

Fraunhofer

magazine

1/20



Green gains

Sustainability - the tie that binds ecology and the economy closer together

Health: A way out of the antibiotics crisis

Transportation: Autonomous, but not dangerous

Security: Fending off drones with microwaves

Ole Hansen,
Project Manager at
Fraunhofer WKI

SUSTAINABILITY IS THE FUTURE!



CONTINUING EDUCATION AT FRAUNHOFER

Experience innovation in action, earn qualifications with part-time training and gain the competitive edge bestowed by knowledge.

www.academy.fraunhofer.de/en

Maintaining innovative strength in times of crisis



Prof. Reimund Neugebauer
© Fraunhofer/Bernhard Huber

In the midst of the warmest winter since records began, a single topic dominated the World Economic Forum Annual Meeting earlier this year: climate change. The message that reached us from the fresh mountain air of Davos, Switzerland, at 1560 meters above sea level, was a positive one. Industry is not the sworn enemy of climate policy. On the contrary, industry is our best hope for finding a way out of the climate crisis.

And then, just a few weeks later, we saw how this issue was suddenly and unexpectedly swept aside by another crisis, which affects all of us personally and soon became the only topic of public debate. A novel virus, which the World Health Organization has named "Severe acute respiratory syndrome coronavirus 2," has profoundly disrupted every aspect of our lives. And so, once again, a single topic dominates our concerns.

But we should beware of abruptly switching directions in these turbulent times. Instead we should be thinking in terms of longer-term developments. This is what is expected of the Fraunhofer-Gesellschaft, the world's leading applied research organization, as its contribution to the German and European economies.

The present situation has demonstrated how much people rely on knowledgeable experts to provide factual information when the world is in disarray. They turn to experts for comfort when panic rises, for a true assessment of dangers threatening their health and lives, and for reassurance that vaccines and therapeutic drugs will soon be available.

Scientific research was never as essential as today. Whatever the current crisis – climate, public health, or the economy: whenever society has to redefine its basic precepts, added

value must be brought to bear on the changes that ensue if these are to take hold successfully. In this context, economy and ecology are not opposing forces. They will always come together in a concerted effort to create a sustainable future for everyone.

According to the Bloomberg Innovation Index 2020, which rates national economies in terms of their innovative strength, Germany has moved up to the number-one position, beating South Korea into second place after six years at the top.

The USA has slipped down to ninth place. We have the strength to shape the future. So let us continue unabated to put our energy and passion into research for the long-term benefits it provides. It will be decisive for our economy, our prosperity, and our wellbeing.

Stay safe and stay healthy!

Yours sincerely,

Reimund Neugebauer
President of the Fraunhofer-Gesellschaft

Contents

10 Green gains

Sustainability is spawning lots of new business models. Anita May aims to produce platform chemicals based on bio-organisms – and reduce the amount of fossil resources used to make plastic.

36 Decontamination robots

There are an estimated 263,950 contaminated sites in Germany. Robots can do the cleaning up in situations that are too hazardous for humans.



03 Editorial

06 In brief, Editorial notes

10 **Lead article: Green gains – sustainability, the missing link between ecology and the economy**
Environmental protection and profitability are not opposites, as many emerging business models go to show.

24 **“That saves huge amounts of money!”**
In this interview, Prof. Julia Arlinghaus makes the case that more efficient factories conserve resources.

26 **Your discarded smartphone is a goldmine**
A new approach to recycling, in which laser techniques help recover reusable materials from cellphones.

28 **Rectifying some common misconceptions about chemistry**
Germany’s chemicals sector: An article in defense of an often-vilified industry that accounts for 460,000 jobs.

30 **Doing the math for smarter mass transit**
Optimizing departure times by a few seconds can save cities millions.

32 **Fill ‘er up with biofuel**
Synthetic fuels from renewable sources reduce greenhouse gas emissions by up to 30 percent.

34 **Voice of industry**
Dr. Peter Leibinger, Trumpf GmbH & Co.KG

36 **Autonomous clean-up crew**
An estimated 263,950 sites in Germany are contaminated by hazardous waste. Time to call in the robots.

38 **Unraveling myths and truths about the dark net**
Drugs, weapons, pornography, and much more. Prof. Martin Steinebach casts light on the dark web.



34 Voice of industry

Dr. Peter Leibinger of Trumpf GmbH + Co.KG calls for Germany to step up its commitment to quantum technology.

61 Solving the antibiotics crisis with phage therapy

A century-old idea gives cause for renewed hope in the battle against multi-drug resistant bacteria.

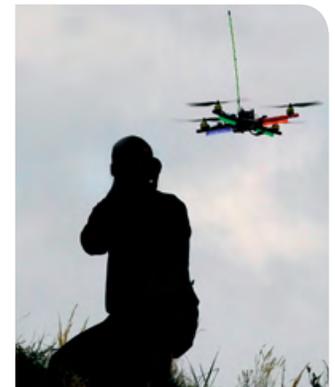
42 Anti-drone defense with microwaves

Drones pose a growing threat. Fraunhofer is looking to boost security and safety.



46 The quest for an anti-icing formula

In the air yet or still stuck on the ground, de-icing? New technology saves time and money, and spares the chemicals.



- 41 How will we eat in the future?**
Fraunhofer ISI is investigating the trends that will shape tomorrow's food industry.
- 42 Anti-drone defense with microwaves**
Drones pose a growing threat, but new tech can boost security and safety.
- 44 Fraunhofer worldwide**
Applications and projects
- 46 The quest for an anti-icing formula**
De-icing aircraft takes time, costs money and consumes lots of chemicals. New solutions are in the works.
- 48 A new audio experience for movie and music lovers**
Much of life takes place at home in times of crises like the coronavirus pandemic. Fraunhofer IIS researchers are perfecting ways of replicating the concert-hall or movie-theater experience.

- 50 Hunting the killers in the body**
Fraunhofer ITEM is investigating the mechanisms of metastasis.
- 52 Heat from a coal mine**
Water sourced from disused collieries provides heating in winter and cooling in summer.
- 57 Little things, big opportunities**
Memristors could be a boon to artificial intelligence.
- 61 Multi-drug resistant germs**
Phage therapy was discovered 100 years ago and then forgotten. The antibiotics crisis is fueling its renaissance.
- 67 Putting safety to the test**
Fraunhofer is creating new opportunities for smart vehicles.

In 2019, **wind power** became the **biggest source of energy** fed into the German national grid, having **increased by 15.7 percent** compared with the previous year. In 2020, the winter cyclone Storm Ciara fed up to 43.7 gigawatts into the grid at times, setting a **wind power record** in Germany. According to an assessment made by Fraunhofer ISE, last year the **share of renewable energies** increased overall from 40.6% to

46%



The screech of the barn owl is a sound unlike any other. © AdobeStock



Surveying wildlife with animal sound sensors

Experts have to take stock of local fauna when planning a wind farm or a nature conservation area. A new sensor system will make this task a lot easier.

Researchers at the Fraunhofer Institute for Digital Media Technology IDMT in Oldenburg have teamed up with colleagues from Berlin's Museum für Naturkunde (natural history museum) and industry partners to develop a system that automatically captures and assesses sounds made by wildlife.

"Today's technical means for recording animal sounds are very expensive – either that, or you have to resort to homemade devices. This is practically impossible to do over an extended period or at spots that are hard to reach," says Dr. Karl-Heinz Frommolt, who heads up the Biodiversity Informatics department at the Museum für Naturkunde in Berlin. He adds that it takes a great deal of effort to assess the data once it has been collected. This a job often

fraught with errors. The recording device fails to capture animal some sounds, while recording others twice. Frommolt finds this method to be imprecise and time-consuming.

These issues are to be resolved by a proposed sensor system that goes by the name of DeViSe – an acronym for the German words for automatic detection, localization and tracking of birds and vocalizing animal species using intelligent acoustic sensors. Affordable, robust and small, this is a recording device replete with controller and analytics software. "This smart system automatically captures the data and determines things like the species or the frequency of animal calls," says Frommolt. DeViSe can also locate vocalizing animals and map out patterns.

A cure for periodontitis

A research team at the Fraunhofer Institute for Cell Therapy and Immunology IZI in Halle has joined forces with scientists from the University of Krakow and the Zahnmedizinischen Klinik (dental clinic) at Bern to develop and patent a highly specific active ingredient to treat periodontitis. This venture is an EU project.

Periodontitis is a very common disease. More than half the adults in Germany suffer from this bacterially induced inflammation of the gums. There is no cure, and merely administering broad-spectrum antibiotics is not a viable solution.

"The new active substance is absorbed by and acts only on the germs that cause the disease. Administered locally in the periodontal pocket, it does not stress the organism. And it mitigates the development of resistances," says Dr. Mirko Buchholz from Fraunhofer IZI, one of

the two managing directors and founders of PerioTrap. An initial idea for a delivery system has been developed to optimize the drug's effect: An absorbable rod as flexible as a thread releases the test agent over the course of 42 days, a very long period by any count.

PerioTrap Pharmaceuticals, a startup launched in 2018, is striving to bring this new development to market. Researchers from Halle and the Fraunhofer-Gesellschaft have a stake in the company as its founders.

Periodontitis patients would like nothing more than to bounce back with a radiant smile. © AdobeStock



A smart way of tapping renewable power



The amount of energy produced by renewable sources ebbs and flows. But excess solar or wind energy is hard to store and transport over long distances. The Fraunhofer Institute for Industrial Mathematics ITWM has found a smart solution to that problem – an innovative energy management system.

Featuring wood, glass and synthetics, the award-winning architecture of Amsterdam's floating homes is certainly an eye-catcher. Their innovative energy management system is no less compelling.
© Isabel Nabuurs

This system serves to connect photovoltaic systems, batteries, heat pumps and electric cars in a smart way to power individual households – largely with renewable energy despite these sources' fluctuating power production. This system has passed muster in a pilot project encompassing 30 floating houses in an Amsterdam neighborhood.

"We built on our energy management system for individual houses to develop a system for entire energy communities," says project manager Matthias Klein, deputy head of the High Performance Computing department at Fraunhofer ITWM. "It controls photovoltaic systems and heat pumps, and recharges home and electric cars' batteries, thereby supporting sector coupling." Furnishing enough energy to everyone in the neighborhood – all the time, even on dark days and without overtaxing the shared power line to the public grid – is no simple matter.

This energy management system is modular. It serves as a communal energy hub that constantly analyzes the situation to determine where the power needs to go. The photovoltaic systems, heat pumps and batteries installed in the individual houses interoperate as one big system. A case in point: House A's residents are on vacation. House B's residents are throwing a party, so its demand for power is spiking. The energy produced by the photovoltaic system then flows from house A to house B. The system taps the home battery when it is dark outside and the solar unit is not generating electricity. It can do this across homes too.

The energy management system's modules may also be deployed individually and tailored to the given application. "There is already a permanently installed base of 60 to 70 of our systems ranging from private households and cafeterias to entire businesses and one sewage treatment plant," says Klein. Wendeware AG, a Fraunhofer ITWM spin-off, has been selling the system since early 2019.

Getting power to where it needs to go with modular energy management

Side panels in the digital model of the demonstrator helicopter. © Airbus



With blazing speed to the scene

Affordable, sustainable and able to travel over 400 kilometers an hour, the new high-speed helicopter known as RACER – short for Rapid And Cost-Efficient Rotorcraft – certainly lives up to its billing.

Researchers at the Fraunhofer Institute for Casting, Composite and Processing Technology IGCV in Augsburg have developed a sustainable process to manufacture the helicopter's sandwiched side panels in a highly automated way. The outer layers of the sandwich are a carbon fiber-reinforced plastic (CFRP); its honeycomb core is made of phenolic resin. These very light components help reduce fuel consumption. RACER is to be deployed on missions that demand high speeds, efficient aerodynamics and high fuel efficiency, such as air ambulance, medevac, and search and rescue operations. Other international partners have joined Airbus in this project.



RACER could one day provide a fast means of traveling through urban airspace unimpeded by traffic jams. © Airbus

Most sandwiched CFRP side panels have had to be laminated by hand in a rather elaborate process. The Fraunhofer IGCV team working on this project managed to manufacture these panels in a highly automated process chain. This workflow and smart production planning practices help save material and conserve energy. Aside from making components as large and complex as this, their greatest challenge was to integrate the core into the sandwich. The researchers conducted parameter studies and sensitivity analyses with an eye to optimizing the laminating process and achieving a strong bond at the core ramps.

Catching criminals that much faster with 3D scanners

Forensic technicians have to make a plaster cast to secure footwear impressions. This protracted procedure destroys trace left by the criminal.



Plaster takes a long time to set, especially in cold or wet weather. © AdobeStock

A new portable 3D scanner now provides a quick, easy way of securing tracks left by footwear. "The scanner captures the form of footprints in three dimensions," says Roland Ramm, a researcher at the Fraunhofer Institute for Applied

Optics and Precision Engineering IOF in Jena. "At just 4.3 kilograms, it is very light, battery-powered and robust. What's more, it works without physical contact, so the footprint remains intact after scanning." With a very fine resolution of less than 200 micrometers, the device can reliably detect even the smallest details. This depth of view is crucial to detecting small scratches in the tread that identify a specific shoe.

Forensic technicians can easily define scan settings on a touch display and assess the scan data right after they hold the scanner over a footprint. Detailed analysis takes place later in the lab, where technicians also compare these prints with those of other crime scenes and perpetrators.

Editorial notes

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



Fraunhofer

Published by:

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

Free subscription:

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

Editorial team: Janis Eitner (responsible for content), Josef Oskar Seitz (editor-in-chief), Dr. Sonja Endres, Roman Möhlmann

Editorial assistants: Janine van Ackeren, Mandy Bartel, Christine Broll, Katja Engel, Sirka Henning, Daniela Leitner, Eric Schütz (2issue), Jacob Schmette, Mehmet Toprak, Eva Rathgeber, Britta Widmann.

Layout & lithography: Vierthaler & Braun
Cover image: Norman Konrad on behalf of Fraunhofer

Printed by: H. HEENEMANN GmbH, Berlin
Translation: Burton, Van Iersel & Whitney

© Fraunhofer-Gesellschaft e.V.
Munich 2020





The Ariane 5's two boosters hold 238 metric tons of fuel each, but fuel costs are just part of what makes launches so expensive. Microlaunchers are to provide a more affordable means of hauling CubeSats into space.
© John Kraus/ESA

The aerospike engine consumes up to
30%
less fuel.

Speeding sats into space

Small satellites called CubeSats may soon account for the lion's share of sats in low Earth orbit (LEO). Affordable and easy to make, Airbus has been cranking out CubeSats on a Florida assembly line since last year.

Fraunhofer researchers have designed an efficient new engine for mini rockets that will soon take over from large launch vehicles to haul CubeSats up into space and send them off into the desired orbit. Until now, CubeSats have had to wait for the likes of Ariane, Vega and other rockets to launch. Then they have to set out on an orbit dictated by the rocket's main passenger, usually a large satellite. This could soon change with mini rockets engineers call microlaunchers. Latched onto the underbelly of an aircraft wing, they can be launched in flight and propelled into space, quickly and accurately. These versatile microlaunchers do not need a spaceport to take flight. An airport that can accommodate the special launch aircraft will do. Talks about repurposing a former military airfield at Nordholz near Cuxhaven, Germany, are underway.

The one great drawback of microlaunchers is that their payload is limited to 350 kilograms, so they need light engines that consume little fuel. Aerospike engines happen to be a perfect fit.

"The technology behind aerospike engines dates back to the 1960s. But our ability to produce engines as efficient as this is owed to the freedom brought by additive manufacturing," says Michael Müller, a research fellow at the Additive Manufacturing Center Dresden (AMCD), which is

operated jointly by the Fraunhofer Institute for Material and Beam Technology IWS and TU Dresden. On its way from Earth to orbit, the aerospike nozzle adapts to the changing pressure at various altitudes. This makes it more efficient, so it burns up to 30 percent less fuel than conventional engines. The nozzle consists of a spike-like center-body designed to accelerate combustion gases. The fuel injector, combustion chamber and nozzle are all printed layer by layer in an additive manufacturing process called laser powder bed fusion.

The aerospike engine is more compact than conventional systems, so the rocket is lighter. "Every gram saved is worth its weight in gold in space flight. The heavier the overall system, the lighter its payload has to be," says Müller. Temperatures of several thousand degrees Celsius prevail in the combustion chamber – a major issue for aerospike engines. This has changed with an additive manufacturing process designed to enable effective cooling. This workflow creates a complex system that cannot be milled or cast in conventional ways. Its one-millimeter-wide cooling channels follow the combustion chamber's contours.

Researchers have already tested a prototype aerospike engine, achieving a burn time of 30 seconds. They are now striving to further increase the propulsion system's efficiency.

Green gains

How sustainability is bringing
ecology and the economy closer

Climate protection doesn't mean doing
without. Recycling plastics saves money
and benefits the environment. Sustainability
will spawn a host of new business models.



Research for a healthier world: "People need to relearn how to live with nature," says Anita May. She works as a group manager at the Fraunhofer Center for Chemical-Biotechnological Processes CBP.

According to corporate consultants McKinsey, global production of plastics currently lies at 400 million metric tons a year. Of that total, little more than 10 percent is recycled.

Germany tops the league in the use of plastics, accounting for 25 percent of the total consumption in Europe. And now Germany intends to play a leading role in the fight against plastic waste. Back at the beginning of 2019, 28 companies from the consumer goods and chemicals industries announced a joint campaign to combat this problem. It was around that time that the media began to fill with images of dolphins and seabirds choking to death on the plastic trash in our oceans. Over the period from 1950 to 2015, the plastics industry produced more than 8.3 billion metric tons – more than one ton for every person currently living on earth. In other words, the problem has never been more acute. Yet what technologies do we have to tackle it? Are they affordable? And, going forward, which new business models might we see emerge from the current sustainability debate?

Substitution



In early 2019, Porsche released a small production run of a couple of hundred vehicles – the Cayman GT4

Clubsport – featuring body parts made of natural fiber-reinforced composites. The Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut, WKI is working on new processes to replace fossil-based fibers in composites. “Lightweight parts for aircraft and upmarket automobiles use a lot of carbon fiber-reinforced plastics,” explains Ole Hansen, research associate at Fraunhofer WKI. “Carbon fibers are light in weight and provide the necessary rigidity for body parts. But they are also expensive and require a lot of energy to produce. That’s why we’re using natural fibers such as wood, hemp, flax or jute, which also meet the specifications required for a vehicle door.” In the case of the Porsche Cayman, that not only makes ecological sense but also brings sound economic benefits: it takes less energy both to produce natural fibers and also to recycle them at a later date. Moreover, once these natural fibers can be mass-produced, they should be significantly cheaper than carbon fiber.

Polymers made entirely of biobased materials – lactic acid, for example – are not yet able to compete on price with fossil-based polymers. In addition, it is important that these new biobased plastics can be produced with existing processing technology and that they are compatible with standard polymers and other materials.

Nonetheless, lucrative business opportunities are already emerging – especially for products such as children’s toys and lunch boxes, where environmentally conscious consumers are opting for ecological alternatives to conventional items. “Changes to the political framework, such as a carbon tax or carbon trading, can also help tilt things further in favor of biobased polymers and pave the way for a broad commercial use,” says Dr. Stephan Kabasci, departmental head at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT. “All of these materials have a substantially smaller carbon footprint.” The institute is therefore working on the development of biobased polymers to meet this demand. Current projects include polymers composed of biobased molecules that can be used as additives in adhesives or as biobased lubricants.

