, in doing so, optimize the maintenance intervals,” explains Hendrik Haße from the CCIT Data Spaces Research Center. “But companies are hesitant to transmit sensitive production data to outside parties, because it’s unclear who can inspect the data and what happens with it.”

With the Shared Digital Twin of Fraunhofer CCIT, companies can securely share data from their production processes with partners and customers. The provider of the data maintains control over the data at all times. The solution consists of an IoT architecture, a digital twin and the connectors of the International Data Spaces (IDS). The IoT architecture takes raw data from the processes being executed – such as vibration, temperature or friction – and uses it to generate meaningful indicators in real time. This information is then stored in a digital twin on the company’s server, where the company still has control over which data is shared and who is able to use it. The IDS connectors transfer the data to the recipient securely and in a controlled manner. Both companies have the ability to enrich the digital twin with additional information. The data can be applied to various analyses – for example, on machine-learning processes and methods involved with artificial intelligence. The technology is compatible with existing solutions for the secure exchange of industrial process data, such as the Plattform Industrie 4.0 Administration Shell or the IDS architecture. It can accommodate any type of database or application.

In practice, skilled employees only have a few seconds to recognize errors in running production and monitor the quality of parts. “If they are unable to do so, errors go unrecognized or are only partially documented, and then optimization work is delayed,” reports Gerrit Holzbach from the Fraunhofer Institute of

Optronics, System Technologies and Image Exploitation IOSB. “It would be perfect if the employees could simply use gestures or their voice to record errors. That not only saves time compared to manual entry into a computer, but a digital assistant also ensures that no information gets lost while the data is being recorded and entered.”

## Recognizing and easily documenting errors

All that is now possible thanks to the multimodal dialogue assistant (MuDA) from Fraunhofer CCIT. Holzbach points to an error in a component, and this gesture alone is enough to mark the corresponding spot. A camera above the workpiece recorded the movement and transmitted the information to the digital assistant. A projector shows Holzbach all of the errors found directly on the component, and he then speaks to describe the nature of the error. A speech dialogue system records his voice, and this information has now also been recorded completely digitally. “We optimized the voice control and microphone placement specifically for recordings in loud environments, so that no information gets lost,” says Oliver Walter from the CCIT Machine Learning Research Center. During the improvement phase, the error markings can be precisely reproduced at another station using digital images and once again projected onto the component. This prevents errors from being overlooked and thus not corrected. Once this has been completed, the employee confirms that directly on the component. The MuDA also makes note directly in the system that this has been completed.

“The three solutions are nearly set for use in practice at our industrial partners,” underscores Christian Banse, head of the administrative office of the Fraunhofer CCIT. But the cluster’s research is not only geared towards the industrial sector. “Cognitive Internet technologies are relevant for the entire economy. They improve yields in agriculture, make traffic at intersections safer, optimize logistics processes, protect sensitive patient data in networked medical devices and make online retail more efficient and sustainable.” ■

## Effectively helping the elderly avoid falls

 As the body ages, it has an impact on mobility, muscle strength and balance, which significantly increases the risk of falls. At the Fraunhofer Center for Assistive Information and Communication Solutions AICOS in Portugal, researchers are developing the FRADE technological platform for assessing the risk of falls and assistance in the event of a fall.

FRADE consists of various components: wearable sensors that collect and monitor movement data, a program for analyzing the risk of a fall, an app for tablets with exercises to prevent falls and a back-end server with a web interface for visualizing the data.

The risk of a fall is continuously assessed based on the analysis of the movement data. Caregivers are informed about the time and place of a fall via an alarm function and have access to the patient's data stored in the back end. With its fall prevention training, the app offers users the ability to monitor their own performance and assess their own progress.

Although there are already a number of technological solutions aimed at dealing with falls, they only factor in individual aspects: the assessment of risk factors in a fall, the automatic recognition of falls or strategies for preventing falls. FRADE hopes to now close this gap by offering a comprehensive solution for fall management.

Portugal



Chile

## Sustainably mining and storing copper

 With a global market share of more than 27 percent, Chile is the world's largest producer and exporter of copper. Be it for electrical engineering, the construction industry or medicine – the global demand for the metal is enormous, but deposits are limited, which is why copper ore now has to be mined with a high proportion of poisonous arsenic, which then has to be removed and stored later on. The Fraunhofer

Research Institution for Materials Recycling and Resource Strategies IWKS is working together with partners from Chile and Germany on optimizing and developing processes as part of the Reduction of Arsenic in Copper Concentrates (ReAK) project. In doing so, they are factoring in the entire copper mining process chain, from the separation of by-products and stabilization of the arsenic to storing the residues. "We are looking for new combinations of processes

## France

**High-powered magnets: making new from old**

 High-powered permanent magnets contain rare earth metals and are irreplaceable when it comes to high-tech applications in electronics, industrial motors, wind turbines and electric cars. To date, however, no industrial recycling process exists to separate and reuse polymer-bound magnets and the valuable materials they contain – but a French-German consortium wants to change this.

More than 90 percent of the rare earth elements used around the world come from China. “We want to establish a circular economy in Europe so that these elements no longer need to be imported, thus increasing our level of self-sufficiency,” explains Dr. Benjamin Balke, head of the Energy Materials division of the Fraunhofer

Research Institution for Materials Recycling and Resource Strategies IWKS. In doing so, particular attention is paid to polymer-bound rare earth magnets. Their advantage is that they can be produced faster and more efficiently than common magnets using injection molding and 3D printing, which makes them corrosion-resistant and more flexible with regard to shape. However, the magnets and polymers are firmly joined, which makes recycling significantly more difficult.

Under the leadership of Fraunhofer IWKS, the researchers of the SupplyPBM project are examining various possibilities for developing a recycling process that can be implemented in the industrial sector to use old polymer-bound magnets to produce new magnets that meet the same requirements.

## Morocco

**Using green hydrogen to create green ammonia**

 When it comes to climate change, many people think about emissions coming from power plants, road traffic and the industrial sector – hardly anyone thinks about synthesizing ammonia. But this process accounts for around 480 million tons of carbon dioxide emissions each year. Around the world, more than 170 million tons of ammonia are produced each year using petrochemical processes. Among other uses, it serves as a base material for fertilizers.

Regeneratively produced – so-called green – hydrogen is a key element in “power-to-X” technologies, which enable the carbon-neutral production of

fuels, chemicals and ammonia. In collaboration with partners from Morocco, researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB and the Fraunhofer Institute for Microstructure of Materials and Systems IMWS are now constructing a demonstration facility for generating green ammonia in the Maghrebi nation.

OCP, one of the project partners from Morocco, is the world’s leading producer of phosphate derivatives and therefore one of the largest importers of ammonia. OCP hopes to be able to meet a portion of its demand with carbon-neutral ammonia in the medium term with the help of the Green Ammonia project.

# Fraunhofer worldwide

that already exist. At the same time, we bring these together with possible innovative solutions such as bioleaching,” reports Anna-Lisa Bachmann, project coordinator at Fraunhofer IWKS.

Leaching is a term used in technical chemistry and describes a process by which the components involved in a chemical bond are separated. During bioleaching, this task is carried out by microorganisms.

# Extreme research

He began in the theoretical field because, 30 years ago, practical application was unthinkable. Now, Dr. Sergiy Yulin – together with his Fraunhofer colleagues and partners from ZEISS and Trumpf – has taken EUV lithography into the practical field. The technology is a milestone on the road towards increasingly powerful energy-saving microchips – the prerequisite for advances in artificial intelligence, autonomous driving and 5G. The team of researchers is now nominated for the German Future Prize.

By Mandy Bartel

Ten billion transistors on a chip the size of a fingernail – EUV lithography makes it possible.

**T**he limelight? Not really his thing. Dr. Sergiy Yulin prefers an extreme ultraviolet (EUV) light. In his laboratory at the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena, this physicist has been tinkering along with his team on complex multilayer mirrors for EUV optics that make extreme short-wave EUV light usable for the manufacture of microchips. His high-performance layered mirrors for extremely precise large-surface EUV optics are indispensable for so-called extreme ultraviolet lithography (EUVL). The procedure enables the tiniest three-dimensional structures of 7 nanometers – by comparison, the average human hair is 70,000 nanometers thick – to be transferred to wafers. This enables more than ten billion transistors to be placed on a single chip the size of a fingernail.

The first smartphones with microchips manufactured using EUV lithography have been on the market since 2019. They are not only significantly more powerful, but they are also cheaper and more energy efficient. For his preliminary research on this innovation, Sergiy Yulin and his fellow researchers from ZEISS and Trumpf have now been nominated for the German Future Prize 2020, which the German Federal President presents each year to honor outstanding technical achievements that enable ready-to-use products and promise great benefits for people and the economy.