The problem of the higher price of biobased polymers

disappears, however, when waste materials are used in combination with inexpensive processing methods. This is the goal of HyperBioCoat, an EU project now underway at the Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS. Researchers are using apple pomace as a feedstock to produce a biobased and biodegradable polymer material. Apple pomace is available in sufficient quantities and, as a waste material, inexpensive to source. What’s more, its use as a plastics feedstock does not deprive the food industry of an otherwise useful commodity. The hemicellulose product extracted from the apple pomace is suitable for various purposes. These include coatings to provide a barrier against oxygen and water vapor; polymer films, trays and bottles; and natural waxes, paper additives and cosmetic articles. ▶

Natural fibers instead of carbon fiber: Ole Hansen, project manager at the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut, WKI, is using wood, hemp, flax and jute to reinforce plastics – and save energy.



A polymer with entirely new properties? "We've created a genuine alternative to anything currently available,"

says Dr. Michael Richter, Fraunhofer IGB

► In a similar project, researchers from the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are likewise using waste materials as a polymer feedstock. Here, the basic idea is to endow biobased polymers with special characteristics by means of biomolecules displaying structural motifs that are not easy to achieve with petrochemical feedstocks. Given such characteristics, these polymers may then prove more attractive than petroleum-based products, despite costing more. In a joint project, researchers from Fraunhofer IGB and the Technical University of Munich have developed a new biobased family of polyamides using an industrially viable chemical transformation of naturally occurring terpenes. The resulting polyamides feature structural characteristics of the parent compounds. In place of a linear polymer chain, the process gives rise to a chain that contains a large number of small rings and other side groups. This endows the polymer with completely new properties. "We've created a genuine alternative, with clear distinguishing features, to anything currently available," says Dr. Michael Richter, head of the innovation field Bioinspired Chemistry at the Straubing branch of Fraunhofer IGB.

This process also has benefits from an industry perspective. Synthesis takes place in a single reaction vessel, which substantially reduces costs. It can be easily scaled up to large volumes and is therefore efficient. Furthermore, as a by-product of the pulp and paper industry, the feedstock – turpentine – is available in industrially relevant quantities. It makes most sense to replace fossil-based polymers in large-volume applications, where a lot of plastic is required. "We're currently looking at vegetable crates, for example; they weigh around two kilograms and contain a lot of plastic," says Christoph Habermann, research associate at Fraunhofer WKI. "And we're hoping to identify similar products in other sectors." Up to 30 percent of the plastic is replaced by wood fibers. This not only makes the material itself more environmentally compatible but also reduces the cost of raw materials by around 20 percent. A test run of 1000 vegetable crates has now been produced.



In the case of some applications, however, it is not as easy to replace the use of plastic with a biopolymer or another material. At the Fraunhofer Center for Chemical-Biotechnological Processes CBP in Leuna, a pilot plant is therefore producing so-called platform

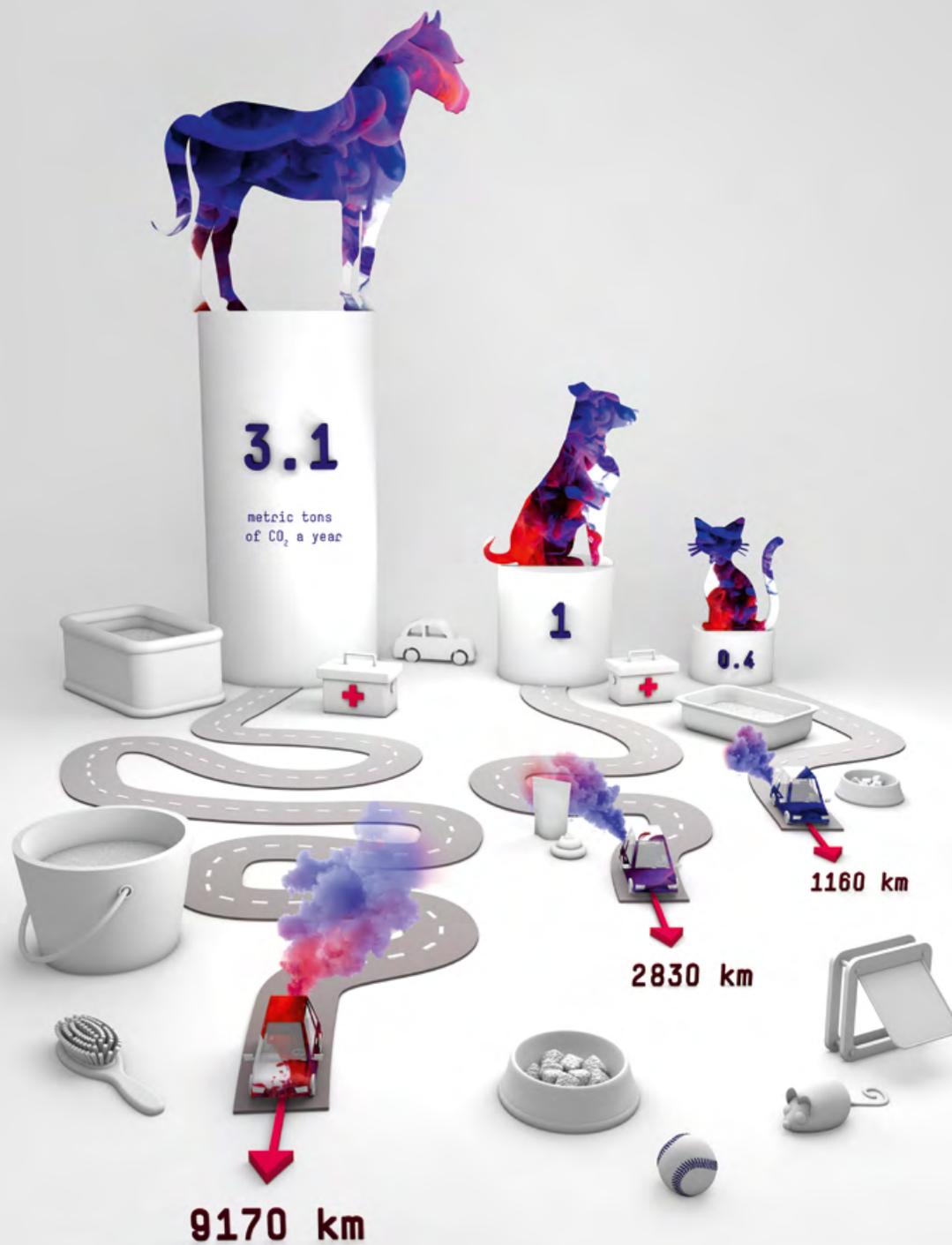
chemicals in a sustainable process based on bio-organisms. Conventionally, these bulk chemicals are produced from petroleum feedstocks on a huge scale. At present, 99 percent of all plastics are made from fossil-based feedstocks, with around 6 percent of global oil consumption attributable to plastics production. Fraunhofer CBP covers the entire process here: in the department for biomass fractionation, researchers use wood chips to produce the sugar required to

feed bio-organisms; in the department for biotechnological processes, these bio-organisms are used to produce the required platform chemicals; and in the department for chemical processes, these platform chemicals are modified according to customer requirements. Concrete examples of this setup include the fermentative production of isobutene, a project for industrial partner Global Bioenergies (GBE). Here, a team 15 people working in shifts around the clock is operating a pilot plant to produce the platform chemical isobutene by means of a biotech process based on *Escherichia coli* bacteria. On the strength of the scientific results and process know-how accumulated during the pilot phase, GBE has long-term plans to build a plant for production on an industrial scale.

Recycling

Germans are big recyclers of plastic packaging. In 2017, however, more than half of this collected plastic packaging (61 percent) ended up in waste incineration plants, with a modest 39 percent being recycled. Moreover, genuine recycling remains very much the exception: only 15.6 percent of the collected recyclable waste found its way into new plastics, while 23.4 percent was used for so-called lower-grade applications. For a highly successful examples of recycling, we need look no further than the humble PET bottle, 98 percent of which are recycled. Inspired by this, a number of retail chains are now looking at introducing their own recycling systems for other types of plastic packaging. Bioplastics such as polylactide, for example, could be sorted and recycled to produce the same material.

The Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE® pools the expertise of six Fraunhofer Institutes. Its job is to improve product design and increase recycling rates so as to make the production of plastics more circular. "A key aspect here is to organize a dialog between all the different stakeholders along the value chain," explains Dr. Hartmut Pflaum, who heads the central office for CCPE at Fraunhofer UMSICHT. "It's only by joining forces that we can accomplish this task." ►



Are cars the only problem? Swiss environmental consultants ESU-services have investigated the carbon footprint of domestic animals. Perhaps it's time to say "neigh" to pets.

Keeping a horse generates CO₂ emissions of 3.1 metric tons a year. According to ESU-services, that corresponds to driving 9170 kilometers in a car. In fact, when all environmental impacts are included, the equivalent comes to 21,500 kilometers. By comparison, a car in Germany is driven, on average, some 13,000 kilometers a year.
 © Illustration: Daniela Leitner

► Two of the cluster's six research departments are investigating the production of sustainable plastics. Projects here include the development of additives that cause the plastic to decompose as soon as it comes into contact with saltwater or other environmental elements.



Other research departments are focusing on recycling. For example, one group of researchers is investigating whether it is possible to digitally mark and map individual flows of plastic goods – i.e., to create a digital twin. In the case of a PC housing, for example,

this would mean that a datafile created at the moment of production would be maintained throughout the entire product life cycle. Another group is looking at whether a “multicycle” plant might be used to recycle different types of plastic. Here, the most profitable business models are being identified and then scaled up. Parallel projects are examining whether, in terms of sustainability, recycling is necessarily better than one-way usage, and whether product recycling or chemical recycling is more effective. A Laboratory for Technical Biopolymers, to be established by Fraunhofer IGB in Straubing, will likewise focus on materials for a circular economy. In particular, it will concentrate on developing biobased polymers and identifying potential applications.

Fraunhofer CCPE® is also looking into what has become a huge issue in Germany and elsewhere – namely, the millions of packages delivered each working day. “Online retailers employ systematic processes,” Pflaum explains. “As a rule, ordered goods are delivered in a box that, in most cases, ends up in the recycling container. Might it be possible to introduce reusable packaging? And, if so, what specifications would the system need to meet?” The research department for Business and Transformation markets new developments in this field and consults with stakeholders along the value chain, starting with industrial companies and progressing right down to individual consumers. For the industry, it's an idea whose time has come. “We've been approached by companies from right along the value chain,” says Pflaum. “Polymer producers, packaging manufacturers, product distributors and retail chains.”

With between 80 and 90 percent of all foodstuffs being wrapped for sale, it's little wonder that a large proportion of plastics – 40 percent, to be precise – is used in this way. Food packaging has to meet strict high requirements and often consists of multilayer laminated plastic film – a complex mix of different materials for which there is currently no suitable recycling process. That said, the CreaSolv® process from the Fraunhofer Institute for Process Engineering and Packaging IVV could offer a way out here. “We use a solvent mix tailored to the precise mix of plastics,” explains Dr. Andreas Mäurer. “This is then filtered in order to remove any

contaminants and unwanted additives.” Here, researchers are focusing on a closed-loop approach, whereby the recycled material is able to assume the same function as before.

“We've now been able to scale up our various business models to the point where we can recycle profitably.” Examples include a demonstration plant built in Indonesia by Fraunhofer IVV, which is now recycling 3 metric tons a day of – previously nonrecyclable – multilayer plastic films of the type used for potato chip bags and wurst skins. With its powerful cleaning properties, the CreaSolv® process is also suitable for dealing with heavily contaminated plastic waste. This includes electronic scrap coated with flame retardant and expanded polystyrene used for building insulation. In an EU project, Fraunhofer IVV is currently building a recycling plant for expanded polystyrene with a capacity of 3000 metric tons a year. Similarly, a pilot plant in Bavaria is now recycling waste packaging collected from private households. In an initial phase, the plant will recycle several truckloads of waste a day.

Longer use

Increasing attention is now being devoted to closed-loop economies in areas other than plastics. As the saying goes: “Waste materials are simply raw materials in the wrong place.” Closed-loop cycles of materials have a vital role to play in sustainable economic activity. “Here, we're focusing not only on the flow of materials but also, and most importantly, on the trio of ecology, economy and social acceptability,” explains Dr. Andreas Stegmüller, research associate at the Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS. This is a complex task. A car, for example, consists of thousands of individual parts, each of which is optimized to perform a specific function. “Viewed from the perspective of the circular economy, however, every part would have to be produced sustainably and contain no toxic materials et cetera. ►

Up to 14 million parcels a day are delivered in Germany. Does all this cardboard really have to end up in recycling?

Caught between two stools? Dr. Hartmut Pflaum, head of the CCPE central office at Fraunhofer UMSICHT, is investigating the sustainability of child car seats as a potentially circular product.



IHG 470 S
NDER 1300-675

KREIBURG

Alle
Frontplatte
Ella

670

“Using a hydro-mechanical process, we can separate each component into its constituent materials to a purity of practically 100 percent.”

Dr. Jörg Zimmermann

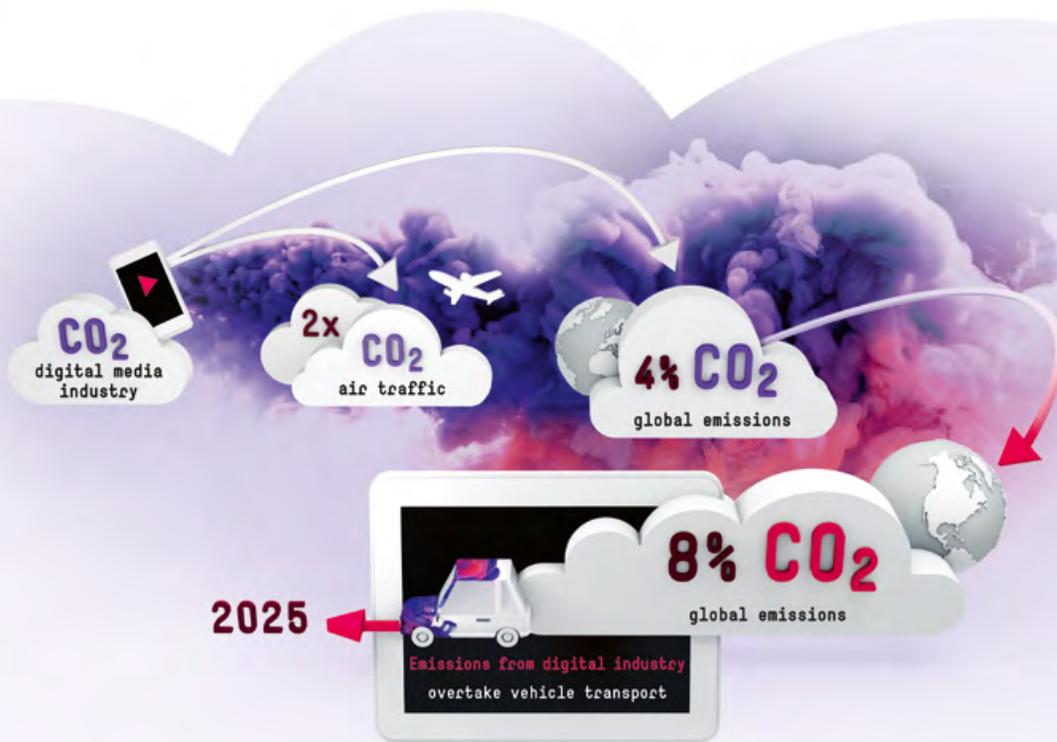
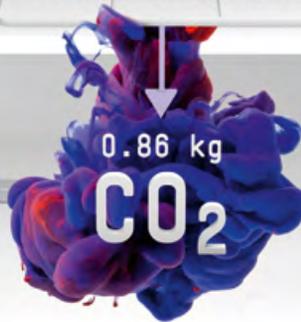
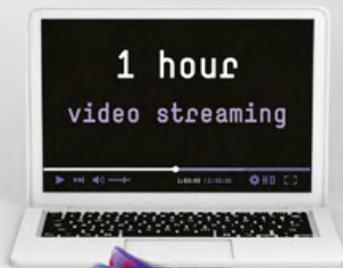
► “Recycling, too, has to meet a whole bunch of technical requirements.” In terms of today’s automotive manufacturing, such conditions would be difficult to fulfill. However, the switch to electromobility offers a prime opportunity. Here, the industry is focusing on modular design, whereby individual components are connected to one another but can be easily exchanged. “We’re putting together a unified concept that comprises materials, processes – both manufacturing and recycling – and the overall business model,” Stegmüller explains. On behalf of industry, a research team devised a model to show the various options – classified according to profitability – for recycling electric vehicle batteries that no longer deliver the required performance. The project revealed that while conventional recycling of battery materials will yield a solid return, up to ten times as much can be earned by initially using the decommissioned batteries for localized storage of electricity generated from renewable sources. Battery performance is still adequate for this purpose, even if it no longer suffices to power an electric vehicle. However such a repurposing would require the establishment of an appropriate infrastructure. In other words, it would require a network of suppliers who would buy up the decommissioned batteries and then sell them on to, for example, private households to provide intermediate storage of excess electricity generated by photovoltaic panels. Here, too, the Fraunhofer researchers specified suitable business models. And, once again, the message was clear: Fortune favors the bold!

Life cycle

Companies can face major challenges when it comes to making an effective contribution to achieving greater sustainability. After all, a lot of work has already gone into making their manufacturing processes and high-tech products as efficient as possible in terms of materials and energy consumption. Yet appearances can be deceptive. As Michael Dieterle, research associate at the Fraunhofer Institute for Chemical Technology ICT, explains, looking at the problem in a new way can help reveal new potential. He is referring to the so-called life cycle gap – i.e., the difference between the energy and the raw materials that go into a product during manufacture and what can be extracted by means of recycling. Consider the lithium ion batteries used in electric vehicles. “In this case, there is a potential saving in carbon emissions of 45 percent,” Dieterle explains. Simply recycling

the battery casing would reduce the life cycle gap to 35 percent. Viewed over its entire life cycle, a battery’s carbon footprint would shrink by 8 percent despite the additional work required to remove the casing for recycling.