## Most threw in the towel

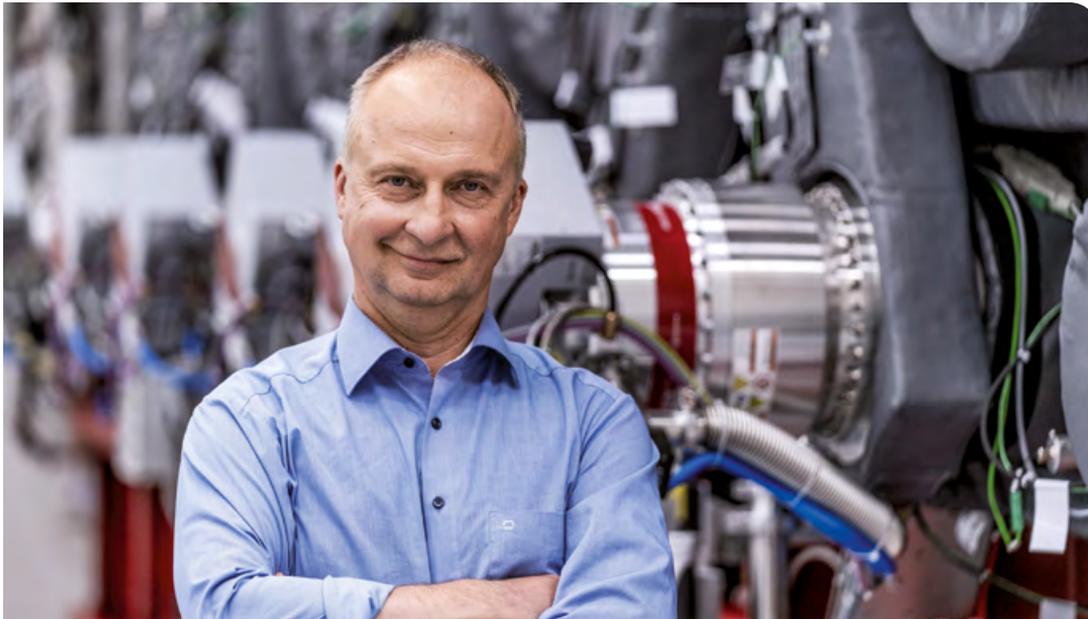
Too complex, too expensive, not practical: For a long time, nothing indicated that the process would be transferrable to an industrial scale. Companies like Canon invested in the technology and ultimately threw in the towel due to the complexity. But a team consisting of ZEISS, Trumpf, Dutch company ASML and Fraunhofer persevered in their belief that the process had a future, continuing to develop increasingly sophisticated components.

**A series of superlatives** ultimately enabled the breakthrough: The extreme UV light was generated using the world's most powerful industrial pulse laser, developed by Trumpf AG. This laser ignites 50,000 tiny tin droplets per second inside of a plasma source to a temperature of 220,000 degrees Celsius – 40 times hotter than the surface of the sun. The procedure takes place in a high-vacuum atmosphere, because air would completely absorb the sensitive light with a wavelength of 13.5 nanometers. Previous optic lithography processes work with wavelengths of 193 nanometers.

To make use of the radiation for the exposure process, the light is reflected in the direction of the actual lithography unit using collector mirrors and ultra-precise projection optics

## Long-standing tradition at Fraunhofer

Research with extreme-ultraviolet light and EUV lithography also has a long-standing tradition at other Fraunhofer Institutes. For example, in 2001, researchers from the Fraunhofer Institute for Material and Beam Technology IWS in Dresden, also active in coating technology, achieved what at that time was the world's highest degree of reflectivity of EUV mirrors. They broke their own world record of 70.1% in 2015 by achieving reflectivity of 70.75% – an important step towards increasing the productivity of EUV lithography. In 2006, Fraunhofer ILT in Aachen developed the first prototypes of an EUV laser source that rapidly discharges electrically stored energy in the form of pulses. There is now a beta version available that is already being used in the industrial sector for exposing chips. All three institutes – IOF, IWS and ILT – were awarded the renowned Joseph von Fraunhofer Prize in 2012 for their research work.



manufactured by ZEISS AG. As the final step in the production chain, Dr. Yulin's surface coating technology is the primary factor in ensuring the atomic precision of the mirrors. "The requirements in terms of reflectivity as well as thermal and tilt stability of the mirrors are enormous, because as much as possible of the elaborately generated light has to be aimed precisely at the target," explains Dr. Yulin. "To do so, in our coating system, we apply 100 nanolayers – which have to be the exact same thickness – to a mirror." If you stretch this mirror out to the size of Germany, the largest irregularity in thickness would amount to a mere 0.1 millimeters. With a normal household mirror, the deviation would be 5 meters. Similar to a slide projection, the EUV light is then projected onto a screen whose structures are then burned onto the wafer positioned behind it. The procedure is repeated to create a miniature three-dimensional work of art in the form of a microchip with its circuit paths.

This is all integrated in a machine the size of a school bus. Intel Fellow Mark Phillips – the director of lithography there – once said of this machine: "The EUV scanner is the most technically advanced tool of any kind that has ever been made." To date, the only provider of these complex machines is the Dutch company ASML. The customers of ASML are major chip manufacturers such as TSMC and Intel, who produce chips for Samsung, Apple and the like.

### Third-generation "Nessy"

This technology – which is extreme in every regard – had a long journey to become ready for series production. This voyage began in 1988 for Sergiy Yulin. Finding the perfect composition of layers for the mirrors required for this process has kept him busy since his studies in his home country of Ukraine. Theoretically at first – because, at that time, no devices existed that were capable of applying layers to large mirror substrates with the necessary degree of precision. So

he began building devices in the 1990s that were able to do just that. In 1995, the durability of the mirrors that he helped develop was put to the test in outer space on the Russian MIIR space station – and the results were a success. The story of his achievements made its way through the scientific community and an appointment to Fraunhofer IOF followed. His "Nessy" device is now in its third generation and is still being used today by the institute and project partners to produce high-quality optics. "In 2009, our team managed to use Nessy 2 to produce the first EUV collector mirror with extremely precise layer thicknesses. At that time, that was something truly extraordinary," the physicist says, remembering the milestone. "A few years later, however, the EUV experiment seemed to be headed for failure, primarily because the EUV light sources available were not powerful enough to generate light with a wavelength of 13.5 nanometers. Businesses lost interest, and the research was put on the back burner."

**What kept him going during this time?** "Researching for 30 years is not that unusual for a technology with this level of complexity and for a researcher in my field. We did have several smaller innovative milestones along the way that were important for series production. What always fascinated me about working with extremely short wavelengths was their enormous potential for practical application. They are good for more than just lithographic chip manufacture. They can open up new insights into yet-unknown spheres in the world of microscopy in the so-called water window, in the observation of outer space or in spectroscopy in the EUV spectral range. This potential just had to be tapped," says Yulin.

On November 25, Sergiy Yulin has to trade in his EUV light for the limelight, and his lab coat for a suit. He will be taking the stage together with his colleagues from ZEISS and Trumpf for the finale of the German Future Prize in Berlin – and will be presenting how three decades of research have now made their way into reality and practical application. ■

Dr. Sergiy Yulin invested three decades into the project of his life. He has kept his smile since the 1980s, when he presented his very own sputtering system in Ukraine.  
© Photo credit left: Fraunhofer/Ansgar Pudenz; right: private

"This potential just had to be tapped."

Dr. Sergiy Yulin,  
Fraunhofer IOF

# When cars need an X-ray

Some 125 years ago, Wilhelm Conrad Röntgen discovered X-rays. Today, X-ray technology is an essential part of medical diagnostics. X-rays are also increasingly used in the automotive industry.

By Christine Broll

“Typically the vehicles are taken apart by hand after crash tests. But deformations can be identified much easier and more precisely in the 3D data from the computed tomography.”

Michael Salamon,  
Fraunhofer IIS

The engine quietly chugs in idle. It belongs to a motorcycle and is now standing in the worldwide unique XXL computed tomography facility at the Development Center for X-Ray Technology EZRT at the Fraunhofer Institute for Integrated Circuits IIS in Fürth. Dr. Richard Schielein checks the position of the engine between the X-ray source and the camera again, then begins the countdown. A deafening alarm goes off, and the red security lights begin to blink. Now, Schielein and his colleagues have to get out of the facility, which is protected by a three-meter-thick concrete wall. Only then is the source of radiation switched on.

The scientists track the X-ray images on the monitors in the control center in the basement of the adjacent building. The engine runs at between 800 and 1,000 revolutions per minute, which corresponds to approximately the level of idling.

**The movement is recorded using a high-performance camera that was developed at the EZRT** and produces 1,000 high-resolution images per second. On the monitor, Schielein can closely observe the movement of the pistons and valves, as well as moving details such as timing belts, springs and flaps in step with the engine.

“To penetrate the metal of the engine and, at the same time, to get an image with an extremely brief exposure time, we need a powerful radiation source like the one we have in this facility,” explains Dr. Theobald Fuchs, lead scientist at the EZRT. The researchers are supporting advancements in the automotive industry – not only with innovative technology on-site, but they are also helping companies in the industry install their own robot-aided CT equipment.

## Post-crash investigation

The vehicles that come to undergo XXL computed tomography are usually pretty destroyed. They have undergone crash testing and are inspected very thoroughly. To this end, they are placed vertically on a rotating table in a special apparatus and then moved between the radiation source and the detector. Michael Salamon, engineer for physical

technology, helped construct the XXL machine and leads the examinations. “Typically the vehicles are taken apart by hand after crash tests to document the deformations. But they can be identified much easier and more precisely in the 3D data from the computed tomography,” the expert says, explaining the advantages of this technology.

## When it comes to crash tests with new electric vehicles, the focus lies on the behavior of the batteries.

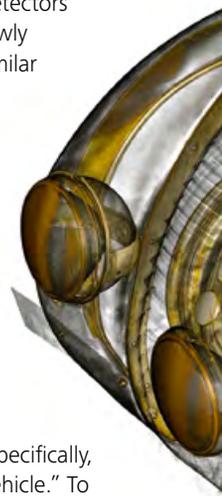
CT scans offer major advantages in this regard, as disassembling a complicated car battery is not without its risks. “Using our technology, we could simply scan electric cars that were damaged in accidents to see how much of an impact it had on the battery,” says Salamon.

To optimize the XXL CT for this application, Salamon is taking part in a collaborative project with the company MT-Mechatronics to develop a simplified process. The most important difference to the common methods is that the vehicle does not rotate; instead, the radiation source and the detectors rotate around the vehicle. The vehicle is moved slowly forward through the “drive-through” machine – similar to medical CT devices, where the patient is slowly moved while lying down.

## Reticing the crowbar

Wolfgang Holub, an engineer at EZRT, and his team have developed another procedure for nondestructive examinations. Holub explains: “Every year, hundreds of new car bodies are broken up as part of quality control in automotive production to check the quality of welded and bonded joints as well as bolts and rivets. Our new RoboCT makes it possible to examine these spots specifically, without having to destroy the entire body of the vehicle.” To do so, the radiation source and detectors are fixed on robot arms and rotate in sync around the object.

The BMW Group has already commissioned two RoboCT units in collaboration with the EZRT: one in the BMW Group Research and Innovation Centre (FIZ) in Munich, where

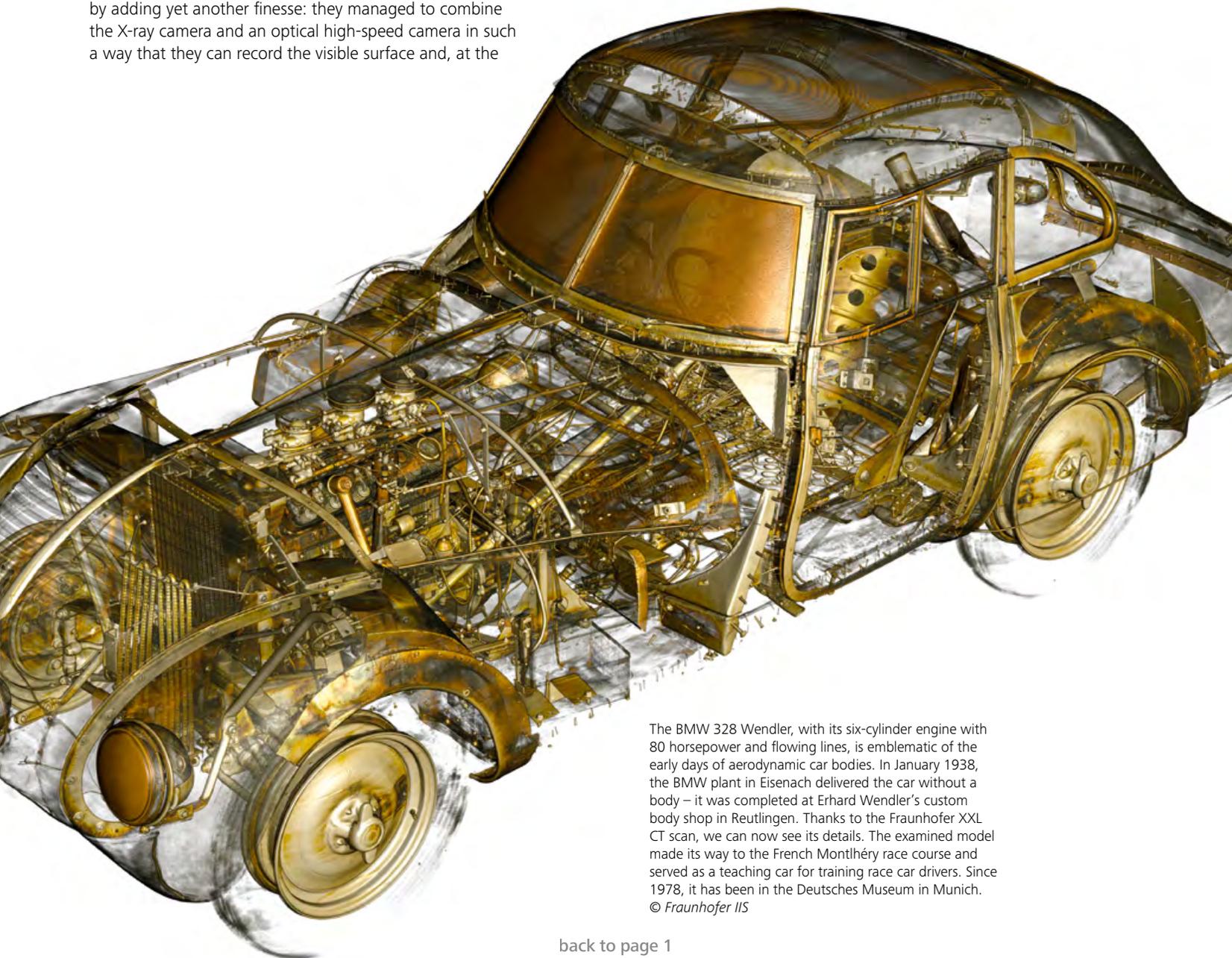


RoboCT investigates the handmade prototypes, and the other in the testing center in Eching, where the pretest vehicles have to prove themselves under the toughest conditions. In addition to the bonded and welded joints, tests are also carried out on seals as well as the location of cable harnesses in the headliner. "Because we have the CT results significantly faster than those of a traditional disassembly, car manufacturers can really reduce their development times," emphasizes Holub.

### What happens inside during a collision

Rolf Behrendt, head of the group, and his team have fine-tuned the performance of the high-speed X-ray camera by adding yet another finesse: they managed to combine the X-ray camera and an optical high-speed camera in such a way that they can record the visible surface and, at the

same time, see from the same perspective what is going on inside the object. As part of an initial series of tests with a sporting goods manufacturer, they examined how a bike helmet deforms when it collides with a block of granite. "Quality control using optical high-speed cameras is the state of the art today," says Behrendt. "By using the X-ray image as a supplement, dynamic processes such as deformations or intermixing can be analyzed much more closely." He is already contemplating a number of application scenarios – from drop tests with laptops to the correct deployment of airbags. ▶

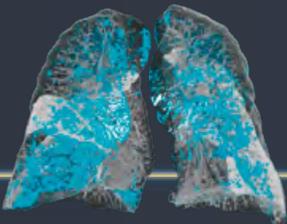


The BMW 328 Wandler, with its six-cylinder engine with 80 horsepower and flowing lines, is emblematic of the early days of aerodynamic car bodies. In January 1938, the BMW plant in Eisenach delivered the car without a body – it was completed at Erhard Wandler's custom body shop in Reutlingen. Thanks to the Fraunhofer XXL CT scan, we can now see its details. The examined model made its way to the French Monthéry race course and served as a teaching car for training race car drivers. Since 1978, it has been in the Deutsches Museum in Munich.  
© Fraunhofer IIS

# 125 years of X-rays

On November 8, 1895, physicist Wilhelm Conrad Röntgen discovered rays that could penetrate objects. The possibilities were enormous, as was the damage caused by the rays in the early stages.

## Use in human medicine



2019:  
Digital assistants can use artificial intelligence to automatically evaluate CT scans and identify any pathological abnormalities.

1989:

Willi Kalender develops the spiral CT. The patient lies on a table, which is then pushed through a rotating X-ray tube, resulting in a spiral-shaped movement of the X-ray beams.



1939 – 1983:

In Germany, mandatory systematic series of X-ray examinations are carried out for the entire population for early recognition of tuberculosis.



1933 – 1945:

During the Nazi reign, radiotherapy machines are abused and used for abortions and forced sterilization.