A profitable prospect, in other words, not least with experts forecasting that the number of electric vehicles is set to rise to between two and three million by 2025. Promising recycling methods are also emerging for the battery innards, which are a rich source of valuable and, in some cases, strategic resources such as cobalt, lithium, nickel and copper, most of which have to be imported from countries outside the EU. Moreover, batteries also contain materials that pose a danger to health and the environment if not disposed of properly. In other words, battery recycling makes perfect sense from an economic and an ecological point of view. The problem is that batteries comprise a complex combination of composite materials. At present, therefore, they are either mechanically shredded or processed pyrometallurgically. In the former case, material purity lies at around 70 to 80 percent, since the shredding process merely reduces the battery to smaller pieces that may well consist of two or more different materials, which in turn require substantial further processing. In the latter case, the batteries are heated in a process known as pyrometallurgical extraction, which yields high material purity but fails to recover all the recyclable materials. What’s more, it is very energy-intensive. Researchers at Fraunhofer IWKS have therefore developed an alternative process. “We use a hydromechanical process to separate all the various components according to material type,” Dr. Jörg Zimmermann explains. “For the anode and cathode materials, the degree of purity is over 99 percent, and it’s practically 100 percent for materials such as aluminum foil, copper foil and stainless steel. Our process is considerably more selective than a purely mechanical process.” ►



The environmental impact of digitalization: an hour's video streaming is the same as driving 3.5 kilometers in the car

The digital media industry's carbon footprint is estimated to be twice that of global air traffic – and thereby makes up 4 percent of global carbon emissions. On current trends, it will be producing more greenhouse gases than total vehicle transport by 2025.
© Illustration: Daniela Leitner

► The process works as follows: battery cells are placed in a water bath, where a pulse of high voltage creates a shock wave in the water. This attacks the weak points of the battery cells – i.e., at the joints where one material is bonded to another. Rather than being shredded, the cells are broken into their composite parts, which are sorted into fractions. The process already works on a lab scale, and the pilot plant is now to be modified by the end of 2020 to enable continuous operation.

Rental models



Do we really need to own everything we use, particularly the things we only need on an occasional basis? As the debate on sustainability evolves, it's a question more and more people are asking themselves.

Well-established rental models already exist in the mobility sector – car sharing or the public hire of bicycles and electric scooters – and similar schemes are being contemplated for electric vehicle batteries. When it comes to clothing, however, it would mark a radically new departure. That's not to say that such a model wouldn't make sense. Studies by Greenpeace show that as much as 30 percent of all new clothing is never, or only ever very rarely, worn. It would therefore be good if such unnecessary purchases could be eliminated. In fact, new retail models are already emerging. The German chain Tchibo, for example, is now offering its own-brand clothing for hire rather than for sale. Behind the Tchibo Share concept is the company Relenda GmbH. Yet can a clothes rental scheme be both sustainable and economic, particularly given the logistical requirements and the small target group? Researchers from the Fraunhofer Institute for Systems and Innovation Research ISI are now investigating two of the business models currently operated by Relenda. The study forms part of the Wear2Share project, which is funded by Germany's Federal Ministry of Education and Research (BMBF). "We can already say that both of these rental models are economically viable, even if the costs of logistics and cleaning are high," says Dr. Johannes Schuler, project manager at Fraunhofer ISI. As for their sustainability, the researchers have not yet been able to arrive at a definitive answer – it all depends on the base conditions.

We rent cars, we rent e-scooters. Might rental models for clothing also work?

Smart manufacturing

Ensuring the right base conditions is also a vital factor in manufacturing. Take the German foundry business, which produces over five million parts and components a year. Here, energy costs account for around 25 percent of gross value added. The corollary of this is high carbon emissions, with the casting of aluminum and light-metal parts alone responsible for around a million metric tons of CO₂ a year. Here, too, there is room for improvement. As Marc Kujath, research associate at the Fraunhofer Institute for Factory Operation and Automation IFF, explains: "By using movable crucibles and switching from electricity to gas, we can make energy savings of 60 percent, which would correspond to a reduction in carbon emissions of up to 80 percent." This new approach has been developed together with partners in the ETAL project. Researchers from Fraunhofer IFF were responsible for mapping and modeling foundry processes. On the basis of these models, they can now determine for other foundries which approach is best suited to their needs.

With regard to "green" energy – here, too, there is big potential for savings. In the RELflex project, researchers from Fraunhofer IFF are looking at how companies can use photovoltaic and other renewable sources of energy to power their own production processes and thereby increase their operating efficiency, competitiveness and self-sufficiency. This would also enhance their business model, enabling them, for example, to raise the bar even further for green products and not only produce them with biobased materials but also use renewable energy to do so. Ultimately, the most efficient solution would be to integrate buffer storage areas into the production process, and then manufacture to stock when energy is in abundant supply.

As the growing trend towards organic and regional produce illustrates, more and more customers are now demanding sustainability not only for manufactured goods but also for the food on their plate. This is only one of a number of reasons why growers are having to adapt their way of working. Following several long dry summers and an extended period of drought, there is now a real fear that a lack of water is going to render traditional irrigation systems nonviable. ►



Clothing to rent rather than buy? "The models we investigated are all economically viable," says Dr. Johannes Schuler, project manager at Fraunhofer ISI.

► **Hydroponics may provide** a way forward here. This is the method – similar to the hydroculture of houseplants – by which crops are grown on an inert substrate such as rock wool and can subsist with much less water than is required in normal cultivation. In a project entitled HypoWave, researchers from Fraunhofer IGB have teamed up with partners to make this method more sustainable: “We looked at whether it would be possible to use sewage from a wastewater plant and what kind of treatment this would first require,” says Dr. Marius Mohr, head of the innovation field Water Technologies and Resource Recovery at Fraunhofer IGB. Case studies indicate that the most viable option is to implement such a scheme at wastewater plants that would otherwise have to expand in order to meet new and more stringent regulations. This is because the very nutrients that would have to be removed from the wastewater before it can be discharged into a watercourse are instead used for cultivating plants in a hydroponic setup. “And, what’s more, it enables us to achieve smaller and more sustainable water cycles,” says Mohr.

In arid regions such as sub-Saharan Africa, water is a scarce commodity – whether for crops, livestock or people. To make up for this shortfall, desalination – of seawater or brackish water – is increasingly the preferred solution, with reverse osmosis the method most commonly used (65 percent). Yet this technology has considerable drawbacks. “For a start, it uses a lot of energy, which in turn causes a lot of carbon emissions if that energy is generated by conventional means,” explains Dr. Lothar Schäfer, coordinator of the ICON WASTE project at the Fraunhofer Institute for Surface Engineering and Thin Films IST. “Secondly, it requires substantial anti-fouling measures, which means that significant amounts of the chemicals used for this purpose end up in the sea or groundwater.” A number of Fraunhofer Institutes are working on this project. Together with the University of Stellenbosch in South Africa, they are looking to boost the efficiency of the desalination process and to develop sustainable alternatives to antifouling methods, thereby putting a stop to this source of water pollution. Further areas of interest include the development of localized desalination plants and the treatment of water contaminated with microbes for use in food production.

Water is a key factor not only in traditional agriculture. It is also vital for aquaculture, which is becoming an increasingly important form of food production. The reasons for this are twofold: firstly, our seas are largely overfished, and fishing quotas have been introduced to protect fish stocks; secondly, arable land per head of population is becoming scarce, making aquaculture increasingly important for food supply. In addition, fish have an outstanding feed conversion ratio: 1 kilogram of feed yields 1 kilo of edible fish, whereas 1 kilo of pork requires 3 kilos of feed, and 1 kilo of beef as much as

10 kilos. With current UN forecasts suggesting that the world population is likely to grow from 7.7 to 9.7 billion by 2050, this is going to become a critical factor.



Around half of all fish sold to consumers now comes from large-scale aquaculture. In many cases, this does not represent an ecological alternative to fish

caught from wild stocks, since the feed residues and fish excrement associated with aquaculture increase the input of nutrients into the water. Prof. Charli Kruse, director of the Fraunhofer Research Institution for Marine Biotechnology and Cell Technology EMB in Lübeck, and his team are working on a solution: “We’re developing sustainable, land-based, closed-loop forms of aquaculture. In this case, rather than the nutrient-rich water simply being fed into the sewerage system, it is used to cultivate other organisms such as bivalves or macroalgae. We’re therefore recycling the waste from one species by using it to feed another species.” In other words, this not only filters the wastewater produced by fish farming but also creates additional produce that can boost income. This form of closed-loop aquaculture is no substitute for marine-based operations in open waters and the high earnings they generate. “But one way of cutting the environmental impact of intensive fish farming might be to populate the farmed waters with organisms that reduce the level of nutrients,” says Kruse. And this in turn would mark a further step toward achieving the kind of sustainable way of living for which young people have been taking to the streets in their Fridays for Future demonstrations. ■

One kilo of feed yields one kilo of edible fish. One kilo of pork requires three kilos of feed, and one kilo of beef up to ten kilos.



Creating order from chaos

The photographer for the cover story of this issue of *Fraunhofer Magazine* is **Norman Konrad**, born in Gotha, Germany, in 1976. After training as a vehicle mechanic, he studied photography and design in Bielefeld and Prague. His work has been awarded a **Silver Lion** in Cannes, a gold **European Design Award** and a **Silver Cube** from the Art Directors Club, New York.

Konrad, now a **Berlin resident**, is well known for his striking use of color – and for the extreme care with which he orders the apparent chaos of his works. “I have a very precise idea of how things should be arranged,” he explains, “So precise, in fact, that it has some people shaking their heads!” To create the image shown to the right, he used a **large, empty aquarium**. The arm visible at the top of the photo belongs to the janitor. By all accounts, he survived the photo shoot unscathed.



Prof. Charli Kruse is director of the Fraunhofer Institute for Marine Biotechnology and Cell Technology EMB.

“That saves real money!”

Looking at sustainability from the economic perspective is what Prof. Julia Arlinghaus, Director of the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg, recommends.

Interview by Josef Seitz

Professor Arlinghaus, are ecology and economics mutually exclusive?

Arlinghaus: Anything but. We're living at the most exciting time of all in which companies are outdoing each other in the race for climate neutrality. There are now funds that support green technologies, funds that support sustainability. Ecology has become a criterion for investors.

Will we consumers have to give things up?

The great thing is that everyone has the freedom to behave as they wish as consumers. And what I'm finding is that many younger people in particular are actively and very consciously choosing a new kind of product. As a professor, I experience spirited discussions with my students about whether we really need such services as same-day and same-hour delivery, which are still very resource-intensive at this time, and whether business people ought to be assuming more responsibility.

So how do we reconcile the contradictions in a new sustainability?

With the economic perspective. Our businesses are operating in largely saturated markets, after all. At the same time, we have large segments of the global population, several billion people in all, really living in poverty. If we manage to manufacture and market products adapted to their circumstances, then we could turn this into a classic win-win situation. On the one hand, we're fighting poverty. On the other hand, we're opening increasingly attractive markets for our businesses. Making that sustainable in the sense of social sustainability, however, necessitates more than simply copying and exporting our business models. We have to find

solutions that integrate people locally in manufacturing and supply chains. Then this will generate jobs. Then this will generate education. Then this will generate prosperity.

Back to Europe and Germany. How can we go easy on the wallet and preserve the environment at the same time?

New technologies – whether they be sensor systems, artificial intelligence or robotics – help us make processes more efficient, of course. We are minimizing mileage. That saves energy. We can also improve the quality of our manufacturing processes, though. Just recently, we were able to reduce rejects by thirty percent at a company by employing artificial intelligence and quality inspection integrated in the manufacturing process. That saves real money and resources! Another recent project was about optimizing energy use in a foundry. We developed new technologies for that, but also reorganized production planning and control. This enabled us to cut carbon dioxide emissions by as much as eighty percent and energy expenditures by as much as sixty percent. In other words, we're no longer just optimizing to maximize speed. We're introducing another dimension that enables us to optimize manufacturing by sourcing renewable energy, for instance. Incidentally, we use the same technologies that help us make factories more efficient to do this.

Professor Arlinghaus, you sound remarkably optimistic.

I really am. Personally, however, I want us never to lose sight of the social component whenever we are talking about sustainability. It is important, especially with regard to digitalization, to remember that we're always dealing with people. We have to take them along with us.

“We also have to take traditions, historical processes and established structures into account. That's the only way we'll reach the German Mittelstand.”

Prof. Julia Arlinghaus



Julia Arlinghaus has headed the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg since October 2019. © Viktoria Kühne

You are making yourself the advocate of – pardon the overused expression – the human factor. How do you manage to make your case for this soft factor to businesses in increasingly hard times?

To be honest, I never have to convince any company at all. On the contrary, I'm seeing industry coming to us with these issues. At our institute, we have staff members in every unit who have specialized in learning processes and adaptation processes. In my experience, businesses are grateful for this service, which we provide along with the technology.

Researching for the future without losing sight of the present?

At Fraunhofer, we have to be thinking five, ten and maybe even more years ahead, of course. But we have to remember that the reality of people's lives develops more slowly. A factory stands as long as eighty, sometimes one hundred years. Talking about visionary ideas isn't enough there. We also have to take traditions, historical processes and established structures into account. That's the only way we'll reach the German Mittelstand. We have to bring people and businesses on board wherever they are really situated.

Where do you see major challenges in the future?

This balancing act between the present and the future is one. I have been dealing with supply chain risk management in my research for many years. We have to become more responsive and resilient to disruptions and fluctuations. We have to envision our energy and manufacturing systems collectively – that's an ecological and economic path into the future. ■

“We cut carbon dioxide emissions by as much as eighty percent and energy expenditures by as much as sixty percent.”

Prof. Julia Arlinghaus

Nine partners in four countries have been working since 2015 to find the best way of recovering secondary raw materials from cellphones. © AdobeStock

Rare-earth metals in high-tech products

Tantalum

A rare heavy metal with a high elastic modulus. It is very resistant and stable, and has a very high melting point. Mostly used in capacitors. A conflict mineral mined in the Congo.

Gallium

A soft, silvery, pliable metal with diamagnetic properties. Used in transistors and other semiconductor devices, and also solar cells.

Tungsten

A very hard, shock- and heat-resistant metal. Used to make hardened steel for space rockets and military hardware, but also the filament in light bulbs. Added to steel alloys to give them greater strength. The ore is extracted in China and other countries.

Cobalt

A ferromagnetic heavy metal with multiple uses, including ultra-high-strength steel alloys. Also used in batteries. A conflict mineral mined in the Congo.



Your discarded smartphone is a goldmine

Every smartphone and almost any other electronic device contains valuable, reusable materials. And rising commodity prices are increasing their value.

By Mehmet Toprak

One kilogram of gallium sells for 270 U.S. dollars. Tantalum is worth 260 U.S. dollars per kilo, and cobalt 24 U.S. dollars. Recycling is not only growing in importance because of the scarcity of these raw materials, but also because it is an intrinsic part of many new business models. However, it is difficult to recover such secondary raw materials from smartphones and tablets. For example, the tantalum contained in capacitors is present in such small quantities that it is almost impossible to extract. For lack of other options, many electronic components are simply melted down, with the result that the precious metals and rare earth metals they contain are no longer recoverable. Reinhard Noll and Cord Fricke-Begemann want to change this situation. The two researchers and their colleagues at the Fraunhofer Institute for Laser Technology ILT have developed an entirely new approach to recycling.

Prof. Noll coordinates the EU-funded next-generation urban mining project ADIR, or "automated disassembly, separation and recovery of valuable materials from electronic equipment," in which nine partners from four countries have been studying this question since 2015. Dr. Cord Fricke-Begemann, who heads up the Materials Analysis group at Fraunhofer ILT, is the lead scientist for the institute's share of the ADIR project. The Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg is responsible for the robotics components. Until now, the recycling process for electronic devices consisted of disassembling them and then attempting to extract reusable materials. ADIR takes a different approach, in which the electronic components are analyzed prior to disassembly to locate the desired materials.

The new approach astutely combines elements of existing, proven technologies: smart process control, agile robotics, high-resolution cameras and image processing, and no less than three different laser techniques. It is not without reason that Fraunhofer ILT is recognized as one of Europe's leading addresses for laser technology research. The recycling plant consists of multiple workstations. At each one of them, the first step is to identify the product or component. Cellphones are sorted according to type and model, with the aid of a database. Then the cellphone casing is opened and removed. Special attention is paid to batteries, which are removed undamaged by a robot and recycled

separately. The now exposed motherboard is photographed using a high-resolution camera and the images are processed by analysis software which compares them with data stored in the institute's own database. In most cases, the software is capable of identifying the type of motherboard and pinpointing components containing rare earth metals and other raw materials of value.

This is where a technology in which the ILT possesses a great deal of expertise comes into play: the laser. It is used to perform three different tasks. The first is 3D sensing, which provides a topological profile of the circuit board, enabling further information to be gleaned about its structure and layout. The second is laser spectroscopy, which can penetrate below the surface of electronic components to locate materials worth recovering. Once these first two steps have been completed, a third laser is used to desolder or cut out individual components. By combining these methods, it is possible to extract tiny capacitors containing tantalum and transfer them to a fraction collection station. "We can enrich a tantalum fraction to a grade of over 30%, which is significantly higher than that of the tantalum concentrate used to produce the original product," says project manager Fricke-Begemann.

Sometimes, modules may be glued to the motherboard or smartphone casing, for example the vibration alarm, which basically consists of a miniature motor and a counterweight. The latter is almost entirely composed of tungsten. To detach the motor from the casing, the Fraunhofer experts use an electromagnetic pulse wave.

The combination of people, software and cameras together with various laser-based measurement, desoldering and cutting tools and articulated robot arms create the perfect recycling team. In this way, it is possible to separate the parts of even the most complex and highly integrated electronic devices and recover secondary raw materials of the highest purity. Fricke-Begemann has spent five years working on this basic concept. The project is now nearing its end. It has passed the proof-of-concept stage and the process can now be tested at higher throughput rates to prove its viability in an industrial context. Before then, Fraunhofer ILT and its partners intend to make a few improvements. A few minor adjustments still have to be made before it can be handed over to industrial users. ■

People,
software,
lasers -
the perfect
recycling
team

Rectifying some common misconceptions about chemistry

From lab assistant to bioeconomist Gerd Unkelbach is a trained chemist and the director of the Fraunhofer Center for Chemical-Biotechnological Processes CBP. Chemistry shouldn't be seen as a source of problems but as a means of solving problems, he says.

Interview by Josef Seitz

In the public mind, the word "chemical" is often associated with negative things such as pollution. Mr. Unkelbach, are chemicals as bad as they're made out to be?

Unkelbach: The lives we live today would not be possible without chemical transformation processes. Some 98 percent of the products we use on a daily basis have undergone chemical processing in one way or another. None of this would exist without chemistry – although, admittedly, there would be fewer risks too. But we would also miss out on many, many good things.

I get the gist: Your view of synthetic chemicals is that they are a boon for mankind, not a threat to the world.

Absolutely, especially when they are made from renewable raw materials, as we do here at the Fraunhofer Center for Chemical-Biotechnological Processes CBP. However, even sustainable production processes can do more harm than good, and yet still earn green credentials. That is why I consider two essential questions when developing a new process: Is it genuinely eco-friendly? and Is it safe?

How do you weigh up the different factors?

Take, for example, the water-repellent functional clothing that walkers today consider indispensable when taking a breath of fresh air in the countryside. The perfluorinated chemicals used to waterproof fabrics are notoriously bad for the ozone layer once they escape into the atmosphere. But safer waterproofing products for clothing can be made by

means of biocatalysis. We are working on projects like this at Fraunhofer CBP. Our overriding aim is to find safe substitutes for as many dangerous substances as possible and replace processes requiring harsh reaction conditions with processes based on chemical or biotechnological catalysis, which have the added benefit of consuming less energy.

So, for you, the chemicals industry is not the source of the problem but a source of solutions.

Without synthetic chemistry, we would never have achieved such a high standard of living – and with it, the ability to solve so many of the problems facing humanity.

And this brings us back around to the issue of sustainability. Does sustainability necessarily mean having to do without, being satisfied with less, and earning less money?

My opinion on that point is even more radical: If we can't earn money from what we do as researchers, we will never be able to scale up our projects for industrial application, and our ideas will never gain traction. Of course there are projects dreamed up by idealists who want to do something unique and sensational, but only multimillionaires can spend that much money – usually to soothe their conscience – without having to worry whether a solution is scalable. For any project to succeed without government support, and hence without being subject to the vagaries of politics, it must stand on its own two feet as quickly as possible. Of course we accept seed money to minimize risks and get things started. But the underlying business model must support itself – and be a money-spinner.

“The chemicals industry is just as important to Germany as the automotive sector, except that it is less talked-about.”



Gerd Unkelbach is the director of the Fraunhofer Center for Chemical-Bio-technological Processes CBP. His big passion is the organic material that holds trees upright: lignin.
© Norman Konrad

Judging by the number of people it employs, the chemicals industry is certainly still going strong.

Indeed, it accounts for 460,000 jobs in Germany, which is the largest producer of chemicals in Europe. The sector is a huge contributor to the country's gross domestic product (GDP). The chemicals industry is just as important to Germany as the automotive sector, except that it is less talked-about. Sadly, most people aren't aware of that, or don't want to know. Car owners and drivers rarely ask themselves where the nylon for the seat covers or the polyurethane for the dashboard comes from.

What are you spending most time on at the moment?

My favorite research subject is lignin, a renewable raw material. It is found in wood and straw or basically in any plant with woody stalks or stems, where it holds together the cellulose fibers and protects them from being broken down by bacteria. Lignin is the glue that stiffens plant stems and enables trees to grow upwards so that their leaves can capture the sunlight they need for photosynthesis. However, the lignin in every plant is structured differently. This makes things extremely difficult for chemists who want to use lig-

nin in its molecular form. For me, it is an exciting challenge to grapple with these difficulties and try to create a basis on which new products can be manufactured. Someone once commented wryly that you can make anything from lignin except money! Stubborn as I am, that motivated me even more to prove them wrong by redoubling my efforts to produce lignin-derived compounds that can be used in industry with profitable results.

Fraunhofer CBP does a lot of research into renewable raw materials. In which areas do you see the most potential?

Our aim is to develop sustainable products to substitute for those currently based on fossil resources. Or, preferably, new products with better properties than their fossil-based predecessors. Imagine, for example, a plastic film that is not only bio-based and biodegradable but also more tear-resistant.

So, by combining a lower environmental impact with improved user benefits you enable manufacturers to earn higher profits?

Yes. If a product offers more, then consumers will be willing to pay more for it. At first it will be sold in the high-end market, and later in the mass market. That way we can really make a difference – both for business and for the environment.

How do you go about drumming up young people's interest in chemistry?

With a very simple message: You can serve good causes with chemistry – and earn money while doing so. ■

“We have to be able to earn money from the work that we do. Otherwise our ideas will never gain traction.”

”

“Our aim is to develop new products with better properties than their fossil-based predecessors. That's the challenge.”

Gerd Unkelbach

How to save hundreds of thousands of euros in just three seconds

The rail transport sector is the biggest energy consumer in Germany. Scientists in Nuremberg are working on ways to make train timetables more energy-efficient.

By Thomas Röhl

In Nuremberg, the difference is a matter of seconds. Three seconds, to be precise. That's the tiny increase in travel time between two subway stations that the Nuremberg rapid transit system would have to take on board in return for major cost and energy savings.

"Barely perceptible increases in journey times can have a hugely beneficial impact on energy consumption," says mathematician Andreas Bärmann, who leads the project "Advanced driver assistance systems in rail transport" at the ADA Lovelace Center for Analytics, Data and Applications in Nuremberg.

The Center is an initiative of the Fraunhofer Institute for Integrated Circuits IIS in cooperation with Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and Ludwig-Maximilian-Universität München (LMU). Officially opened in December 2019, this center of excellence for data analytics and AI in industry actually started work the previous year. Bärmann – a postdoctoral researcher at FAU – and his team members Patrick Gemander and Lukas Hager work on behalf of transit provider Verkehrs-Aktiengesellschaft Nürnberg (VAG) to find ways of organizing rapid transit systems in a more energy-efficient manner.

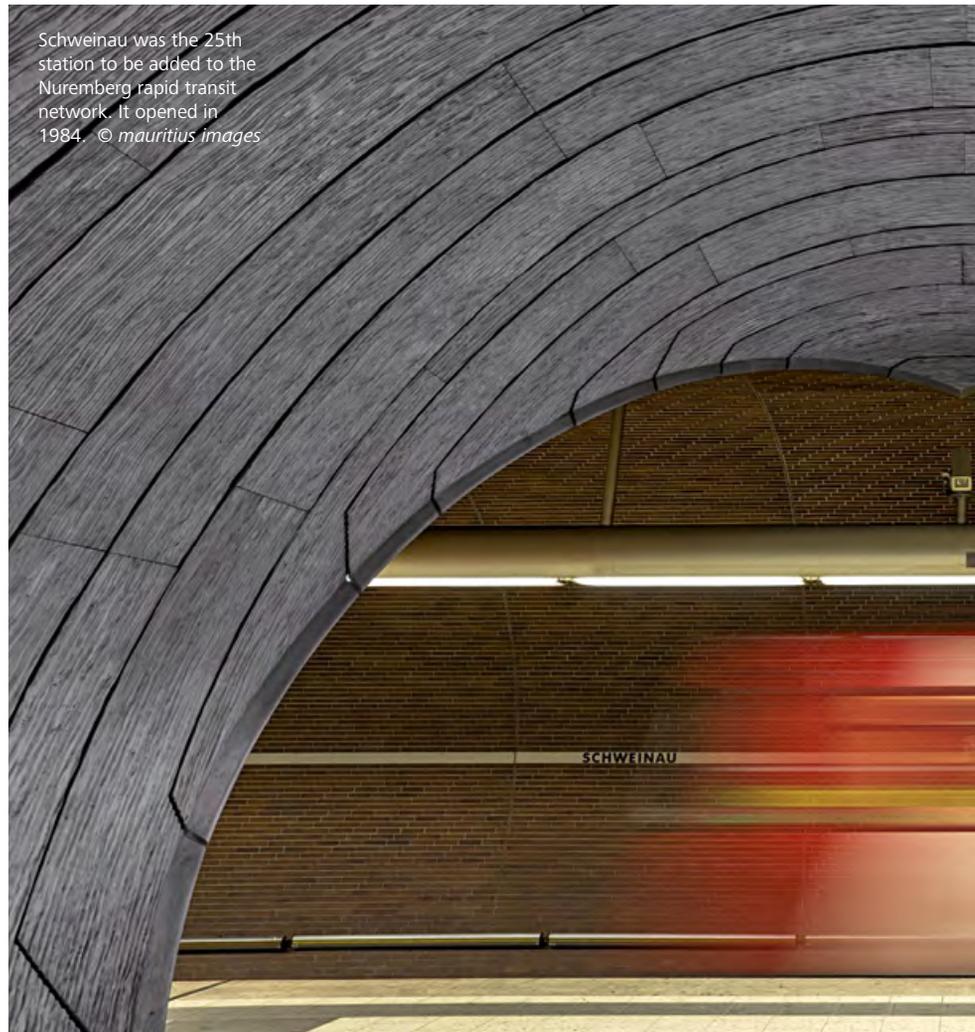
Synchronized arrival and departure times

Operating energy is a key cost factor for rail transport providers, says Bärmann – hence VAG's interest in the project. To find the best ways of reducing power consumption and thereby cutting energy costs, the ADA experts incorporated various factors in their calculations. They discovered that optimizing the timetable is a good place to start. Reducing the number of trains that depart simultaneously has the effect of lowering peak loads in the rail power grid. Peak loads have a significant impact on the price the company pays for its power.

Another important lever is improving the coordination of train arrivals and departures. When a train brakes, it genera-

tes electricity that is fed back into the system. This regenerative energy can be used by a different train to accelerate, but only if it is leaving at the same time the other train is braking. "Otherwise the energy is lost," says Bärmann.

Schweinau was the 25th station to be added to the Nuremberg rapid transit network. It opened in 1984. © mauritius images



Huge potential: in Germany, passenger and freight trains consume 11 billion kilowatt hours of power a year

The third factor that influences energy consumption is how the trains are driven. For example, do they always accelerate to maximum speed and only brake when they reach the station? Or do they travel at a slightly lower speed and then gradually coast to a stop over a longer stretch of track? The researchers at the ADA Lovelace Center calculated that, under optimum conditions, VAG could cut its energy consumption by up to ten percent by exploiting all these options. That would slash the company's electricity bill by up to 500,000 euros a year. Passengers wouldn't notice any significant difference, says Bärmann, noting that the slightly longer travel times between stations would only affect journey times by plus or minus 15 seconds.

The ADA experts had already calculated the huge savings potential of rail timetable optimization in a previous project. With rail transport consuming more energy than any other sector in Germany, it's clearly an important issue. Passenger and freight trains use 11 billion kilowatt hours of power a year, as much as the city of Berlin. One ADA Lovelace

study calculated that Deutsche Bahn could decrease its passenger train power consumption by 38 megawatts a year simply by optimizing timetables and peak loads in the rail power grid. That would reduce the company's energy bill by five million euros a year while also benefiting the environment.

Two years into the project

Yet organizing a train timetable to maximize energy efficiency is a mammoth task, says Bärmann. For example, even running just 4 trains between 3 stops with a choice of 7 times for each departure, you end up with 14 billion possible timetables. Fortunately, mathematical optimization – Bärmann's area of specialization – can be used to reduce the extremely large number of theoretical possibilities to the ones that actually make sense in practice. This required them to program a special algorithm, says Bärmann, which was something of a challenge. It took the Nuremberg-based team of researchers a total of two years to complete that task.

The next step that Bärmann's team and transit provider VAG are planning is to expand the areas in which the model can be applied. The idea is to develop algorithms for driver assistance systems in order to control train journeys in real time. "We need AI methods that are capable of responding to unexpected incidents and disruptions," says Bärmann. This is far from easy, he adds – but it's the only way to exploit potential savings in day-to-day operation. Nuremberg already has computer-controlled, driverless subway trains, which makes it ideal for their purposes.

The algorithms developed at the ADA Lovelace Center could also be applied in other areas, says Professor Alexander Martin, director of Fraunhofer IIS and head of the ADA Lovelace Center. "Many companies don't realize how much potentially useful data they already have. They are unable to assess its quality, and don't know what type of data they need to solve a specific problem or, conversely, what applications they could optimize with their existing data." The research work carried out by the ADA Lovelace Center could help them answer these questions.

Truck platooning is one area where he believes this methods could be successfully applied. This involves linking two or more trucks in a convoy, all controlled by the first vehicle via radio – much like a train, but on the highway. Other areas that could potentially be improved with the help of AI include production processes and energy-efficient machine operation.

This highlights what makes the ADA Lovelace Center so special, says Professor Martin: "We use real-world industry use cases as examples. They provide the basis for developing and enhancing our expertise, methods and processes." ■



Fill 'er up with biofuel

Synthetic fuels from renewable sources reduce greenhouse gas emissions by up to 30 percent compared to fossil fuels.

By Katja Engel

People who go on a cruise want to sleep in a cozy cabin and enjoy the days at sea out in the fresh air, far from the daily grind of life on land. There is just one catch – those intruding thoughts about the climate impact that waft in with the fumes of burnt marine diesel.

That could well change with a new technology developed by researchers at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT in Oberhausen. In this article, Dr. Andreas Menne, Head of Department Biorefinery and Biofuels, talks about synthetic diesel and gasoline made from renewable resources.

Cruise ships, container vessels, aircraft and road vehicles are sure to run on liquid fuel for decades to come. Even if up to 30 percent of the vehicles zipping through cities will be electric by 2030, that is still an awful lot of fuel. One would hope that an alternative based on something other than crude oil could be found. Every day, every adult in Germany consumes 3.5 liters of fuel for transportation alone. This adds up to around 87 billion liters for 365 days a year, accounting for around one-fifth of greenhouse gases.

This is a big burden for the climate. Menne, a mechanical engineer, and his team want to lighten that load by converting bioethanol into diesel, gasoline or kerosene that have nearly the same properties as fossil fuels. Renewables help slash the transportation sector's CO₂ emissions. "Straw, leaves, sawdust, waste wood – we can use almost anything as the raw material for bioethanol," says Menne. The new climate-friendly biofuel produces a lot less greenhouse gas.



The researchers use bioethanol made of wheat straw for the new fuel.

© Adobe Stock

A full-fledged fuel rather than an additive, vehicles should be able to run on it alone. By contrast, just five to ten percent of the E10 fuel is bioethanol; the rest is of fossil origin. "We're not going to feel much of a climate effect with that," says Menne. "Electric, hybrid and fuel-cell vehicles are not going to reduce greenhouse gas emissions as quickly as this has to happen. We need a holistic approach and a diversity of solutions for tomorrow's fuels." The pressure to take action is mounting with the revised Renewable Energies Directive (RED II) calling for advanced fuels to account for a share of 3.5 percent by 2030.

The UMSICHT researchers are producing up to 20 liters of the new biofuel a week in an experimental plant. Amid the pipes and tanks and insulation, a pair of weighing scales stands on the floor. A small metal drum containing ethanol sits on one side of the scale, balanced by a bulbous glass vessel into which the finished fuel is poured. This setup enables researchers to check at a glance how much ethanol is flowing into the plant and how much fuel is being produced from it.

The feedstock is bioethanol sourced from wheat straw. "Actually, I could use any other alcohol," says Menne. The straw alcohol initially retains its liquid form as it flows from the metal barrel through the pipes of the test plant into a vaporizer. When the temperature reaches 350 degrees Celsius at a pressure of 20 bar, the gaseous alcohol flows into the heart of the plant, a tubular reactor. The reactor is filled with pieces of activated carbon coated with a newly developed catalyst material. These catalysts accelerate the condensation reaction by which gas is converted into liquid by multiplying the number of carbon bonds. This produces gasoline, kerosene or diesel, depending on how many carbon molecules are combined.

Alcohol to fuel

Menne had discovered this reaction accelerator while working on his doctorate in 2008. "A catalyst is often developed in the lab but may then turn out to be difficult to produce in large quantities. But we can buy the materials for this catalyst cheaply because it doesn't consist of precious metals or rare earths. And most importantly, it remains stable over the long term," says Menne, who submitted a patent application for it in 2012.

The biofuel packs plenty of power, as researchers at the Fraunhofer Institute for Chemical Technology ICT in Pfinztal have confirmed. They put standard commercial engines on a test bench to run trials with the new fuel.

Menne supplied a hundred liters for testing. The ICT researchers took precise measurements of engine perfor-

mance and exhaust emissions in trial runs that are much like an ergometer stress test, where a person wired up with sensors pedals away to measure cardiac function. Readings were taken at different operating levels, during cold starts, under different loads and at varying engine speeds.

Lots of power, low exhaust emissions

This biofuel's energy density was found to be slightly higher than that of conventional fuels. That means a vehicle with this new fuel in its tank would have a slight advantage in a real race. The synthetic fuel's exhaust emissions were also a selling point with less carbon monoxide, carbon dioxide and hydrocarbons, and a lot less exhaust soot. This biofuel's physical properties come close to those of fossil diesel, so it can be made to comply with prevailing standards.

Venkat Aryan, a chemical engineer at Fraunhofer UMSICHT, has added up every molecule of the greenhouse gases in each process step to assess the ecological impact. A well-to-wheel analysis factors all greenhouse gases into the equation, from the extraction or harvesting of the raw materials to the fuel's conversion into kinetic energy. They include crude oil extraction from underground wells, the cultivation of plants for biofuel and the exhaust gases. He found that the CO₂ equivalents for synthetic diesel made from wheat straw amounted to 64.3 to 91.6 grams per megajoule, depending on the ethanol source. The figure for petroleum-based diesel fuel is 94 grams, which biofuel beats by as much as 32 percent. Aryan already has some ideas that could easily achieve further savings.

"Our fuel can be converted into gasoline, diesel or even jet fuel for airplanes. But the latter is the most complicated," says Menne.

Marine diesel is a much simpler matter. It does not have to be processed in a refinery. "You could simply set up our plant in a port. Our process is so straightforward that shipping companies could produce their own diesel. Then the age of the big stinkers would soon be over," says Menne.

Despite there being just the one test plant in Oberhausen, the technology is ready to go to market. Now these researchers are looking for partners to start production on an industrial scale. The Fraunhofer experts have already started talking to refineries. While the synthetic diesel is still more expensive than diesel made of petroleum, Menne is confident that this could soon change. As the new legislation takes effect, fossil fuels will no longer be as cheap to produce. "Consumers' expectations are also changing. They may not only want to truly enjoy a cruise; they may also want to know how climate-friendly the ships are that transport bananas from Colombia to Europe." ■

"Straw, leaves, sawdust, waste wood – we can use almost anything as the raw material for bioethanol," says Dr. Andreas Menne.

More quanta for Europe

Quantum technology is making its way out of the lab. Highly sensitive magnetic field sensors could be on sale in hardware stores within five years. But researchers and industry need to work closer together to make sure Europe prospers as an industrial hub for these kinds of genuine products and the jobs they create – and there's no time to lose.

Peter Leibinger makes an appeal

“Quantum-based magnetic field sensors could be available for 50 euros in hardware stores in just five years – or even sooner.”

There are two “laws of nature” that apply to the industrialization of a new technology. Firstly, gaining a foothold in the market doesn't happen overnight. Time and again, we have seen how the journey from an initial concept to the launch of a commercial product can take a decade or more – and the introduction of EUV microlithography is no exception. TRUMPF has spent over 15 years working on ways to produce EUV radiation using lasers. Now this technology has finally opened the door to the next generation of microchips – and thus to the very latest smartphones, autonomous vehicles and supercomputers.

Secondly, bringing a new technology to market requires a combination of scientific excellence on the one hand and industrial expertise on the other. Many researchers are not accustomed to working with industry in the early stages of the research process. Equally, many industry experts see themselves purely as product developers and are unfamiliar with the world of research. Yet the only way to successfully commercialize quantum technology is by getting research and industry working side by side right from the start.

Quantum technology encompasses a wide range of applications. As well as quantum sensors and quantum communication, these include quantum cryptography, quantum imaging

The **Fraunhofer-Gesellschaft** is bringing the first quantum computer to Europe. Fraunhofer signed the corresponding **agreement** with computer giant IBM **on March 13**. The IBM Q quantum computer will be housed in IBM's data center in **Ehningen near Stuttgart**. Starting in 2021, Fraunhofer and its research and industry partners will be developing technologies, use cases and algorithms aimed at reinforcing **expertise in Germany's business and research** sectors and creating competitive advantages in the international arena.



© IBM



Two “laws of nature” apply to the industrialization of a new technology says Peter Leibinger, executive board member at market-leading company TRUMPF. © dpa

Dr. Peter Leibinger

... was born on April 23, 1967 in Stuttgart. He studied mechanical engineering in Aachen.

... is Vice Chairman of the Managing Board of the high-tech company TRUMPF GmbH + Co. KG. With 14,490 employees, TRUMPF is one of the world’s leading manufacturers of machine tools and lasers for industrial applications.