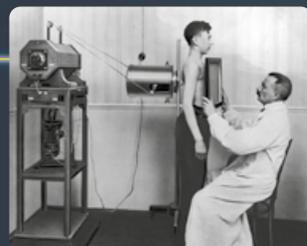
1920:

As part of radiotherapy, the effect of X-rays that is harmful to tissue is used to destroy tumors.



1896

The first medical X-ray images: because Wilhelm Conrad Röntgen does not apply for a patent, the new technology is quickly put to use.



## Milestones of the technology



2007:  
Use of graphic processors for the reconstruction of 3D computed tomographies.



1969:

English engineer Godfrey N. Hounsfield introduces the first functional lab scanner for computed tomography and is awarded the Nobel Prize in 1979 for his efforts.

1913:

In the USA, William David Coolidge develops the hot-cathode X-ray tube (Coolidge tube), which is the predecessor to most of the X-ray tubes in use today.

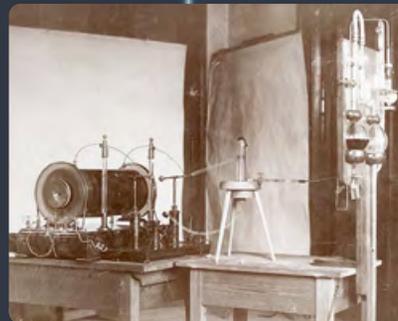


December 22, 1895:

Wilhelm Conrad Röntgen creates the first X-ray image of a human: the hand of his wife, Anna Bertha. The bones and her wedding ring can clearly be seen.



Friday, November 08, 1895:  
At the University of Würzburg, physicist Wilhelm Conrad Röntgen discovers rays that can penetrate objects. The image shows his laboratory.



1895



## ⦿ Nondestructive testing

2017:  
The world's largest X-ray laser XFEL is commissioned in Schenefeld, near Hamburg. It is more than three kilometers long and opens up wholly new possibilities in the field of research.



2010:  
The world's largest publicly accessible facility for XXL computed tomography opens at the Fraunhofer Development Center X-Ray Technology EZRT in Fürth, which is capable of X-raying cars and even airplanes.



1980s:  
Nondestructive quality control using X-ray technology is introduced to series production for cast aluminum parts.



1897: Wilhelm Conrad Röntgen X-rays his hunting rifle, thus carrying out the first nondestructive test.



In 1901, Wilhelm Conrad Röntgen receives the first Nobel Prize for Physics for his discovery of X-rays.



## ⦿ Danger to life and limb

1936:  
The radiology memorial for the victims of X-ray technology is unveiled at the hospital in St. Georg in Hamburg. A total of 359 names memorialize the people who died as a result of their work with X-rays.



1928:  
Founding of the International Commission on Radiological Protection (ICRP), which declared for the first time a quantitative limitation on dosages for people exposed to radiation.

1904:  
Burns, hair loss and cancer result from the indiscriminate use of the new type of radiation. In 1904, a book is published for the first time on the effects of and protecting against radiation. Protective lead clothing – reminiscent of knight's armor – is used for working with radiation.



## ⦿ The roads less traveled

Since 1896:  
X-rays are used early on for artistic photography. The most famous X-ray artists include the two Britons Hugh Turvey and Nick Veasey. One of Veasey's most popular works is titled "Marilyn" (photo).



Until 1973:  
So-called pedoscopes in shoe stores use X-rays to check how shoes fit the feet of customers.



1897:  
Only a few years after discovery, X-rays are used in X-ray machines to foil smugglers.

# Cleverly designed campus

While most universities still struggle to create a good Wi-Fi network, research is already being done at the “campus of the future” at the Bildungscampus in Heilbronn.

By Bianca Busch

“When conceiving new use cases, we always investigate the question of how the campus could be made more innovative, more livable or more convenient.”

Veronika Prochazka, head of the Smart Campus Initiative

It is easy to get lost in the impenetrable jungle of buildings found on the campuses of large universities. Libraries, administration buildings, computing centers and teaching and research facilities are often strewn across several buildings and locations. Locating offices, classrooms and lecture halls is an art in itself that even some of the more seasoned students are unable to master.

In the future, a new app – the Campus Navigator – is intended to offer orientation through navigation based on augmented reality (AR). This app is one of a series of digital service offers currently under development as part of the Smart Campus Initiative research project aimed at making life easier for college students. The team from the Fraunhofer Institute for Industrial Engineering IAO developed the app in collaboration with the software experts from CAMAO. It is being tested at the Bildungscampus in Heilbronn, which connects various educational institutions with each other in an innovative way. College students, employees



and visitors can download the app to their smartphones and use it to make their way to the media lab, a certain classroom or to the library. Users are then guided directly on their screens using AR technology that works both outdoors as well as inside buildings.

## Head to the cafeteria now or later?

“When conceiving new use cases, we always investigate the question of how the campus could be made more innovative, more livable or more convenient,” says Veronika Prochazka, head of the Smart Campus Initiative.

To improve the quality of living and working on campus, the project team of the Smart Campus Initiative is currently working on a model for forecasting how busy the cafeteria is. To this end, the team plans to place sensors in the cafeteria that record the number of guests using photoelectric sensors, Bluetooth or optic systems. Together with the data from the cash register system in the cafeteria, a neural network can simulate the expected wait time over



The Bildungscampus in Heilbronn – officially opened in October 2012 – brings together different institutions.  
© Roland Halbe

the next half hour, which will be available in an online dashboard in the future.

Similar forecast models are planned for the parking garage and the rooms in the library. Using a campus app, users will be able to see parking options on campus in real time and head specifically towards the nearest available parking spot. Sensors are also planned for the rooms at the campus library to help determine available working spaces and guide students to a suitable place to study.

### Also useful away from campus

First and foremost, the success of the pilot projects determines which of the planned applications will actually be used in the future. “When we develop apps or solutions, we are primarily concerned with demonstrating that the undertaking can be carried out, rather than actually offering the service on a permanent basis,” Prochazka emphasizes. As part of the next step, however, expanding the developed smart services beyond the campus can come into consider-

ation: “It is our stated goal to transfer the things that work out of what we test here on campus to completely different contexts.”

### In the future, many smart services could also be used in large companies or cities.

“At the Smart Campus Initiative, we also deal with the question of what can which of the planned technologies achieve under which framework conditions. Would, for instance, a camera – in compliance with data protection regulations – for automated recording of parking space availability be more cost-effective than installing sensors? Or are there potentially possibilities to access this data using sensor structures already in place?” Prochazka explains.

After the coronavirus pandemic, Prochazka is convinced that there will continue to be mixed models of digital and on-site learning at colleges and universities, which is why she and her team are now thinking more profoundly about service offers that could also make the new virtual experience more user-friendly. ■

Head directly to the closest available parking space with the help of the campus app.

# The future of security force communication



“The Fraunhofer solution presents unprecedented possibilities for sharing complex information during operations.”

Frank-Michael Löst,  
State Office of Criminal  
Investigation in Saxony

Dr. Kamen Danowski  
from Fraunhofer IVI (left)  
and Frank-Michael Löst  
from the State Office of  
Criminal Investigation  
in Saxony receiving the  
Joseph von Fraunhofer  
Prize for their technology  
for information exchange  
and coordination.

© All pictures of Fraunhofer prizes: Fraunhofer/  
Piotr Banczerowski



Setting out to tackle real-world challenges in the fight against terrorism and crime, a team of researchers from the Fraunhofer Institute for Transportation and Infrastructure Systems IVI in Dresden and police officers have developed a new technology for sharing information and coordinating in the field. Their efforts have earned them the 2020 Joseph von Fraunhofer Prize. The solution has since been adopted throughout Germany thanks to its great practical benefit and acceptance on the part of users.

By Janine van Ackeren

**T**ask forces face extreme challenges when responding to assassination attempts, terrorist attacks and hostage situations. The high potential for danger demands consummate professionalism from security forces as well as top-of-the-line technical equipment. "Security forces are under tremendous strain in situations like this – after all, this is about protecting the public," says Sven Mewes, police commander of the State Office of Criminal Investigation in Saxony. "That's why it is so crucial to have secure technology that enables police forces to share information with one another, yet is easy to operate even under great psychological pressure."

Dr. Kamen Danowski from the Dresden Fraunhofer Institute for Transportation and Infrastructure Systems IVI and Frank-Michael Löst from the State Office of Criminal Investigation in Saxony jointly developed such technology. They have garnered the Joseph von Fraunhofer Prize for their achievement. The jury was particularly impressed by the societal relevance of the work.

### The system grows with the flow

"Until this new technology was rolled out, we police task forces had to rely on communication by radio and phone. The Fraunhofer solution is future-oriented and presents unprecedented possibilities for sharing complex information during operations and for coordinating actions. What's more, it also supports fast and reliable communication among states and government agencies," says Löst.