... is the spokesman of the German Federal Ministry of Education and Research’s funding program for photonics and quantum systems.

and quantum computers, as well as applications that harness the power of quantum computers. Each of these fields is distinct – and each has been developed to a differing degree. So where should Europe be directing its attention as it strives to maintain its position as an industrial leader? Experts believe that quantum sensors will be the first area of quantum technology to enter the mass market. They will soon provide the means to measure magnetic and gravitational fields far more accurately than ever before. Highly sensitive quantum-based magnetic field sensors could be available for 50 euros in hardware stores in just five years – or even sooner. This would give do-it-yourself enthusiasts a reliable means of detecting plastic water pipes in the wall. Looking even further ahead, this technology could be used to create highly sensitive non-contact sensors for measuring brain activity. As well as taking brain research to the next level, this might even enable us to control our smartphones with the power of thought.

Our spin-off Q.ant shows just how close we are to opening up this initial field of quantum technology. Q.ant employs 15 people and is already generating revenue. It produces specially designed lasers for quantum sensing and is already working on complete sensor systems based on nitrogen-vacancy (NV) centers. The start-up company is also

working on sensors based on non-linear converters. In the future, these could be used for applications such as new microscopes that would do a far better job of analyzing cells for medical purposes.

Our commitment to quantum technology is shared by many other key players in industry. This is especially true in sectors where Germany and Europe can build on their traditional strengths. Examples include taking automation solutions to a new level with the aid of quantum technology, running industrial processes in completely different ways using quantum technology, and using quantum technology to make major improvements to traditional industrial products such as cars. Europe could become a powerful force in these exciting technological developments.

Quantum technology offers the potential to “re-invent” established technologies and methods. But we need to start by making academic research more application-oriented – and making industry more research-conscious. This will give rise to products that real customers need while reinforcing Europe’s position as an industrial powerhouse. Quantum technology offers us a new approach to tackling today’s challenges – and the time to start embracing it is now. ■

“Making academic research more application-oriented and industry more research-conscious will give rise to products that real customers need while reinforcing Europe’s position as an industrial powerhouse.”

Autonomous clean-up crew

Some work is hazardous to humans – so why not use robots? Examples include the reclamation of landfill sites, waste sorting, and even the decommissioning of nuclear power plants.

Text: Mandy Bartel

In 2019, Germany logged a total of 263,950 sites that experts suspect are contaminated

WALL-E is the last robot on Earth. Humans have abandoned their uninhabitable planet and now live on a giant cruise ship in space. An army of robots was charged with cleaning up the garbage they left behind – and WALL-E is the only one left. Scenes from this 2008 sci-fi movie spring to mind when Janko Petereit talks about his work. A scientist at the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB in Karlsruhe, he heads up the Multisensor Systems research group. He and his team coordinate the Robdekon Competence Center, which involves seven other partners. **Robdekon** is the German acronym for “Robot systems for **de**contamination in hostile environments.”

Figures for 2019 reveal a total of 263,950 sites across Germany that experts suspect are contaminated, including numerous landfill sites, some of which are so old that hardly anyone knows exactly what is buried there. Statistics from the German Federal Environment Agency show that fewer than half of these have been officially assessed to determine how much of a hazard they pose. Some 36,000 sites have already been decontaminated, yet this job is far from easy, and it is

made harder by all the uncertainties involved. For example, hazardous chemicals may leach into the groundwater and react with each other, leading to fires or poisonous fumes.

Reclamation of landfill sites is one of three applications for which Robdekon was primarily designed, based on research conducted by Janko Petereit and his team. The idea is that, in the future, autonomous or semi-autonomous machines could carry out tasks such as taking samples, removing drums and other waste and excavating contaminated soil, says Petereit. “One option is to start by sending spider-like robots onto the site to perform automated sample collection. That gives a rough idea of how the contaminants are distributed across the site. Based on this information, the next step is to draw up an excavation and decontamination plan that involves using autonomous excavators to remove layers of soil and load them onto automated guided vehicles. Any recyclable materials can then be salvaged, while the toxic materials are packed into new, safer containers and transferred to modern hazardous waste disposal facilities.”

Fraunhofer IOSB – the institute where Petereit works – is developing the software and algorithms for this entire process: from crunching the sensor data to calculating excavation strategies and guiding vehicles by remote control. At the moment, their smart excavators “stick strictly to a predefined plan”, but “the long-term goal is to give the machines the ability to detect the presence of any additional hazardous residues such as tar and then dig deeper to remove them,” says the engineer.

From nuclear power plant decommissioning to waste sorting

Another task the scientists have in mind for their robot systems is the decommissioning of nuclear power plants – a topic that has taken on added urgency since Germany’s decision to abandon nuclear power. There are still six nuclear power plants in operation in Germany, all of which are scheduled to go offline by 2022. That’s when the mammoth decommissioning operation will begin. As well as stripping down every building in the contaminated zone, the decontamination crew will also need to trim several millimeters off every concrete surface from floor to ceiling – producing several hundred

VR headsets allow operators to monitor and control the clean-up from a safe distance. © KIT





thousand cubic meters of concrete waste at each plant. The goal of the Robdekon team is to automate a large part of this process. For example, a milling robot will soon be able to tackle the biggest concrete surfaces on its own, and humans will only have to lend a hand in more awkward spots. Meanwhile, surveying robots will be used to produce radiation maps showing areas that are still radioactive.

Waste sorting is the third area in which researchers hope to deploy smart machines to minimize human involvement in potentially harmful activities. According to the country's Federal Statistical Office, each inhabitant of Germany produces around 220 kilograms of waste a year. That equates to an annual total of over 18.1 million metric tons of household waste, including bulky items and paper, some two thirds of which is recycled. Although German consumers are global leaders in separating their household waste, most refuse is still sorted by hand in waste management facilities. The researchers hope that waste-sorting robots equipped with plentiful sensors could soon take over this conveyor-belt work.

Focus on viable systems

Led by the IOSB, the Robdekon competence center also includes the participation of the Karlsruhe Institute of Technology (KIT), the German Research Center for Artificial Intelligence (DFKI), the FZI Research Center for Information Technology and four SME industry partners. Funded by the Federal Ministry of Education and Research, one of its tasks is to function as a national contact point and information hub for issues concerning robot decontamination systems. A series

of specialized technology demonstrators have already been created in seven "living labs" run by individual project partners.

"Practical relevance has top priority," says Petereit. This is the key reason why robots have such different levels of automation. "Right now, fully autonomous operation in such highly complex environments is often unnecessary in practice. Instead, people are looking for smart assistance systems that can take the strain off operators or provide helpful information, because ultimately they still want humans making the decisions and being able to intervene," he explains. That's the message the competence center has received at its annual participatory events that give the team a chance to meet with real-world users. These events allow people to try out the systems and give the researchers feedback that can be fed back into the development process.

One of the key technologies of the Robdekon project is therefore human-machine interaction. The team is currently testing out three different telepresence concepts that are intended to work with all the demonstrators. One option is for the human operator to move freely in a virtual reality environment similar to a holodeck and interact through gesture recognition. Alternatively, they can opt to rely on exoskeleton assistance for certain activities, or interact using joysticks and digital interfaces in a control room.

The question remains whether we will one day be forced to evacuate our planet and leave all the cleaning up to robots. If we do, scientists have yet to determine whether these kinds of telepresence methods would also work from space! ■

Designed for challenging environments by the German Research Center for Artificial Intelligence (DFKI) and enhanced with the help of the Robdekon team, this robot with wheeled legs can drive and walk.
© DFKI/Florian Cordes

Germany produces
18.1
million metric tons of household waste a year

Dark net: let there be light!

The dark web is seen as a hotbed of child molesters, drug traffickers and arms dealers. More and more voices are calling for it to be banned.

By Sonja Endres



Professor Martin Steinebach from Fraunhofer SIT strives to unravel myths about the dark web.

© Josef Seitz

There's no doubt that the "dark net" is used for criminal purposes – but there's not enough robust scientific data to establish the extent of these illegal activities. Professor Martin Steinebach and his team at the Fraunhofer Institute for Secure Information Technology SIT in Darmstadt hope to cast some light on this question. To find out which services were most in demand, they set up dark net servers through which users could make connections to other dark net servers – and then logged the addresses those users were heading for.

"We found marketplaces selling weapons, drugs and malware. But our top ten also included sites that provide information and sites hosting social or political forums," says Steinebach, who has spent years working with his team to investigate the dark net and, in particular, the popular Tor network.

Tor uses a special encryption mechanism that enables users to remain anonymous. The network has gone through some major changes and developments since it came online in the 2000s. "Far more people use it nowadays. There are clearly a lot of criminals doing business under the cloak of anonymity, but there are also whistleblowers, human rights activists and, increasingly, regular citizens who want to escape constant monitoring by Amazon, Google and the like," says Steinebach.

Using the dark net doesn't require any special computer skills. Anyone can download the Tor Browser – a modified version of Firefox – for free. "You can also use the Tor Browser to surf 'normal' websites such as eBay and Amazon – the difference being that, with Tor, eBay and Amazon don't know who you are and can't collect data on the products

you show an interest in,” says Steinebach. “The Tor network is becoming increasingly popular for online shopping. People are realizing that different prices pop up depending on the device, browser or IP address they’re using. Tor enables users to surf the internet anonymously. That makes it a powerful tool for preventing mass surveillance.”

Dark web takes off

More and more people are turning to the dark net as a cool digital lifestyle choice. All the key players now have a presence on the dark web – even Facebook has a Tor address.

Dark web sites have the ending “.onion”. They can either be found via search engines such as DuckDuckGo, which allows users to perform anonymous searches with no tracking of user behavior, or through “hidden wikis,” which list dark web pages under various keywords. Links to dark web pages can also be found on the ‘normal’ internet.

Communication over the dark net used to be exclusively in English, but Russian is becoming increasingly prevalent. “The reasons are more complex than just Russian-speaking hackers offering their services,” says Steinebach, explaining that more and more Russians are using the dark net as a platform for political information. “For example, we found one website that offers independent legal advice and gives civil rights activists tips on how to defend themselves against government reprisals. They were forced to remove this information from the internet in Russia, so they simply migrated the whole thing to the dark net.”

Many major newspapers – such as *The New York Times* and the British *Guardian* – have set up their own dark net domain to enable informants to contact them anonymously. The dark net is also home to a comprehensive selection of academic libraries seeking to make information available to everyone without censorship.

“Our study revealed an extremely diverse range of dark web offerings. People are using both illegal and legal services to much the same extent,” says Steinebach.

However, he and his team found no evidence to support the widely held belief that the dark web is teeming with child pornography: “It’s similar to what we saw with file-sharing sites in the 2000s. It was claimed that up to 80 percent of the shared content was child pornography. At the time, we were carrying out studies to find technical methods of detecting copyright infringement on behalf of the music and film industry. So we built systems to analyze huge quantities of files – and we didn’t find any child pornography. It’s the

same with our list of the top ten dark web sites: none of them include child pornography.”

There’s no doubt that the dark web is used by pedophiles, but the idea that they are a predominant force is clearly untrue. “Our analysis of 5,000 dark web sites showed that just four percent were based around child pornography,” says Steinebach, who keeps in regular touch with law enforcement agencies. In 2017, criminal investigators pulled off a major coup against the Elysium child pornography network, which had more than 111,000 users worldwide. Elysium demonstrated that the police were not as helpless as is often claimed – and there have been plenty of other successful investigations against cyber criminals, drug traffickers and arms dealers on the dark net. “All the major marketplaces get taken down by the police sooner or later. But rather than using sophisticated hacking techniques, investigators primarily rely on undercover agents and traditional detective work,” says Steinebach. The dark net only provides cover for so long – and the moment when a user orders something and enters a delivery address is often when police can strike.

Expert hackers find vulnerabilities

Steinebach and his team specifically search for flaws in the Tor network – a standard method used by IT experts to make systems more secure. “When we find a vulnerability, the first thing we do is notify the Tor developers. That gives them the opportunity to fix the flaw before we publish it.” But why publicize the vulnerability at all? “Smart hackers working for a dictatorship somewhere are bound to spot the coding error – it would be naive to think otherwise! So it’s better to inform the developer community so they can fix the bug and ensure that people who might otherwise be hacked are no longer in jeopardy.”

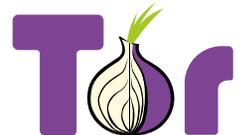
For dictatorships like China, the dark net is a thorn in their side. By imposing a range of restrictive measures, China’s digital surveillance state has made it much harder to access the Tor network. “But civil rights activists there are still constantly finding new ways in,” says Steinebach.

With so many issues involved, Steinebach feels it would be unrealistic to try and ban access to the dark web. “The internet simply isn’t a place where you can just ban things. The Tor network isn’t centralized. It currently uses more than 6,000 nodes worldwide. Even if you were to make the Tor Browser illegal in Germany, people there would still be able to download it from a French or American site. You can make it harder to use the dark net, but not switch it off entirely. Even if you could, I don’t see that as a desirable goal.” ▶

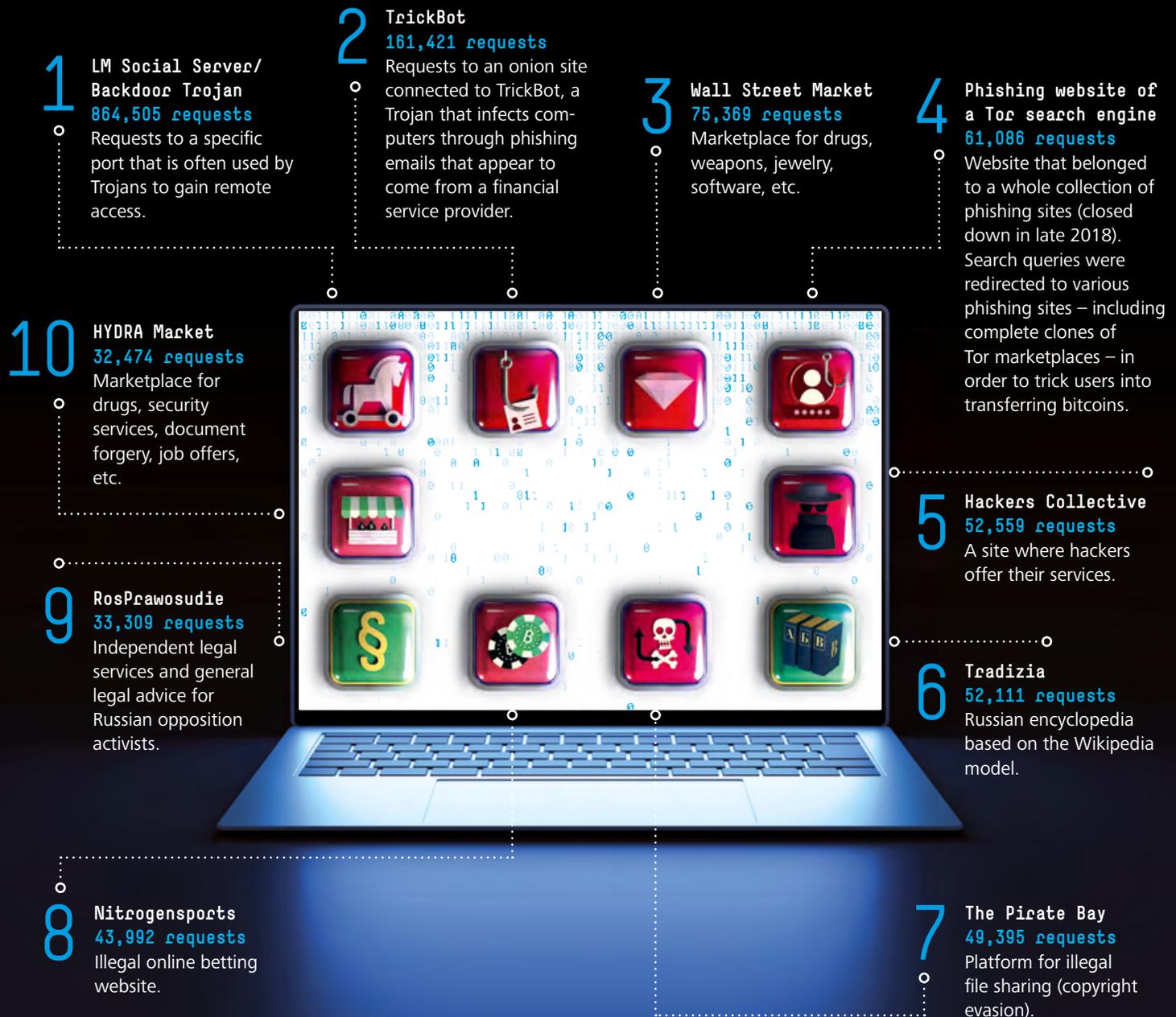
“It’s increasingly used by regular citizens who want to escape constant monitoring by Amazon, Google and the like.”

Prof. Martin Steinebach

Tor stands for “The Onion Router.” The word onion refers to the fact that the system uses a series of layered nodes, bouncing the request across multiple servers to keep the user’s IP address hidden.



Top ten 10 dark web services



Data collected: April through September 2018

Original publication: Martin Steinebach et al., Detection and Analysis of Tor Onion Services, published January 23, 2020 • <http://s.fhg.de/darknet>

How will we eat in the future?

In an EU-funded project, researchers from the Fraunhofer Institute for Systems and Innovation Research ISI have investigated which trends will shape the European food industry over the coming 15 years. A selection of key developments:

Reducing food wastage

Globally, 1.3 billion metric tons of food are thrown away each year. In the main, the cost of this wastage – some 750 billion U.S. dollars – is borne by consumers and farmers. Researchers estimate that around two-thirds of all food wastage in industrialized countries could be eliminated by, for example, improvements in production and logistics. Growing public pressure and state regulation will encourage a shift towards better practices and help fight wastage.

Alternative proteins

On average, Europeans eat 65 kilograms of meat a year, U.S. Americans as much as 90 kilos. The negative consequences – for climate, environment and consumer health – are well known. To meet the world's protein requirements on a long-term basis, we will need to make changes to the food system. Innovative options here include plant-based meat substitutes, insect-based products and the *in vitro* cell culture of meat. Researchers at Fraunhofer ISI predict that in the future the meat and alternative protein industries will coexist, side by side.

Vegetarian, vegan, gluten-free

With more and more people opting to cut meat from their diet – whether for health reasons, concerns about animal welfare, or a growing awareness of sustainability issues – vegetarianism and the use of vegan and gluten-free ingredients is now a significant trend. In fact, only one percent or so of the world's population actually suffer from celiac disease, which is an autoimmune disorder not to be confused with gluten intolerance, or non-celiac gluten sensitivity. Nonetheless, grains such as quinoa and amaranth are increasingly regarded as healthier alternatives to wheat flour. Researchers predict that the global market for gluten-free foods will rise to 13 billion U.S. dollars by 2025.

Short food circuits

There's a lot to be said for buying locally grown food directly from the producer, either via online stores or in the form of weekly boxes

of seasonal fruit and vegetables. Such produce is not only fresher and eminently traceable; it also generates less packaging waste and has a lower carbon footprint on account of the shorter transportation distances. On the flip side, some products are not available all year round, either due to a limited growing season or on account of adverse weather conditions. Nonetheless, short food circuits could play a part in the predicted shift from a centralized to a decentralized and partially autonomous system of food production and distribution between now and 2035.

Precision farming systems

The advent of new production and cultivation methods in agriculture will help boost productivity and sustainability. For example, sensor technology can be used to monitor and measure plant growth. This enables targeted and controlled application of nitrogen-based fertilizers, which in turn reduces their overall use. Likewise, on the basis of a simple photo taken using a smartphone, special software can identify and classify the incidence of crop disease, weeds and insects, as well as provide recommendations for action and other useful information. The precision farming market currently generates annual revenues of 4.07 billion U.S. dollars. This is forecast to rise to 10.23 billion U.S. dollars by 2025.

Artificial intelligence and machine learning

Artificial intelligence and machine learning are the basis of smart agriculture. Automated, self-learning machinery can assist with the sowing of crops (soil preparation, seed breeding, and water uptake monitoring), while harvesting robots automatically detect crop ripeness. In addition, artificial intelligence can help improve food quality and freshness as well as reduce wastage by adjusting harvesting dates to actual data on customer orders and customer demand.

Sustainable food for all

Sustainable foods have a low environmental impact and play their part in ensuring global

food security and healthy lifestyles. Innovative approaches here can help bring about increased sustainability throughout the food industry. These include stimulating demand for regional and seasonal produce, campaigns to raise awareness of the benefits of healthy, sustainable food, and the use of artificial intelligence or other new technologies to make food production more sustainable.

Nutrigenomics

A person's genetic makeup has an influence their personal health and nutrition (nutrigenomics), and vice versa. Using this insight, it is possible to draw up individual dietary recommendations that help people reduce the risk of disease and improve their health. The nutrigenomics market was valued at 252 million U.S. dollars in 2017 and is projected to increase by 16 percent over the period to 2025.

Greater transparency

Eighty-five percent of German consumers would like full traceability for their food. Informative labeling plays a role here. Government agencies and private companies are now responding by introducing new labels and standardizing old ones such as Germany's Tierschutzlabel, which documents animal welfare. Digitalization will provide enhanced product transparency and traceability, thereby increasing pressure on producers to respect consumer wishes.

The growing market clout of food retailers

Consolidation in the retail food market has never been greater, with a small number of companies now controlling the main distribution channels and dominating the market. The result has been a shift of power away from food producers and in favor of retailers. In 2018, for example, a dispute over prices led to a European association of six retailers removing all of a major brand's products from its shelves in order to force concessions from the company in question. There is a real worry that retailers will make increasing use of their power in order to maximize profits.



There are an estimated 450,000 privately owned drones in Germany. Misuse cannot be ruled out.
© ddp images

Anti-drone defense with microwaves

An increase of drones in German airspace has led to a reassessment of the threat they pose to security and the economy. High-power electromagnetics offers a potential solution.

By Mehmet Toprak

In March 2020, a drone sighting forced an aircraft carrying Minister-President Armin Laschet to abort landing.

The Bundeskriminalamt, Germany's Federal Criminal Police Office, warns of "a host of possible scenarios involving drones, ranging from the disruption of events to spying activities and even terrorist attacks." In 2019, the German Unmanned Aviation Association estimated that there were 450,000 privately used drones in Germany. It would be naive to rule out the possibility of misuse. As recently as March of this year, a delegation with North Rhine-Westphalia's Minister-President Armin Laschet was unable to land at Frankfurt Airport after returning from a trip to Israel. An unidentified drone forced the aircraft to divert to Cologne. Back in Frankfurt, the airport went into lockdown for 90 minutes, causing a major financial hit.

The Fraunhofer Institute for Technological Trend Analysis INT, based in Euskirchen, is investigating the use of microwaves

to counteract this threat. Marian Lanzrath works at the business unit for Electromagnetic Effects and Threats. He is part of a team of six scientists and two technicians currently testing the efficacy of high-power electromagnetics (HPEM) to counteract the threat of drones. "We're looking at microwaves in the high-frequency range," Lanzrath explains, "and using directional antennas to focus them into a narrow beam. This means that the electromagnetic radiation can be precisely targeted on the object, with everything else around it left unaffected."

Electromagnetic waves cause an interference voltage wherever electric currents flow. If the radiation is sufficiently strong, it scrambles or interrupts signal transmission and plays havoc with the electronics. In some instances, it causes an overvoltage that can result in the total failure of a

component. To research this technology, Fraunhofer INT uses a test hall measuring 15 meters long, six meters wide and four meters high. High-energy pulses of microwave radiation are fired at a drone circling above a safety net. Initially, the drone continues to hover. All of a sudden, however, it sheers off to the left, and then to the right. It drops a meter, seems to regain control, but then falters and falls. While the safety net prevents any external damage to the drone, its control electronics are completely fried.

“All drones are vulnerable to the influence of microwaves,” Lanzrath explains. That’s their weak spot, one they share with practically all electronic devices. A metal housing will shield electronic components against microwave radiation. This, however, increases weight, which is not ideal in the case of drones. Besides, Lanzrath says it is impossible to fully protect a drone in this way: “Even if you shield the electronics with metal, the microwaves can still find a way in through the gaps where the rotors or antennas are mounted.”

Rigorous testing: as many as ten drones a month are destroyed

But does this method work outside of the test hall? To answer this question, the team from Fraunhofer INT is now trialing the system outdoors as well. However, before HPEM can be used to disable drones flying outside, authorization must be obtained from the appropriate authority. This is because the law in Germany forbids the use of powerful transmitters without official permission. Once outside the hall, the conditions are much more challenging: the drone is now several hundred meters away instead of eight, and powerful models fly at a speed of over 100 kilometers per hour. Here, you need an HPEM system with greater range and accuracy. Once again, Lanzrath is confident. “By using directional antennas to focus the microwaves and employing a more powerful transmitter, it’s perfectly possible to target and disable unidentified aerial systems (UAS).” A feasibility study is scheduled to run until mid-2021. At peak testing times, as many as ten drones a month are destroyed.

It is also thanks to Angela Merkel that Lanzrath first took up the fight against the potential threat of drones. In 2013, during an election campaign event held by Merkel’s party, the CDU, in Dresden, a video drone suddenly appeared before the federal chancellor. It was piloted by a member of the Pirate Party, who wanted to draw attention to the problem of mass surveillance. Both pilot and drone were soon apprehended. But the incident set off alarm bells for the security officials. What if the drone had been carrying explosives instead of a video camera? Since then, the authorities have been working with industry and various Fraunhofer Institutes (see box) to minimize such risks. ■

Protecting ourselves against drones

In addition to the HPEM project at Fraunhofer INT, there are a further five initiatives currently underway at Fraunhofer to detect and defend against drones. Four of these receive support from Germany’s Federal Ministry of Education and Research under its “Research for civil security” program.

PROJECT AMBOS – Defense of unmanned aerial vehicles for security agencies | **INSTITUTE** Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE | **PURPOSE** A German-Austrian alliance project launched in February 2017 to develop systems to detect drones, analyze their threat and implement defense measures.

PROJECT ARGUS – System for situationally aware defense against unmanned aerial systems | **INSTITUTE** Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB | **PURPOSE** The system is designed to detect unmanned aerial systems and respond with feasible countermeasures.

PROJECT ORAS – Sensor-based monitoring and alerting system for the detection and tracking of unmanned aerial systems | **INSTITUTE** Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR | **PURPOSE** The system is designed to detect unmanned aerial systems in urban environments. It uses radar networks to create a closely meshed monitoring network. It can be used in conjunction with defense systems to provide security at large-scale events such as festivals or at airports.

PROJECT MIDRAS – Micro-drone defense system | **INSTITUTE** Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut HHI | **PURPOSE** Using massive MIMO antennas – a combination of many antennas in a single device to increase coverage – this system is designed to detect micro-drones and if necessary, provide targeted defense.

PROJECT MODEAS – Modular drone detection and assistance system | **INSTITUTE** Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB | **PURPOSE** This system links a battery of sensor stations, which work with high-resolution 360-degree cameras, tracking units, directional microphones, radar, telephoto zoom cameras and laser range finders. This enables reliable detection of all kinds of flying objects. MODEAS is financed solely by Fraunhofer.

“Even if you shield the electronics with metal, the microwaves can still find a way in through the gaps where the rotors or the antennas are mounted.”

Marian Lanzrath,
Fraunhofer INT

Bringing quantum bits to the fiber-optic network



Fiber-optic links with the capacity to transmit quantum information over long distances would put the quantum Internet within easy reach. The Fraunhofer Institute for Laser Technology ILT and QuTech, a Netherlands research center, are working together to make that a reality. They have developed a quantum frequency converter that will allow quantum processors to be connected to fiber-optic networks. These converters will form part of the world's first quantum Internet demonstrator that will link four Dutch cities as of 2022.

Photonics is a key technology for this quantum communication. The researchers use lasers to generate, manipulate and control individual photons and quantum states. With the help of specially developed technologies, it will be possible to convert the photons' frequency in systematic way that does not interfere with the quantum information. The next step is to transmit the photons through today's fiber-optic networks with little signal loss and to couple the smallest computing units of a quantum computer, qubits, across vast distances.

The great challenge here is to design highly efficient frequency converters that add very little noise to the output signal. "These photons have to be modified so their wavelengths fall into the 1500 nm to 1600 nm telecommunications band to enable long-distance connections with the lowest possible signal loss," says Florian Elsen, project manager and coordinator for quantum technology at Fraunhofer ILT.

Nether-
lands



Italy

Smart construction with automated and digital assets

 The truck bed of the remote-controlled Husky A200 rolling over the curbs and lawns of the NOI Technology Park in Bolzano in South Tyrol is still empty. But this mobile robot platform could soon be carrying bigger loads as it negotiates the terrain of a construction site and finds its way around on its own.

Research fellow Camilla Follini and her colleagues in the Process

Engineering in Construction team at Fraunhofer Italia are working towards this goal. "The aim is to build a bridge between robotics and the construction industry," she says. But this burly little transporter still has a lot to learn before that it can close that gap. Fellini says the results of indoor tests have been positive, so it is only a matter of time before the robot is able to maneuver autonomously among the scaffolding, concrete piles,

China

Political stability is crucial

 What are the key site selection criteria for German small and medium-sized enterprises (SMEs) looking to establish a presence in China? What do these companies need? Researchers from the Fraunhofer Institute for Industrial Engineering IAO investigated these questions on behalf of the regional government of Pujiang.

As it stands, the eastern coastal regions have had the edge in China's domestic competition for jobs and foreign investments. The regional government of Pujiang county in central western China aims to change that. It wants to attract SMEs from Germany to the region with a German-Chinese cooperation center and a new industrial park.

The Fraunhofer IAO researchers made a surprising discovery. "We had expected that financial factors such as government subsidies would be crucial to companies. But political stability was most important to them – it is tantamount to investment security," says Adrian Barwasser, a research fellow at the Digital Engineering department of Fraunhofer IAO, summarizing the study's results. Companies also said they want support in legal matters and political issues. "The legal situation can change in just a few weeks in China. New laws are enacted much faster than in Germany. Companies then have to respond quickly and make the right decisions," says Barwasser.

Fraunhofer worldwide

mounds of gravel and workers that populate construction sites.

Fraunhofer Italia is also setting up the BIM Simulation Lab to provide digital support for decision-making in construction processes. BIM is short for building information modeling, a method to enable connected building planning, execution and management. This project's participants are developing three software systems to this end.

Israel

Game over for herpes viruses

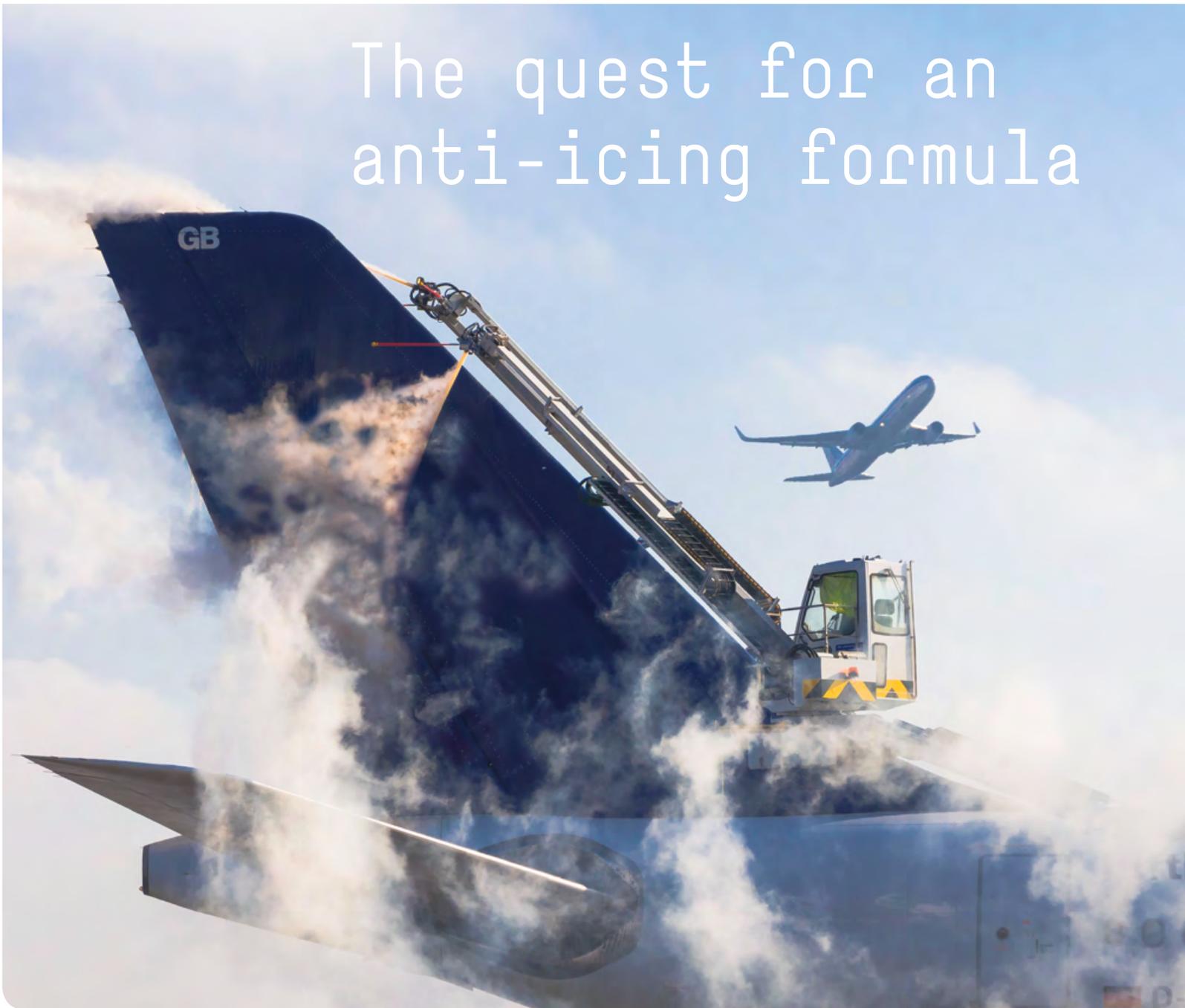
 Herpes viruses linger for a lifetime in the human body. Unrecognized by the immune system, they lie dormant in nerve cells and can trigger repeated infections from their hideaways. Treatments available today alleviate symptoms but cannot prevent renewed outbreaks. Researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB in Stuttgart have teamed up with colleagues from the Hebrew University in Jerusalem to change that.

An encoded protein in the core of the infected host cell causes the herpes simplex virus-1 (HSV-1) to

multiply. This triggers an outbreak, for example, causing sores on the lips. Certain ribonucleic acids can block this protein. The team led by Hebrew University's Gershon Golomb and Fraunhofer IGB's Steffen Rupp is researching and developing a liposomal carrier system that stabilizes these blocking ribonucleic acids, targets the infected cells and delivers these RNAs to prevent the virus's reactivation.

The researchers succeeded in producing an optimized liposomal system called LipDOPE-siHSV. "Significant antiviral activity was achieved in cells infected with HSV," says Steffen Rupp.

The quest for an anti-icing formula



In the air yet or still stuck on the ground, de-icing? That is the big-money question when temperatures drop.
© mauritius images

Ice on wings and fuselage increases the drag of an aircraft and adversely affects aerodynamic flows and flight behavior. A new method of patterning surfaces developed by Fraunhofer IWS, TU Dresden and Airbus Central Research & Technology prevents ice and snow from sticking to aircraft surfaces. De-icing an aircraft exacts a heavy toll - 400 to 600 liters of chemicals and the time passengers spend waiting until the plane is finally in the air.

By Britta Widmann

That layer of ice on a plane annoys passengers because it costs them time. And it costs airlines money. De-icing a single aircraft takes 400 to 600 liters of pricey chemicals. “We are always searching for a more ecofriendly anti-icing formula,” says Elmar Bonaccorso, senior scientist in the materials department at Airbus Central R&T.

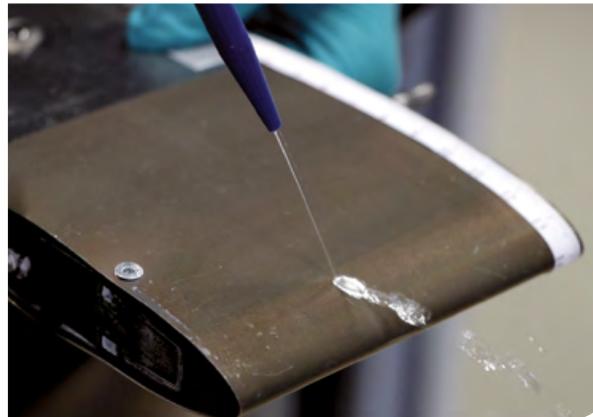
An environmentally sustainable solution has been tested by Airbus with researchers from the Fraunhofer Institute for Material and Beam Technology IWS and TU Dresden. They joined forces in the EU Laser4Fun project to develop a process called direct laser interference patterning (DLIP). It can serve to produce complex surface structures in the micrometer and sub-micrometer range that effectively shrug off ice. “For one, this sharply reduces the adhesion of ice. For the other, de-icing takes less heating power,” says Dr. Tim Kunze, team leader Surface Functionalization at Fraunhofer IWS, commenting on the benefits of DLIP. Ice formation is a problem on the ground, but critical in the air. “Water on the surface freezes within milliseconds when the aircraft flies through the clouds at sub-zero temperatures. Ice protection systems using hot bleed-air from the engines prevent ice accretions from disrupting the airflow around aircraft control elements,” says Bonaccorso. It does not even have to be that cold for ice to complicate matters. Unlike dry ice, which forms at extremely low temperatures, sticky ice materializes at temperatures of around zero degrees Celsius.

What sets this new solution apart is that the researchers combined DLIP technology with ultra-short-pulse lasers to create multilevel microstructures on 3D scaled airfoils in a single step. As a result, some of the ice simply loses its grip, depending the conditions under which it froze, so active de-icing requires up to 20 percent less heating power. The benefits of this method are many: It reduces the amount of environmentally harmful de-icing agents required to clear an aircraft for take-off, the time passengers spend waiting for the plane to be de-iced and the power and fuel consumed in flight. “This combination of these two effects has yet to be achieved with conventional technologies,” says Kunze emphatically.