Asked about the recipe for success, all sides agree: expertise is one key ingredient; the other is that the researchers and police have found the best way of working together. "We live by the code of partnership rather than mere cooperation. The technology side has to understand the tactical side and vice versa – and that works brilliantly in this case," says Mewes. Dr. Kamen Danowski adds, "We are delighted with the high level of acceptance and positive feedback. Our very close collaboration has enabled police forces to have a hand in shaping our development work. This way, we can transfer research results into practical applications, on target and quickly." This joint effort yields new ideas and concepts for the development team to implement step by step. New functions required by task forces are delivered in coordinated cycles.

### Great acceptance gives rise to a nationwide standard

Several German states have since adopted the technology launched in Saxony. It is on its way to becoming a nationwide standard. "From the very beginning, we coordinated our development activities with allied agencies in several German states and won them over as cooperation partners and users," says Löst.

Fraunhofer IVI has been developing solutions for internal security since 2003, mainly command, control and communication systems. Working closely with users, the focus is very much on translating these developments directly into real-world applications. Their partners and users are the command staff and relief forces from police, forces, fire departments and emergency and disaster management services. ■

**"A secure technology is crucial – one that is also easy to operate even under great psychological pressure."**

Sven Mewes, police commander of the State Office of Criminal Investigation in Saxony

# Glass engineered to defy flames

The Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT in Oberhausen and Hörmann, a family-owned company, has developed a new type of fire-resistant glass - and has brought this glazing from the laboratory to the production line within four years. No more toxic acrylamide, around 85 percent less process waste, a leaner manufacturing process, excellent performance - these product merits garnered the development team the Joseph von Fraunhofer Prize.

“The project had a few instances when something worked that clearly shouldn’t have.”

Thomas Baus,  
Hörmann KG  
Glastechnik

**B**y rights, the glazing developed by Fraunhofer UMSICHT and Hörmann KG, Europe’s market leader in doors and gates, should not work. It does, though, in a way that exceeds every expectation. The new fire-resistant panes do not contain carcinogenic acrylamide, so they can be processed with no toxicological risks. The production line that makes the novel fire protection doors generates just 20 kilograms of process waste a day – far less than the 150 to 160 kilograms produced in the past. Production is more automated, the process is leaner and traceability and reproducibility are ensured across the board. In the event of a fire, the glass withstands flames and heat over 1,000°C for up to 120 minutes, as required by the given fire regulations. Dr. Holger Wack and Damian Hintemann of Fraunhofer UMSICHT and Thomas Baus of Hörmann KG Glastechnik are to be awarded the Joseph von Fraunhofer Prize for this groundbreaking development.

## Cooling water vapor and a heat-insulating salt layer

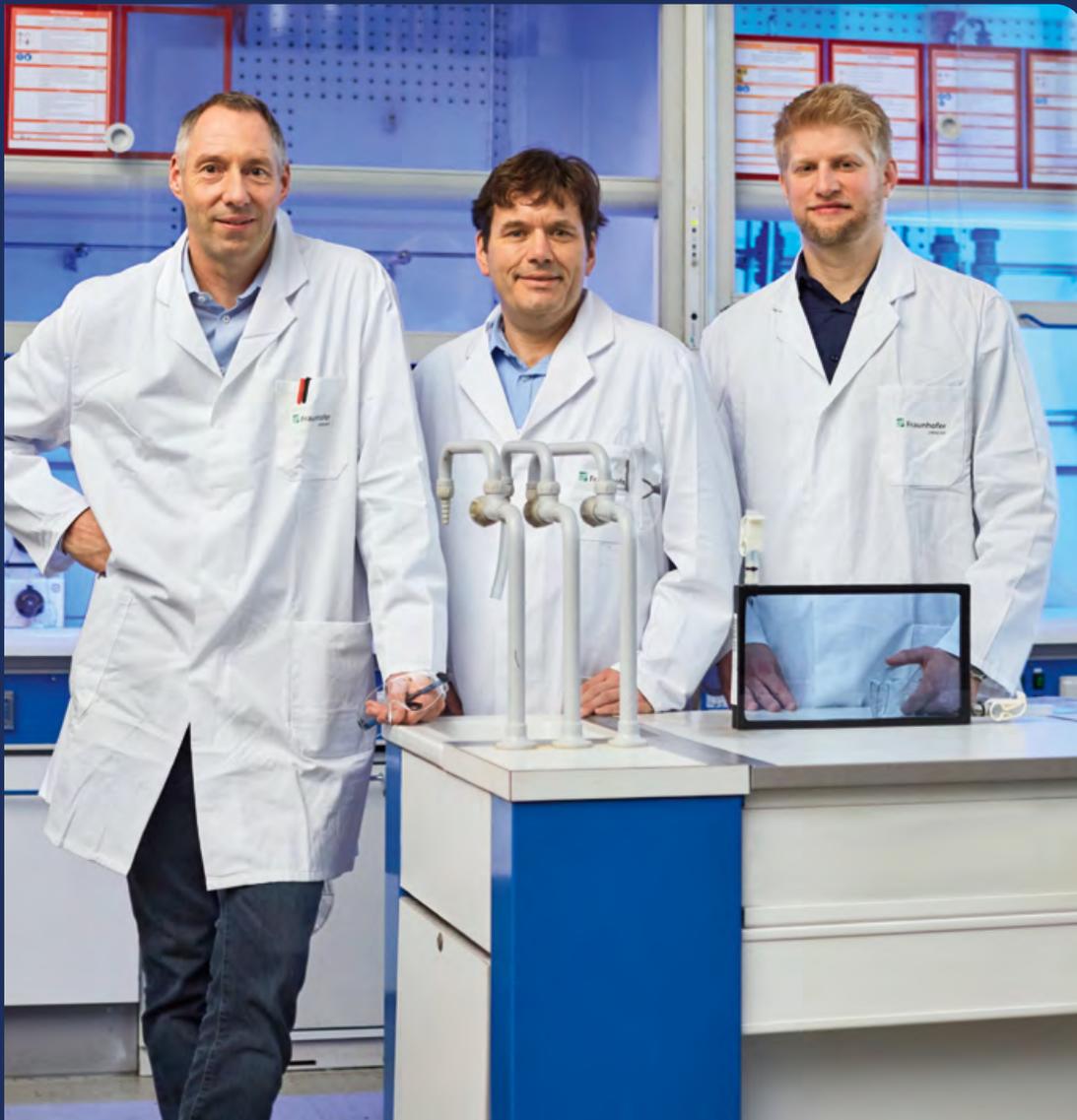
Fire protection glazing contains a transparent gel rich in water and electrolytes between two glass panes. If a fire breaks out, the pane facing the flames does not withstand the high temperature for long and shatters. This actuates two mechanisms: for one, the water in the gel evaporates and cools the intact second pane. For the other, a heat-insulating salt layer forms. The Fraunhofer researchers first combed their database to screen for options: which gels could be suitable for this sort of fire-resistant glazing?

Some 60 attempts failed. Compelled by thoroughness, they tested a basic component that, as the theory goes, would never work. “But it does,” says Wack with a smile. The researchers are reluctant to show their hand. “The project had a few instances like this when something worked that clearly shouldn’t have,” is all Baus is willing to say on the subject.

## Four years from beaker to business

The project was auspicious from the start. The first fire test the researchers carried out after a short time in development already showed promise. The glass held up to a 30-minute fire performance trial. The researchers then scaled it up from the beaker to a demonstration cell at Fraunhofer UMSICHT. “We were able to take the idea out of the lab and into a practical application within just four years – a very short time for the development effort that goes into end-to-end process engineering. Implementation time is usually ten to twelve years,” says Hintemann.

The Hörmann family decided to spin off Hörmann KG Glastechnik in 2016 on the merits of this successful development, building a new plant in Saarland where the fire-resistant glass is now produced. The jury was particularly impressed with this implementation of research results into practice and, on a related note, with the outstanding collaboration between Fraunhofer UMSICHT and Hörmann. “We did more than merely develop fire-resistant glass,” says Baus, emphatically. “We reinvented the production of fire-resistant glass.” ■



Dr. Holger Wack, Damian Hintemann from Fraunhofer UMSICHT and Thomas Baus from Hörmann KG Glastechnik (from left to right) receiving the Joseph von Fraunhofer Prize for their hydrogel-based fire-resistant glass.



“We were able to take the idea out of the lab and into a practical application within just four years.”

Damian Hintemann, Fraunhofer UMSICHT

New fire-resistant glass: no more toxic acrylamide, around 85 percent less process waste, a leaner manufacturing process, excellent performance.

# Tamper-proof satellite navigation

Police, customs, fire departments, critical infrastructure – they all increasingly depend on GPS navigation. But GPS is easy to disrupt and manipulate. A research team from the Fraunhofer Institute for Integrated Circuits IIS has found a fix for that security predicament – a solution that is robust, trustworthy and tamper-proof. It won them this year’s Joseph von Fraunhofer Prize.

“It is the world’s first encrypted signal for use in the civilian sector.”