Durability testing in a wind tunnel

The researchers methodically developed the process and conducted many tests in the Airbus labs to achieve this combined effect. They tested the demonstrator – a complex three-dimensional NACA airfoil structured via DLIP – under realistic conditions at wind speeds ranging from 65 to 120 m/s, with air temperatures below minus ten degrees Celsius and at various humidity levels in the wind tunnel at the aircraft maker’s facilities in Ottobrunn near Munich.

These tests showed that it took 70 seconds for the ice on an unstructured airfoil to disappear at 60 watts of applied heat. The ice on the patterned airfoil receded completely after just five seconds at the same amount of applied heat. “With our DLIP approach, we were able to produce multilevel, biomimetic surface effects on a component as complex as the NACA airfoil, with millimeter resolution, and demonstrate its concrete advantages over other laser processes”, says Kunze. His colleague Sabri Alamri adds, “The water-repellent structure is an attempt to replace conventional technologies with ecofriendly, more cost-effective alternatives.” Flight tests are currently underway with an aircraft that carries small samples (12 x 30 cm) of DLIP-treated surfaces. ■



“The water-repellent structure is an attempt to replace conventional technologies with eco-friendly, more cost-effective alternatives.”

Sabri Alamri,
Fraunhofer IWS

The NACA airfoil with the water-repellent patterned surface © Airbus

Direct laser interference patterning (DLIP)

The principle behind the interference effect may be familiar from high-school physics classes: A light beam passing through a double slit produces alternating bright and dark bands caused by the superposition of overlapping light waves. This is called an interference pattern. Although Fraunhofer IWS experts create these patterns in different ways, this also requires the superposition of overlapping light waves, which they accomplish with direct laser interference patterning (DLIP).

This method can produce nano- and micrometer-sized structures and create surface topographies tailored to many applications. DLIP involves splitting a coherent laser beam into two or more beams and superimposing them on the surface of a component in a controlled fashion. The interference effect caused by this superposition is a “periodic modulation of laser intensity” that can be used to apply 2D and 3D patterns to a component’s surface.

Opera? At home!

A new audio experience for a new era: a look inside the lab that will make this possible. By Josef Seitz

Rarely has so much of life been confined to home as in times of the coronavirus crisis. Dr. Ulli Scuda, head of the Soundlab, and his team at the largest Fraunhofer Institute, the IIS in Erlangen, are working on new ways to turn the living room into a concert hall, movie theater or sports arena.

Hearing what the conductor hears

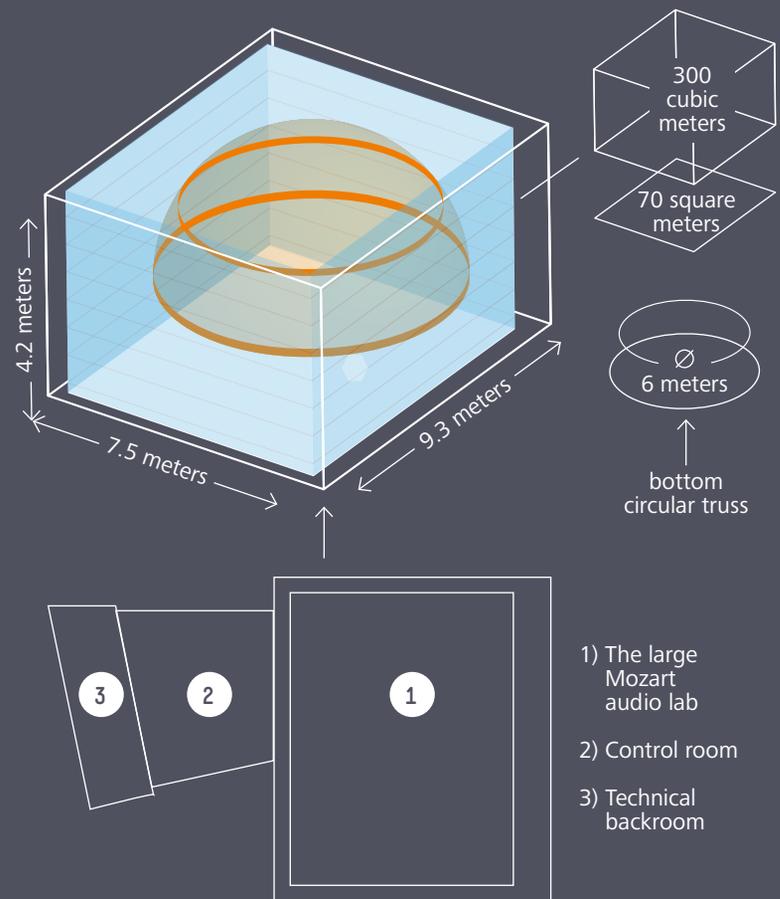
The conductor raps his baton on the podium in the Leipzig Gewandhaus, calling the orchestra to attention, whereupon the musicians strike up the introduction to the choral movement of Beethoven's 9th symphony. A thumb bears down on the TV's remote control. It teleports the viewer's ears from the conductor's podium to a seat high up in the gods. From here, the "Ode to Joy" sounds further away, but all the richer for the reverb and acoustics of the Gewandhaus. With another press of a button, the TV viewer is ushered into the royal box – virtually at least, because in reality they are still sitting safely in their armchair at home, far away from coughing crowds and potential airborne pathogens.

These fascinating audio options come courtesy of the Audio and Media Technologies department of Fraunhofer IIS in Erlangen, the very place that gave birth to that global bestseller, mp3. And the shape of things to come is even more fascinating. Fans of criminal fiction series will no longer have to strain their ears to hear the mumbled words of taciturn detectives. Sports enthusiasts will be able to mute the studio commentary during live transmissions of soccer matches, and experience the event as if they were there in the stadium. And feature films will be accompanied by a 3D soundtrack, enabling viewers to experience the sound design as it was intended – as "emotional storytelling." All this will be accessible via a remote control that "personalizes" the sound of the TV. "I am confident that this experience will be of ever greater value to our society, especially when we are confined by pandemics and lockdowns," says Scuda, who holds a doctorate in media studies. He is fascinated by the immediacy of the audio experience. "You can cover your eyes to avoid watching certain scenes of a movie, but the sound will still filter through."

Scuda and his Soundlab team of 14 audio engineers and highly specialized technicians benefit from a unique asset, the Mozart audio lab pictured on the right. It features loudspeakers, mixing consoles and computers installed to the tune of some 700,000 euros. The silence in this room is deafening without music. It is so silent "that you can hear the rush of your own blood flowing," says Scuda. But with music, "It's like a big man-cave – but for women too." ■

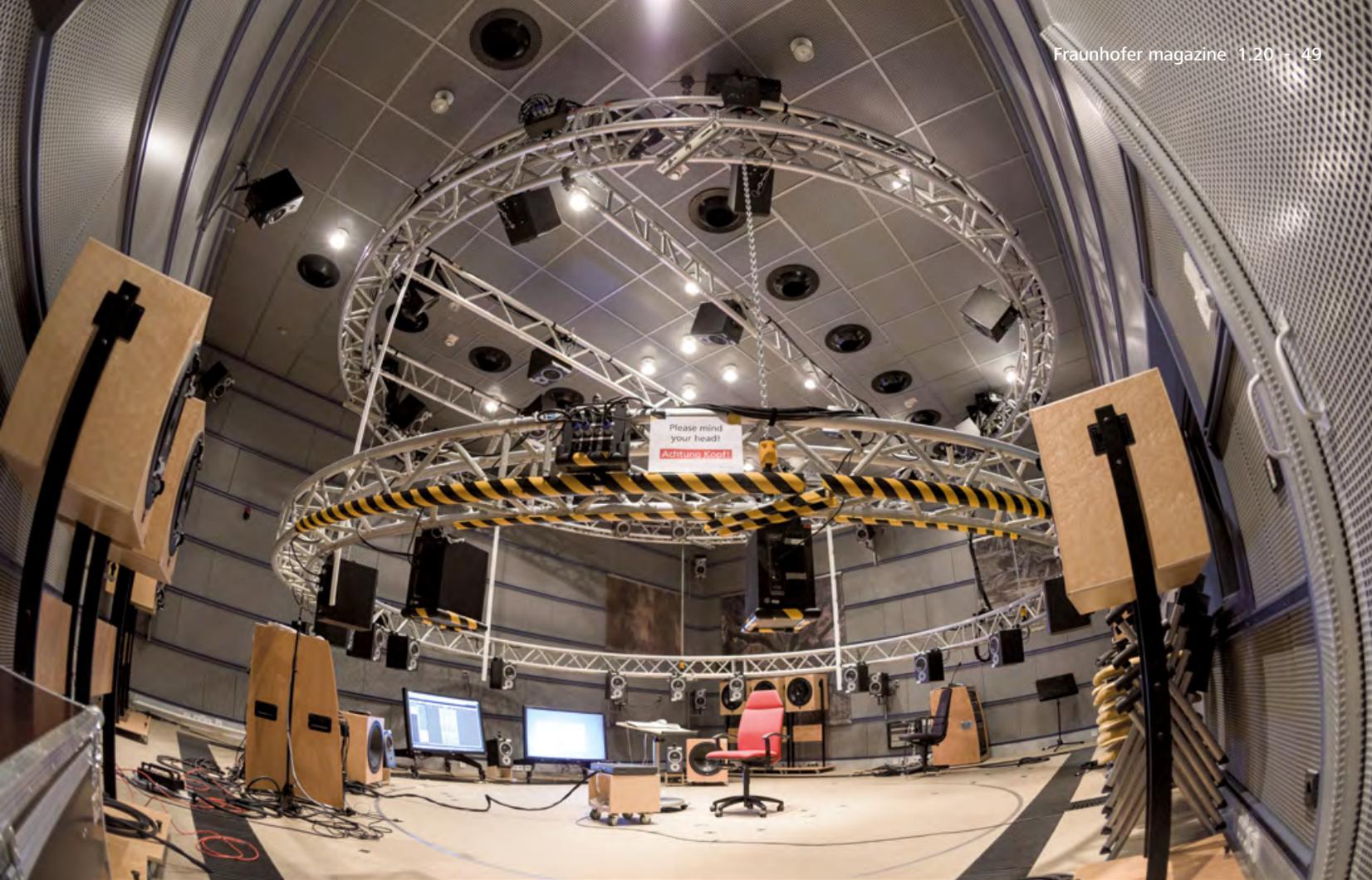
The Mozart audio lab

The Fraunhofer Institute for Integrated Circuits IIS is the birthplace of the mp3 format. The IIS develops audio technologies in labs unlike any other listening room in the world. Two go by the names of Mahler and Ravel. Mozart, the largest of the three, complies with the rigorous specifications of ITU-R Recommendation BS.1116, a standard for comparative subjective assessments. These guidelines serve to develop audio coding methods and signal processing technologies. The buttons in a control room called Stravinsky – that is, Stravinsky spelled German-style – can make instant A/B comparisons of all audio setups ranging from mono to 3D and 22.2 surround sound.



Room-in-room setup for total silence

The Mozart audio lab is acoustically decoupled from its surroundings. Half a meter of insulating material separates the interior room from the outer concrete shell. The floor is also insulated from the rest of the building to eliminate any footfall or impact sound. Even the air conditioning system has been fitted with extra-large inlet nozzles to ensure air flows slowly and even a gentle waft cannot break the silence. It takes a special room like this to render audio for every sonic detail to be heard.



9x

Nine main loudspeakers
Sound source no. 1 is a three-way, coaxial RL 901k enclosure made by Geithain. Founded in 1960, the company supplied studio monitors to the public radio broadcaster in former East Germany.



43x

43 other loudspeakers
Active Dynaudio BM6A mk II near-field monitors are spread around the top circular truss. Their frequency response ranges from 48 to 21,000 Hz.



2x

Two subwoofers
The installed bass bins also sport the Geithain brand name. "Our lab doesn't shake when they're cranked at full blast, but trouser legs do flap," says Dr. Scuda.

The perfect living room?

Sound in the round hits the sweet spot for discriminating music and movie lovers. The listening position is always equidistant to the source with all speakers flown on a circular truss. The engineer in the Strawinsky control room pictured below can configure speakers in any combination to meet every sound design need.



3D tour of the Mozart audio lab
<https://s.fhg.de/iis360>



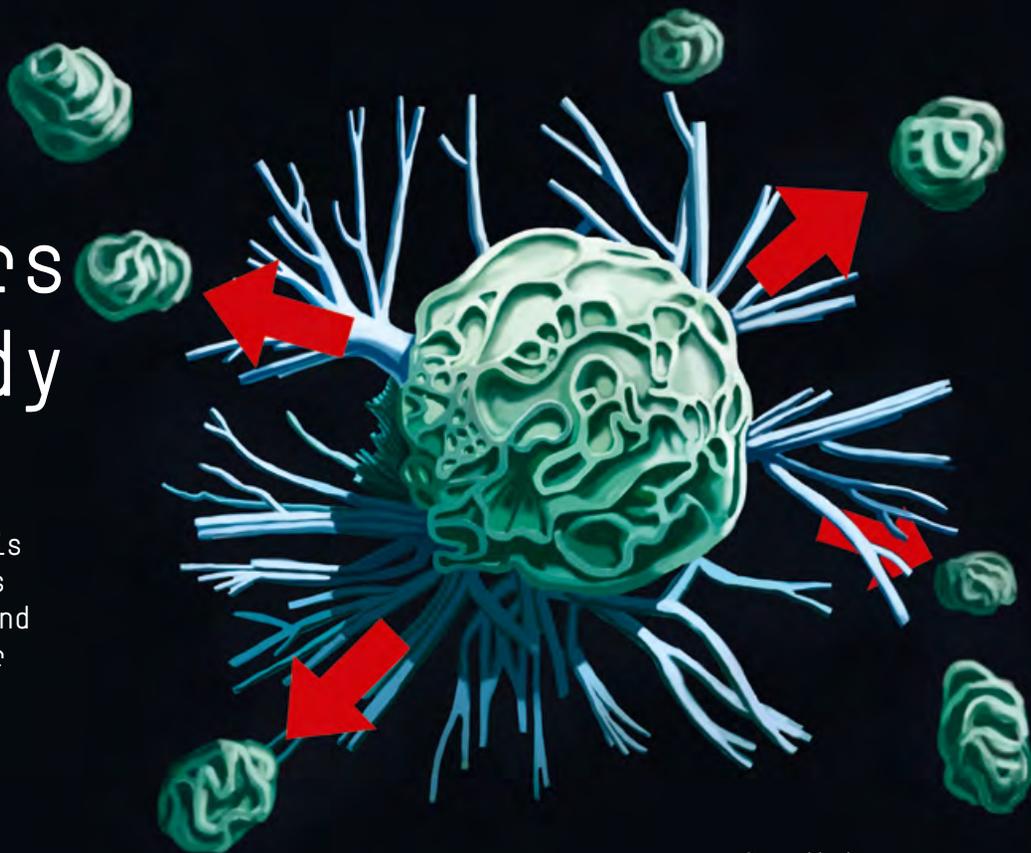
At the console: head sound lab planner Dr. Andreas Silzle

© Infographics: 2issue; source: Fraunhofer

Hunting the killers in the body

What makes tumor cells turn murderous? Fraunhofer ITEM is investigating the mechanisms of metastasis formation – and searching for approaches for new treatments in the fight against cancer.

By Christine Broll



© mauritius images

“Nine out of ten cancer deaths are not caused by the primary, but by secondary tumors.”

Dr. Bernhard Polzer, Fraunhofer ITEM

Dr. Bernhard Polzer is fully concentrated as he looks through the microscope at the slide bearing bone marrow cells from a breast cancer patient. In between the bone marrow cells, he is searching for disseminated tumor cells that he previously labeled with a blue dye. When he finds a blue cell, he suctions it up with a glass capillary and places it on an empty slide.

It is single cells like these that can kill cancer patients: disseminated tumor cells that lie dormant for years in the bone marrow or other organs and one day form metastases that ultimately lead to death. Nine out of ten cancer deaths are not caused by the primary but by secondary tumors.

“We are developing special methods to genetically analyze single disseminated tumor cells and tackle them individually,” explains Bernhard Polzer, deputy director of the Division of Personalized Tumor Therapy at the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Regensburg. The 40-member research team aims to use genetic data to shed light on the not yet well-understood

process of metastasis formation – and, in this way, to develop approaches for new forms of treatment.

Heading up this research division is Prof. Christoph Klein, who in 2014 received the German Cancer Award in recognition of his work. “In carcinogenesis, cells revert to programs that are important in embryonic development,” explains Klein. “When a degenerated mammary cell detaches and is transported through the blood to the bone marrow, it tries to form a new mammary gland there.” But instead of a mammary gland, only a tumor is formed that destroys the surrounding organ.

Examining lymph nodes just like a century ago

Christoph Klein sees great potential to avoid metastases in a diagnostic approach that learns to understand the onset of metastasis at the molecular and cell biological level. Important information for such an approach can be obtained by conducting a pathological examination of lymph nodes

removed during a tumor operation. The same method has been used for more than a hundred years now to examine lymph nodes to see whether a tumor has already disseminated. Ultra-thin slices of tissue are taken from multiple locations and a pathologist searches them for cancer cells. "Unfortunately, the tissue between the cutting planes is not examined," Klein criticizes. "So any metastases located there are overlooked."

Together with Fraunhofer IPA and Fraunhofer IIS, Christoph Klein's team has developed a method that makes it possible to analyze the entire lymph node. Samples are prepared using a tissue grinder, which carefully separates the cells. Afterwards, the sample is treated with a special dye that stains the disseminated tumor cells. Two million lymph node cells are scanned automatically and suspicious objects are then examined under the microscope. "Using our method, we detected tumor cells in half of the examined lymph nodes," says Bernhard Polzer. "With the conventional method, in contrast, pathologists found cancer cells in just 15 to 20 percent of the samples." A market-ready version of the new method is currently being developed.

Disseminated tumor cells mutate

Once Bernhard Polzer has isolated individual disseminated tumor cells under the microscope, he takes the sample to the next room, where the latest generation of DNA sequencers stand at the ready. But even for these modern machines, a single cell contains too little DNA to deliver reliable results, so Polzer has to multiply the cell's DNA prior to analysis. To do this, he uses a method that Christoph Klein developed back in 1999 – important pioneering work that first made it possible to analyze individual cells and that is now established as the standard method worldwide.

Genetic analysis reveals, for instance, whether the disseminated tumor cells have the same properties as the primary tumor and might therefore respond to the same treatment. Often, however, they do not. The disseminated cells mutate when they reside in a foreign tissue environment for a longer period. "When breast cancer cells reside in bone marrow, they can take on the properties of the hematopoietic cells that surround them," says Christoph Klein. "The cells evidently adapt to their surroundings." But the disseminated cells can also activate additional cancer genes in their new environment. Then they become more and more aggressive and dangerous.

If the genetic analysis reveals that the disseminated tumor cells have mutated, fighting them requires different remedies than those used for the primary tumor. Polzer and Klein are

currently researching how to find the right drug for each patient. Their starting point is a technology that already works for large numbers of cells and must now be adapted for single cells. It analyzes 450 cancer-specific mutations for which drugs are already available on the market or in clinical trials.

Bernhard Polzer is clearly focused on the goal: "We want to isolate the disseminated tumor cells in lymph nodes or bone marrow and examine them for these 450 mutations. Then we could target them with the right drug to prevent them from metastasizing." To this end, the researchers in Regensburg are working with a number of companies that want to transfer this innovative diagnostic approach to everyday clinical routine.