Alexander Rügamer,  
Fraunhofer IIS

**N**avigation satellites orbit the Earth some 20,000 kilometers over the planet’s surface at a speed of around four kilometers per second. As they make their rounds, they send a constant stream of data on their current position, including time stamps with atomic-clock accuracy. Many applications depend on this data – everything from car navigation systems to critical infrastructure such as power, IT and cellular networks. But this system is vulnerable. Jammers can disrupt satellite data reception. So-called spoofer can fool GPS navigation systems by providing incorrect information about the time and place. The civilian sector has had no alternative to this unprotected satellite data – until now, that is.

## Secure reception with Galileo

A research team at Fraunhofer IIS in Nuremberg has closed this gap with robust, reliable and tamper-proof receiver technologies based on European Galileo navigation signals.

Alexander Rügamer, Dr. Günter Rohmer and Dr. Wolfgang Felber will be awarded the Joseph von Fraunhofer Prize on behalf of the team. Explaining the rationale for its decision, the jury pointed to several achievements, one being the prize winners’ pioneering work in the field of server-based crypto receivers and systems. “The Galileo Public Regulated Service, or PRS system for short, is the world’s first encrypted signal for use in the civilian sector,” says Rügamer. Its benefits are manifold: Galileo is a civilian European system free of any dependence on the USA or Russia, whose systems are operated by military units. It is also robust enough to foil jamming and spoofing attempts. The IIS research team has developed a PRS receiver for civilian use accessible exclusively

to authorized users. This receiver technology has already been installed in police cars and fire engines to gain practical experience for future products.

## Affordable, miniaturized and low-power devices

These new types of receivers are too expensive and complex for the authorized mass market, however. “This is why we had to reimagine PRS systems, thinking about them in a completely different way,” says Rohmer. It turns out that these satellite signals only need to be analyzed in special server infrastructure instead of in the device. Then the server can send only the verified information on location and time back to the end-user device. The research team at Fraunhofer IIS in Nuremberg now operates the world’s first and so far only PRS server in a setup that includes application demonstrators.

## Simulators for testing

Simulators are indispensable in application developments. A PRS signal simulator enables manufacturers and users to answer fundamental questions: How does the receiver respond to rapid acceleration – for example, on board of an aircraft? Will it work in Australia? Spirent, a British company, built the world’s only commercially available system that serves this purpose. In the wake of Brexit, it can no longer offer products that use PRS signals. These are reserved for EU companies. “This is why we have taken over the further development of PRS modules for the signal simulator,” says Felber. The simulator is still from the UK, but everything related to PRS data originates with Fraunhofer IIS. ■



Dr. Wolfgang Felber, Dr. Günter Rohmer and Alexander Rügamer (left to right) accepting the Joseph von Fraunhofer Prize for their new secure receiver technology.

“We had to reimagine PRS systems, thinking about them in a completely different way.”

Dr. Wolfgang Felber, Fraunhofer IIS



The receiver technology has already been installed in police cars and fire engines to gain practical experience for future products.

Dr. Stefan Matlok (left) and Dr. Bernd Eckardt receiving the Joseph von Fraunhofer Prize for the development of a new generation of DC/DC converters.



High efficiency despite compact footprint: the DC/DC converter from Fraunhofer IISB is an important advancement in the energy and mobility transition.



“Our DC/DC converter achieves an efficiency of up to 99 percent, which means that losses are more than halved.”

Dr. Bernd Eckardt, Fraunhofer IISB

# A new generation of DC/DC converters

Fuel cells play a key role in the transition to renewables in power and mobility. But the energy efficiency of these cells poses a major challenge, particularly in automotive engineering. The individual components need to be as light and small as possible, yet attain a high efficiency factor. Researchers at the Fraunhofer Institute for Integrated Systems and Device Technology IISB defied that discrepancy, making the impossible possible by developing a new generation of DC/DC converters that meet precisely these requirements. This stride into the future has won the researchers the Joseph von Fraunhofer Prize.

A quick trip to the supermarket or into the city? Battery electric vehicles get the job done well when it comes to short distances. But a fuel-cell drive that converts hydrogen into electricity looks to be the more promising prospect for commercial vehicles, aircraft and ships. However, this requires many components, and they all have to be smaller and lighter to make the vehicle as energy-efficient as possible. One of these components is the DC/DC power converter. It adapts the fuel cell's voltage to the drive and controls the flow of energy.

## Efficiency increased, losses halved

Dr. Bernd Eckardt and Dr. Stefan Matlok from Fraunhofer IISB in Erlangen have developed a DC/DC converter that achieves very high efficiency despite its extremely compact footprint – and have garnered the Joseph von Fraunhofer Prize for their accomplishment. The jury hailed the outcome of this effort for its future relevance and successful commercial application. “While conventional DC/DC converters have an efficiency of around 97 to 98 percent, ours achieves up to 99 percent,” says Eckardt. “This may not sound like much at first, but it means that the losses are more than halved – and every tenth of a percent matters.” After all, 200,000 watts of power flow through the converter. A loss rate of one percent would mean that two kilowatts of power dissipate in the form of heat.

## In defiance of conventional wisdom

While today's electrical converters for fuel cells occupy more than ten liters of installation space, the Fraunhofer IISB

converter takes up just half as much room. In conjunction with its high efficiency factor, this is a sensational advance given that high switching frequencies and small components are generally said to cause greater losses. Defying this conventional wisdom, the two engineers developed new technologies that enable converters to be highly efficient yet very small. “What we've achieved was thought to be impossible,” says Matlok. “And what made it possible was delving deeper into the physical effects of circuits and components. It is this attention to detail that enabled us to understand and take advantage of new effects. This led to new switching methods, among other things. What is more, new technologies are constantly emerging: our colleagues and specialized companies from the relevant fields are developing ever more powerful individual components, which we as a team can combine to create increasingly powerful converters. After all, Fraunhofer IISB covers all the key technologies in power electronics and has the measuring and manufacturing equipment needed in the various fields.” This is how the institute actualizes the entire value chain – from materials development, chip manufacturing and packaging technology to power electronics systems.

## Transfer to industry

The researchers installed the voltage converter in a car to test its functional efficiency in an on-site climate chamber, where temperatures varied from –25 degrees to 50 degrees Celsius. A practical test carried out in frosty Norway by an automaker also went very well. The two award winners intend to set up a company before the year 2020 is over, with a small core team to market the DC/DC converters. ■

“What we've achieved was thought to be impossible.”

Dr. Stefan Matlok,  
Fraunhofer IISB

# Ultrashort pulse lasers for large components

A paradigm shift is underway in manufacturing: a research team with staff from the Fraunhofer Institute for Laser Technology ILT in Aachen on its roster has broken new ground by using numerous laser beams as tools to structure surfaces. This accelerates the process and opens the door to new applications. The Stifterverband "Forschung im Verbund," a donors' association for joint research, acknowledged the efforts of these researchers with its Science Prize.

"We are practically undertaking the art of tool cloning."

Dr. Arnold Gillner,  
Fraunhofer ILT

Ultrashort pulse lasers can serve to apply functional microstructures and nanostructures to any surface. This type of laser machining is usually done by just one beam from a single source, a far too time-consuming and thus expensive approach to applying the micro- and nanostructures to the large rollers that imprint textures and patterns on fabrics, leather and cardboard. This is why the practice of etching such structures into embossing rollers has prevailed. This is hardly ideal from the environmental perspective, but there was no economically viable alternative – until now, that is.

## Anything but corrosive

A special sort of teamwork has turned laser structuring into a sound business proposition. Instead of a lone ultrashort pulsed laser beam roaming the surface, the laser energy is split into many laser beams of equal power – specifically into 200 partial beams. A special optical system serves to control these beams individually and modulate their power. This has created a new digitally driven tool. With so many of these tools working the surface simultaneously, this process is much faster than conventional laser machining. It is the first affordable option for machining large components. Developed in a joint project called MultiSurf, this technology owes its existence to Dr. Arnold Gillner, Martin Reininghaus and Dr. Johannes Finger from Fraunhofer ILT, Dr. Stephan Brüning from Schepers GmbH & Co. KG, Dr. Gerald Jenke from Matthews International GmbH, Dr. Keming Du from EdgeWave

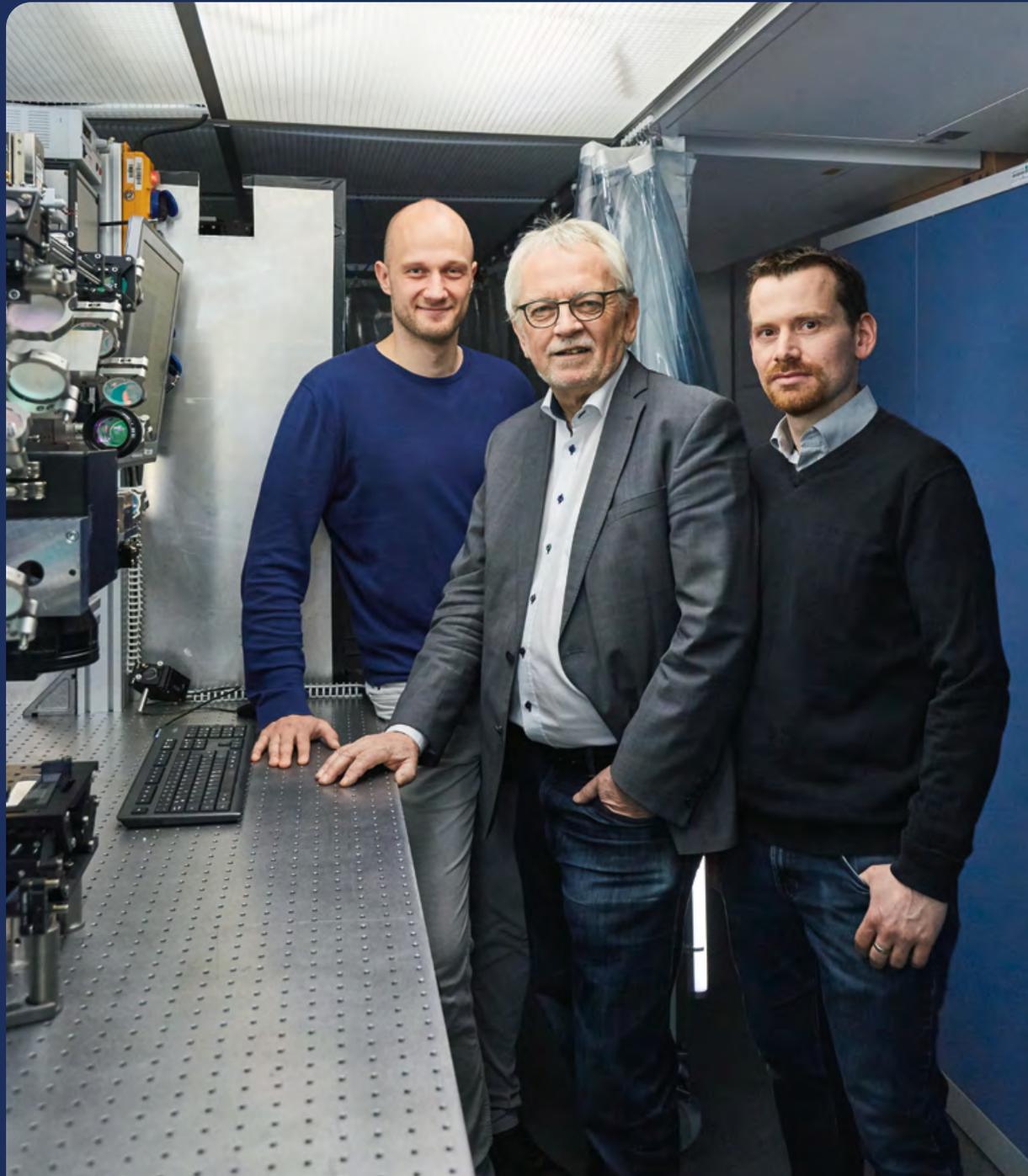
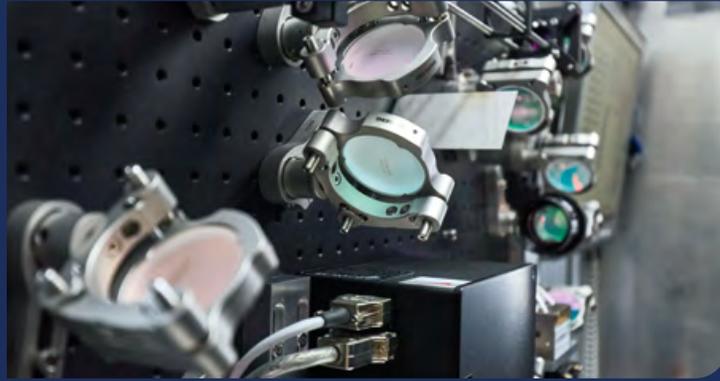
GmbH Innovative Laser Solutions, and Dr. Manfred Jarczyński from LIMO GmbH. They have been singled out to receive the Science Prize from the Stifterverband "Forschung im Verbund" for their efforts.

"We are practically undertaking the art of tool cloning," says Gillner, head of department at Fraunhofer ILT. "This is a paradigm shift in manufacturing – to date, only one tool has been used." What is simple in words is very complicated in the real world. It takes a sophisticated beam guidance system to split the laser beam without losing energy or compromising beam quality. And the beam quality must not suffer. The researchers developed a capable laser and the required optics to this end and adapted the technology on the process side. With simulations providing insight, they were able to get a better picture of the process.

## Teamwork at the human level as well

The collaboration in this project extends beyond the teamwork of the laser beams. Schepers and LIMO are already working on an eight-beam laser structuring system, with Matthews International GmbH using the new laser process to produce press rollers. This cooperation was another of the project's merits that swayed the jury. The jury also felt it was important for the consortium to accurately mirror and be a perfect fit for the value chain and for medium-sized enterprises to be able to afford to adopt this approach. ■

A paradigm shift is underway in manufacturing: a research team has broken new ground by using multiple laser beams as tools to structure surfaces. This accelerates the process and opens the door to new applications.



The jury praised the consortium for its ability to accurately mirror and be a perfect fit for the value chain and that medium-sized enterprises are able to afford to adopt this approach.

Martin Reininghaus, Dr. Arnold Gillner and Dr. Johannes Finger (left to right) receive the Science Prize from Stifterverband "Forschung im Verbund" for their development.

The risk of terrorist attacks is rising wherever large groups of people come together. An innovative software can accurately calculate the details regarding the potential danger posed by explosives. © Unsplash



# Deadly fragments

Homemade bombs can be stored nearly anywhere. New analytical software from Fraunhofer EMI supports the police in their efforts to protect citizens.

By Britta Widmann

**P**aris, Brussels, Manchester, London – the major cities of Europe are increasingly coming under the crosshairs of terrorists. Terrorists with homemade explosives. The level of danger is on the rise. There are instructions on the Internet for how to build them, the components are not hard to come by and the necessary chemicals can be found in everyday products such as detergents and fertilizer. But the actual risk posed by an explosive device can vary significantly. To determine the damage caused by the explosives, police departments will be able to use the analytical software that was developed by a team of researchers at the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, in Freiburg.

Not every bomb goes off. So that the courts can determine the legal penalty, they have to know how dangerous the bomb actually was. "Our tool will calculate the damage an explosive device could cause. We use simulations to generate information on parameters such as the distance traveled by flying fragments, the type and amount of explosive, and the type and geometry of the material used to encase the explosive," says Dr. Katharina Ross, mathematician at Fraunhofer EMI. "It is not always possible to dispense with an actual reconstruction of an explosion, which is costly and time consuming, but our software tool does substantially reduce the requirement for this."

## The thicker the material encasing the device, the more dangerous the fragments

The work of the research team focuses on homemade explosive devices. These can vary enormously in type, ranging from repurposed beverage cans to pipe bombs. To evaluate the potential damage of an explosion, it is necessary to determine the impact of the resulting pressure wave and flying shrapnel. As a rule, the thicker the material encasing the device, the heavier and more dangerous are the fragments produced by the explosion. Two of the key factors

that affect the scale of damage are the mass of the fragment and its velocity. A unique feature of the software tool is its ability to analyze the behavior of not only rounded but also angular and intricately shaped fragments, about which little research exists.

To assess the degree of danger, a distinction is made between three different types of fragments: harmless, liable to cause injury and fatal. The potential damage of an explosion is calculated on the basis of special numerical simulations. This in turn delivers a risk assessment. "We can calculate which fragments are produced and accurately predict their initial velocity and angle of projection. On the basis of this information, we can then develop precise algorithms," Ross explains. The findings from these numerical simulations are supplemented by actual test explosions performed with a typical homemade explosive corresponding to the one used in the device.

## Improving safety concepts

Not only will the police benefit from this expert tool, but it will also enable event agencies and municipal authorities to review various safety concepts in advance of mass events such as city marathons or large-scale religious gatherings. Based on a range of variables, they can determine, for example, whether and where runners and spectators are safe, as well as factor in the impact of preventive measures or evacuation zones. At the same time, should the attack be foiled by police intelligence, the tool can be used to reconstruct the incident and quantify the damage that would have been caused.

An initial test series with explosive devices of complex geometries has shown that the simulated results are a close match to the actual explosions. Further simulations to reconstruct forensic and preventive scenarios are planned for the fall and are, at the same time, an evaluation of the analytical software with experts from the Bundeskriminalamt. ■

Important for sentencing: what would have been the explosive force of the bomb?

Will there soon be more waste in the ocean than fish?  
The amount of plastic that reaches the ocean each year is  
constantly on the rise. © *Grant Thomas*



# Tidying up the ocean floor

Country-sized floating islands of plastic waste in the middle of the ocean are literally only the tip of the world's "trashberg." Around 90 percent of plastic waste is unseen, strewn about the ocean floor. Now, the European SeaClear initiative hopes to make use of robots over and under water to support the clean-up effort.

By Mandy Bartel

When Victor Vescovo dove to the deepest point in the Pacific Ocean in May 2019 looking to set a new record for depth, he could not believe his eyes. He had originally hoped to discover a new biological phenomenon – but what he found in the light of his high-tech submarine at a depth of 11,000 meters was just regular old plastic waste.

Each year, as much as 12.7 million tons of plastic waste make their way into the world's ocean according to estimates of the World Wide Fund for Nature (WWF). This represents an entire semitrailer full every minute. According to a study by the World Economic Forum (WEF), the ratio of plastic to fish had already reached a level of one to five. If you consider that – according to forecasts – global plastic production could quadruple by the year 2050, in 30 years there would be just as much plastic waste in the ocean as fish, if not more.

## Clean-up robots

The true scale of the enormous garbage dump can only be seen beneath the surface: more than 90 percent of the waste is on the ocean floor. The coastal regions are particularly hard hit. As part of an EU project with international partners, the Fraunhofer Center for Maritime Logistics and Services CML in Hamburg has helped develop a concept for cleaning up the ocean floor.

"We network various robot vehicles on and under the water – as well as in the air – with each other," says Johannes Oeffner, head of the Maritime Technologies & Biomimetics team at the CML, explaining the idea behind it. An autonomous or remote-control unmanned mother ship on the surface (unmanned surface vehicle – USV) is supported by

remotely operated underwater vehicles (ROVs) and a drone in the air. The drone, the USV and an ROV chart the waste on the surface and in the water column. A second underwater robot uses this information to collect the located waste from the ocean floor with a specially made gripping arm and a suction unit. The robot then takes the collected waste to an underwater container on the USV, which then transfers the waste to a ship for removal.

## Turbid waters and coastal tourist areas

The process is currently being tested at two locations with quite different challenges. In Hamburg, the project partners are investigating how the process works in an industrial port scenario. The conditions there are characterized by high shipping traffic, existing infrastructure, regulated procedures and, above all, poor visibility under water. "We are relying on a combination of multiple sensors. Primarily acoustic sensors help us measure distances and recognize objects in the turbid environment," explains Cosmin Delea, CML project head.

"In Hamburg, we hope to further develop the ruggedness, suitability for industry and individual features of the SeaClear system under the harshest conditions, so that, in the future, it could be used as a fixed service in ports." To this end, the researchers are working in close collaboration with the Hamburg port authorities.

The coastal scenario being tested in Dubrovnik, Croatia, has a completely different focus. There, the waters of a tourist hot spot with typically clear waters and good visibility are to be freed from underwater waste. The crux is that public access to the waters cannot be restricted, which means ►

"We network various robotic vehicles on and under water."

Johannes Oeffner, head of the Maritime Technologies & Biomimetics team at Fraunhofer CML

► that a number of safety measures are necessary to avoid any potential accidents. Using drones and intelligently linked sensors on the underwater units is intended to generate an additional level of safety.

### A case for AI

So that the fleet of clean-up vehicles can work together seamlessly, the research team is using so-called multiagent control technology for heterogeneous robots. This means that a command – for example, a change of position – only needs to be given to one of the three different robot types; the others then adjust automatically. Thanks to deep-learning algorithms, the robots are able to recognize and classify waste from among the flora and fauna of the ocean.

Because there is currently no clear statistics about the type and amount of underwater waste, the systems still have to undergo complex training. “To this end, we first use information from publicly available sources, such as large online databases that provide footage of marine life. Then we conduct further training with dummy targets,” reports Delea. Using the sensors and the recognition mechanisms, the robots should also be able to uncover plastic in fragile ecosystems such as coral reefs without harming the ecosystems.

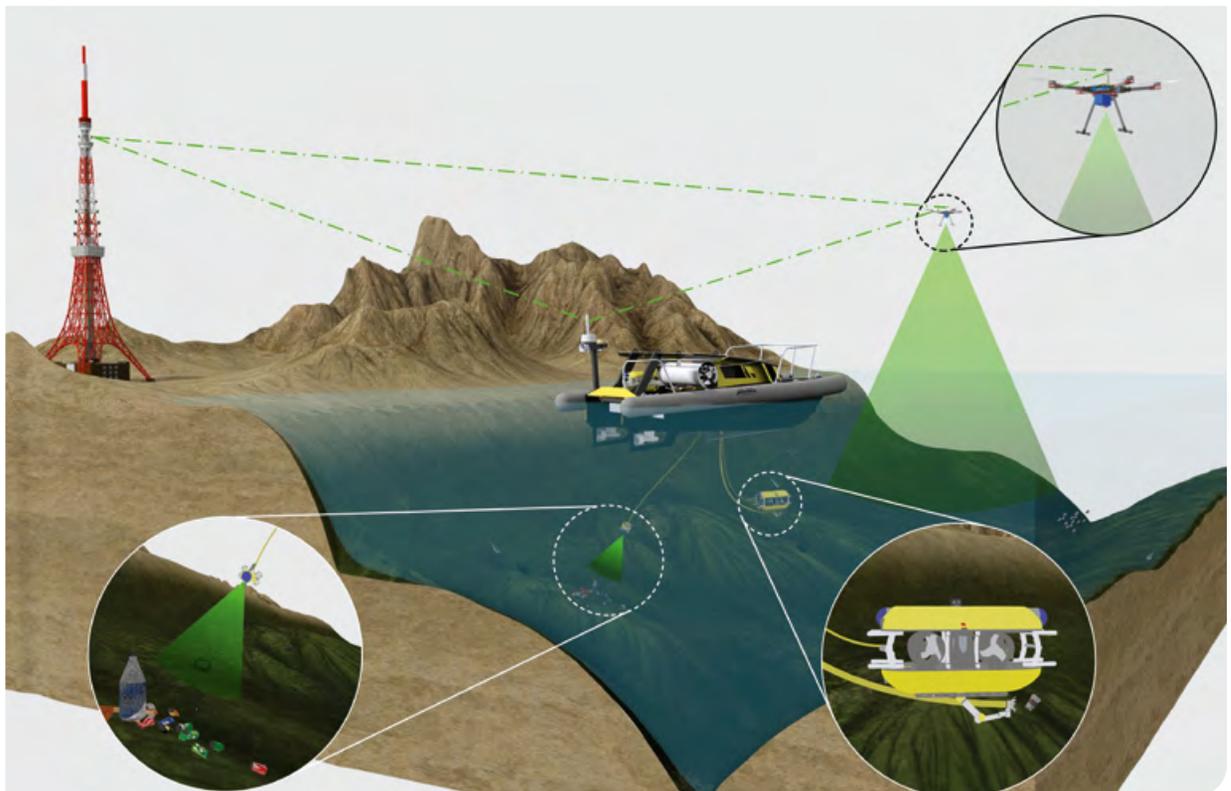
### European partnership

The technical universities of Munich, Delft, Dubrovnik and Cluj-Napoca, as well as SubSea Tech Marseille, the Hamburg Port Authority and the DUNEA Regional Development Agency Dubrovnik, are working hand in hand with Fraunhofer CML on the SeaClear project. As technical coordinators of the project, the Hamburg-based researchers from Fraunhofer CML are responsible for integration of the system as a whole. This includes setup of the virtual monitoring center where the robots are controlled as well as the development of the communication network and the necessary server infrastructure.

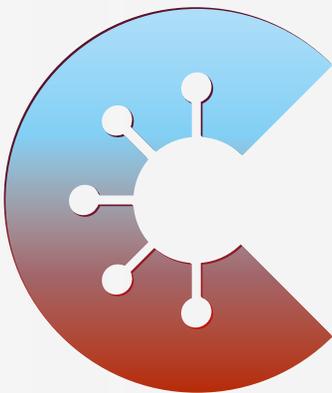
Until the end of 2023 – with the conclusion of the SeaClear project – the robots will clean up the underwater coastal areas, either partially remotely controlled or autonomously. The system will then be able to be operated by the Hamburg Port Authority and the relevant authority in Dubrovnik. Other regions will follow. For the time being, the robots are designed for depths of 20 to 30 meters. The plastic waste in the Mariana Trench – which, at nearly 11 kilometers, is the deepest point in the ocean – will thus likely remain a symbol for the man-made pollution of the world’s oceans for decades to come. ■

The robots will be cleaning up the underwater coastal regions until the end of 2023.

The SeaClear clean-up fleet consists of an autonomous mother ship with collection containers on the surface, a drone flying in the air and two underwater robots, with one finding and the other gathering the waste. © S. Sosnowski – SeaClear Project



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