The team also uses conventional methods to determine which drug is effective against a patient's metastases. To do this, they propagate the tumor cells in a nutrient medium, where they grow into spherical structures known as organoids. These cells can then be used in the lab to test the various potential active agents. It is hoped that this will enable them, in collaboration with the clinic in Regensburg, to one day help many patients.

What turns cells into killers?

When Bernhard Polzer suctions up a blue-stained disseminated tumor cell, he often asks himself: Would this cell have had the potential to kill the patient? Or would it have remained dormant and not done any harm? After all, not all disseminated cells form metastases. Christoph Klein calculated that, in a breast cancer patient with no visible metastases, there may be 10,000 to 20,000 disseminated cancer cells in the bone marrow. Only a few of those have the potential to metastasize. But which properties enable them to do this? Do they trick the immune system? Do they activate aggressive cancer genes? What turns them into killer cells?

To find an answer, Christoph Klein, in collaboration with several clinics, launched a study involving 200 breast cancer patients. His team examines these patients' primary tumors, disseminated tumor cells and metastases. In each cell they examine, they analyze all the genes that cell activates. These data are then correlated with the patients' clinical course – a vast amount of data to which the research group's bioinformatics team gives structure. "We search the tumor cells for markers that are associated with a poor prognosis for the patient," explains Christoph Klein. The full results of the study will be available by the end of the year – and will hopefully provide clues as to what turns cells into killers. ■

Even in breast cancer patients with no visible metastases, there may be as many as 20,000 disseminated cancer cells in the bone marrow.



An artist's impression of MARK 51°7, with research buildings in the foreground and a DHL parcel distribution center behind.
© Bochum Perspektive 2022 GmbH

The former Opel site, covering 70 hectares: right, the new DHL parcel distribution center; left, construction of buildings for research institutes and tech companies, which are to be supplied with geothermal energy from mine water. © Lutz Leitmann



Heat from a coal mine



Supplied with geothermal energy from the flooded Dannenbaum colliery, a new technology campus could provide a model for the entire Ruhr region.

By Christine Broll

The galleries in a mine are built like subway tunnels. When a mine is abandoned, it is often flooded with water, which can then be used a source of energy. © Shutterstock

It's over half a century since the Dannenbaum colliery was abandoned. In 1957, a year before it shut for good, the colliery was still churning out 239,500 metric tons of coal annually. But then the mine-shafts were filled in. Today, the underground tunnels and galleries are flooded with water. On the surface, some 800 meters above the lowest level of the mine, the world has moved on. Opel, the German automaker, arrived and built a huge factory on the former coal mining site, only to shut it down again. And now a new chapter is about to begin at the Dannenbaum site: the construction of an industry and technology campus, which will generate 6000 jobs as well as find a new role for the former mine workings.

Responsible for rousing the colliery from its 60-year slumber is the utility company Stadtwerke Bochum and the newly established Fraunhofer Research Institution for Energy Infrastructure and Geothermal Energy (IEG). These two partners intend to use the flooded mine workings to cover the technology campus' energy requirements: with heating in the winter, when mine water at a temperature of 35 degrees Celsius will be pumped up from a depth of 800 meters; and air conditioning in the summer, when mine water at 18 degrees will be pumped up from 300 meters.

An ecological alternative for the entire region

For Prof. Rolf Bracke, director of Fraunhofer IEG, this project could point the way forward for the Ruhr region as a whole: "There are mine workings from around 200 abandoned collieries across large areas of the Ruhr. In some cases, these workings extend over 50 square kilometers and descend to a depth of over 1000 meters. Most of them are flooded, so they could serve as heat stores for waste heat produced by industry or power companies." In addition, thermal energy from the mine water could provide an environmentally friendly source of energy for district heating grids in the region. At present, most of these are supplied with waste heat from gas- and coal-fired power plants.

The new technology campus is known as MARK 51°7, a name every bit as inventive as its proposed mode of energy supply. The designation is based on the map coordinates of the former Opel site: 51 degrees north and 7 degrees east. Around half of the 70-hectare site is to be occupied by tech companies and research institutes from the Max Planck Society and Ruhr-Universität Bochum. This area will be supplied with energy extracted from mine water.

"According to our latest calculations, we predict that the natural energy potential of the mine water will be enough to cover up to 85 percent of the heating and air conditioning

requirements of the various consumers connected to the system," explains scientific project manager Gregor Bussmann, deputy director of the department for Storage and Underground Systems at Fraunhofer IEG. "That amount of thermal energy is enough to heat around 1000 single-family homes."

It is by far the largest mine-water project of its kind in Germany, although the principle has already been trialed in a number of small pilot projects. In Bochum, for example, the municipal utility company is now using warm water from the flooded Robert Müser colliery to heat two schools and the city's main fire station.

Converting hundreds of surveyors' maps into a digital 3D model

For the purposes of planning, Bussmann and his team first had to analyze the conditions underground. They were able to fall back on the maps drawn up by successive generations of mine surveyors ever since the colliery first opened in 1859. These are stored in the archives of the mining authorities in Dortmund. "We studied hundreds of plans and maps and converted them into a digital 3D model," Bussmann explains.

This model showed Bussmann the precise location of all the vertical shafts and horizontal galleries that make up the mine workings. This underground network comprises eight levels. At the deepest of these, more than 800 meters below ground level, the scientists estimated the water temperature to be at least 35 degrees Celsius. But before they could pump this water up to the surface, they first had to find a suitable place to drill. ▶

There are 200 disused collieries, most of which could be used for thermal energy storage.

It's over 60 years since the Dannenbaum colliery was abandoned. The last shift left the mine in 1958.
© Johann Schmidt/
Fotoarchiv Ruhr Museum



Use these pages of
Fraunhofer Magazine
to note down your
own thoughts about
sustainable development.

Ready for a

A large rectangular area with a light green background and a repeating geometric pattern of overlapping lines. This area is divided into 15 horizontal sections by thin, light green lines, serving as a template for handwritten notes.



“To me, sustain-
ability means
expanding the
horizon of my
decisions. I try to
act sustainably
by understanding
that developments
in developed
countries and
developing
countries are just
as interconnected
as a company’s
different units and
a supply chain’s
companies. At the
same time, my
decisions not only
have conse-
quences in the
short and medium
term but also in
the long term. (I’d
definitely eat less
Kinder chocolate
if my waistband
started to feeling
too tight right
away instead of a
few days later.)”
Prof. Julia
Fraunhofer,
IFF

A vertical column of 10 horizontal lines on the left side of the page, intended for additional notes or a list.



Prof. Rolf Bracke (right) and Gregor Bussmann discuss the project in the powerhouse of the geothermal center. © Sascha Kreklau/Fraunhofer

► This proved a challenge, since it was vital to ensure that drilling would not damage the shoring holding up any of the galleries in above-lying levels. But, with planning complete, drilling work is now scheduled to get underway in early summer of 2021.

In the summer, the process is reversed

Once the system is up and running, as many as 70 cubic meters of mine water an hour can be pumped to the surface. The energy from this warm water is transferred, via plate heat exchangers and heat pumps, to the water in the heating circuit that feeds the district heating grid. In the process, the mine water cools to around 18 degrees Celsius, whereupon it is returned, via a second well, to the fourth level of the mine, at a depth of 300 meters. Meanwhile, heat pumps raise the temperature of the water in the heating circuit to an inflow temperature of 48 degrees Celsius.

In the summer, this process is reversed. Cooler water drawn from the fourth level is refrigerated until it has reached a temperature of 10 degrees Celsius. The heat liberated during the refrigeration process is transferred to mine water at the eighth level, thereby helping to replenish the heat reservoir at a depth of 800 meters – in preparation for the coming winter.

Before obtaining official authorization for the project, Fraunhofer IEG had to conduct extensive surveys to exclude the risk of environmental damage, including the possibility of ground heave or subsidence as a result of the water pumping operations. Nor is there any danger of an impact on water quality. “The water is pumped in a closed circuit, so it can’t be contaminated,” Bussmann explains. “Besides, we’re well away from any of the catchment areas for drinking water.”

In the long term, Bracke sees even greater potential for the abandoned mine workings right across the coalfields of North Rhine-Westphalia, from Aachen to Hamm. His plan is to use them to store thermal energy. As part of the EU HeatStore project, Bracke is to trial the principle in a pilot scheme, using a small abandoned coal mine located directly beneath the Fraunhofer IEG campus: “The plan is to use a highly efficient solar system to heat the mine water to between 60 and 70 degrees Celsius in the summer. In the winter, we will use this mine water as the source for a high-temperature water-to-water heat pump to supply water at a temperature of between 100 and 110 degrees Celsius to the district heating grid of the Bochum-South area. At present, this grid is powered by energy from fossil fuels. In other words, the use of abandoned mine workings in former coalfields can help smooth the transition to a carbon-neutral future for district heating systems.” ■

Energy from as many as 70 cubic meters of mine water per hour.

08%

The Fraunhofer-Gesellschaft has a special responsibility for putting the UN sustainability goals into practice. A survey of Fraunhofer employees found that the absolute majority of them holds this to be true, namely

Ready for a

Use these pages of Fraunhofer Magazine to note down your own thoughts about sustainable development.



Professors Heidemarie Schmidt and Stefan E. Schulz have great expectations for miniscule memristors.
© Cornelia Schubert

Little things, big opportunities

Memristors can mimic the behavior of synapses in the human brain. This could be a boon to AI applications.

By Mehmet Toprak

A portmanteau of memory and resistor, a memristor is an electronic component that can both process and store binary and analog data. Remarkably compact, fast and energy-efficient, it promises to be useful piece of hardware in the engineering toolbox. It may not look like a big deal, but appearances deceive.

Researchers at the Fraunhofer Institute for Electronic Nano Systems ENAS certainly think highly of this diminutive component. Prof. Heidemarie Schmidt heads up an ATTRACT project that goes by the name of BFO4ICT, the objective of which is to develop an overall technology for the modular integration of novel electronic components in microelectronic CMOS hybrids. She and her five-member team have been developing technology to manufacture memristors based on bismuth ferrite (BFO) on an industrial scale since 2016. And this ENAS team has succeeded in producing these components under conditions much like those in a real-world fab. But that is not the only reason why Schmidt believes the future looks bright for memristors and is already talking about applications such as artificial intelligence and cryptography.

A component unlike any other

A quick recap of a few electrical engineering fundamentals should help explain why this looks like the next big thing in

little components. As it stands, there are three basic passive components, the capacitor, inductor and resistor. A capacitor stores an electrical charge, an inductor induces voltage, and a resistor limits or splits the current. A transistor is an active component, so it belongs to a different branch of the family tree. In 1971, Leon Ong Chua, a scientist at the University of California, Berkeley, postulated the existence of a fourth component alongside the capacitor, inductor and resistor. Putting forth the theory that this fourth component could incorporate the functions of all three others, he called it a memristor.

Soon the search was on for a material of which this memristor could be made. It was not until 2007 that researchers at the Hewlett-Packard lab managed to build the first memristor based on titanium oxide. Proof of concept was established with this early prototype.

The property that sets this unique component apart is its non-volatile variable resistance. The current, or more precisely, the electrical charge that flows through the component when voltage is applied determines this resistance. When the voltage is switched off, the resistance remains as it was up to this moment. These components can serve to store data and execute computations because their resistance is variable – it can be modulated by varying the electrical charge and voltage – and is retained even when switched off. ▶

“The memristor has what it takes to impel AI development across Europe.”

Prof. Stefan E. Schulz





“Sustainability is the ecological conservation of the environment, but it’s also the economic longevity of products and business models.”

Johannes Schuler,
Fraunhofer ISI



Ready for a

Use these pages of Fraunhofer Magazine to note down your own thoughts about sustainable development.

A large area for writing, consisting of a grid of horizontal lines on a background with a repeating pattern of wavy, overlapping lines.

A vertical column of horizontal lines on the left side of the page, intended for additional notes.

► This would make memristors the perfect device for hardware encryption where keys are generated right there in the electronic component.

Manufacturing is an imperfect science. Production-related variances – experts call them physically unclonable functions – leave each component with a unique variable resistance; a fingerprint that can serve to generate a unique key. For example, memristors installed in a cell phone could encrypt voice messages just downstream from the microphone input.

Artificial intelligence built into the circuit

Heidemarie Schmidt has even more important applications of memristors based on BFO in mind – neuromorphic computing, where data processing and storage functions are co-located. A memristor's resistance is infinitely variable between zero and one – in other words, the control range is analog. With this and its other special properties, it can mimic the behavior of synapses in the human brain. What is more, a BFO memristor can implement any of the 16 possible bivalent logic functions, whereby their output signals are also variable between zero and one. On top of that, this BFO memristor may be reconfigured into any of the 16 logic functions at any time.

“The logic functions are defined and reconfigurable with memristors, so the algorithms for training AI circuits are also controllable and transparent,” says Schmidt, pointing out a decisive advantage. And that is indeed a pivotal point: “It can serve to certify AI applications. This is a key prerequisite for putting AI into practice in sensitive security scenarios and autonomous cars,” says Schmidt.

Memristors for next-generation computing

Prof. Stefan Schulz heads up Nano Device Technologies, the department at Fraunhofer ENAS tasked to pursue BFO4ICT. The work conducted as part of the ATTRACT project will help advance the Next Generation Computing initiative, one of several ventures to be deemed strategically important and designated a priority at Fraunhofer. Schulz says, “Memristors are a disruptive technology with enormous advantages. We have to keep at it and have the staying power to wait out the years it could take until the technology is truly ready for the market.”

Heidemarie Schmidt has been keeping at it for 13 years. This is no easy task. It requires ultra-advanced thin-film technologies, suitable clean rooms and reproducible recipes for manufacturing BFO memristors. Fraunhofer ENAS is

collaborating with researchers from the Helmholtz-Zentrum Dresden-Rossendorf and TU Chemnitz to this end.

Despite the difficulties, Schmidt and her team have risen to these challenges. These researchers have presented the first prototypes and demonstrators. But that was just the first step – they are now able to produce memristors on wafers. Less than a millimeter thick, these silicon discs serve as a substrate for the fabrication of microelectronic components. The larger a wafer, the more components it can accommodate. The Fraunhofer ENAS cleanroom uses wafers with a diameter of 200 millimeters. “This was risky move, technologically speaking, because you never know beforehand if manufacturing processes on a nanometer scale are actually going to work,” notes Schulz. The men and women in the Fraunhofer team have since established that they do indeed work. These wafers have proven their merits on machines that could be found in a real-world fab.

Smart choice of material

The researchers' choice of materials for the memristor and electrode marked a milestone on the road to success. Titanium dioxide has been used frequently as the material for the memristor and precious metals such as platinum or silver as the electrode material. The Fraunhofer team explored a different avenue with bismuth ferrite (BFO), a ternary oxide consisting of three elements. The researchers modified its chemical composition to serve their purposes. How exactly they accomplished this remains their secret. But the effect is there for all to see: BFO memristors can be switched at speeds measured in nanoseconds rather than milliseconds and enable analog data processing and storage in one place.

The odds look good that these memristors are going to drive advances in AI applications and hardware encryption a few years from now. A credible case can also be made for applications in healthcare. For example, a memristor-driven AI module could enable a physician with a tablet in hand to analyze and assess blood counts right there at the bedside. Memristors could also encrypt diagnostic and patient data as the tablet sends it on to hospital servers via Wi-Fi.

Consumers could also benefit. Today, the speech recognition and translation applications that run on a smartphone have to connect to a cloud server to process data. Tomorrow, memristors in the device could process and store data locally. But the most important advance will come when they serve to verify and validate complex AI scenarios such as autonomous vehicles and industrial production lines.

Europe's economic development is very much on Stefan Schulz's mind: “The memristor has what it takes to impel AI development across Europe.” ■

“It can serve to certify AI applications – a key prerequisite for putting AI into practice.”

Prof. Heidemarie Schmidt



08

No beef with
mock meat:
Fraunhofer IVV has
improved wet-textured vegetable
protein. The
mass cools after
the powder is
pressed through
the extruder,
causing the
proteins to unfold
and crosslink. This
resulting veggie
nuggets, goulash
and schnitzels have
the same water
content as real
meat products –
namely 60 to

Ready for a

Use these pages of
Fraunhofer Magazine
to note down your
own thoughts about
sustainable development.

Large area with horizontal lines for notes.

Vertical lines on the left side for notes.

Solving the antibiotics crisis

Bacteriophages infect bacteria and kill them. They were used to aid in curing severe infections as long as a century ago. Now phage therapy is enjoying a renaissance – in the battle against multiresistant bacteria.

By Christine Broll

Antibiotic-resistant pathogens claim around 2400 lives in Germany each year. Fraunhofer ITEM is investigating antidotes.
© Fraunhofer ITEM



Phage therapy has captivated Holger Ziehr ever since he saw a BBC documentary on the subject more than twenty years ago. Since then, he has been working to harness phages in the battle against antibiotic-resistant pathogens, but for a long time, few were willing to join him in this effort. Research proposals were derided and rejected. Companies declined when asked to manufacture investigational drugs for clinical studies. Only as more and more bacteria became resistant to antibiotics and pharmaceutical companies gave up searching for new antibacterial agents did his perseverance pay off.

Today, Prof. Holger Ziehr is an extremely sought-after expert on phage therapy. A division director at the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Braunschweig, he is developing platform technology for the production of phages for use in pharmaceuticals. In parallel,

he is working with regulatory authorities to establish a model process by which phages can be approved as a therapeutic agent in Germany. He sees phages as an important new component of treatment: “We do not want to replace antibiotics. Phages should be used where antibiotics come up against their limits.”

Phage therapy was discovered before antibiotics were. It was in 1917, when French-Canadian microbiologist Félix d’Hérelle was working with shigellosis pathogens he had isolated in infected soldiers. While cultivating lawn cultures in lab dishes, he kept discovering small holes that spread over time. Further experiments showed that these holes were home to tiny microbes that ate the bacteria. He called these as yet unknown microbes bacteriophages – literally, bacteria eaters. ▶

In Germany, 30,000 to 35,000 people are infected with multi-resistant pathogens each year.

Use these pages of
Fraunhofer Magazine
to note down your
own thoughts about
sustainable development.

Ready for a

“For me, sustain-
ability means
humankind has
to relearn to live
with, rather than
against, nature
and stop leaving
traces of human
activity even in
the remotest
areas of the
planet.”

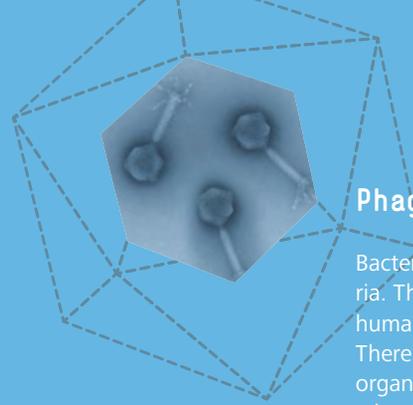
Anita May, group
manager,
Fraunhofer
CBP



A large rectangular area with a light gray background and a repeating pattern of thin, wavy lines. This area is intended for users to write their thoughts about sustainable development.

A vertical column of horizontal lines on the left side of the page, providing additional space for notes or a table of contents.

© Electron microscope image of a coliphage, Leibniz Institute DSMZ



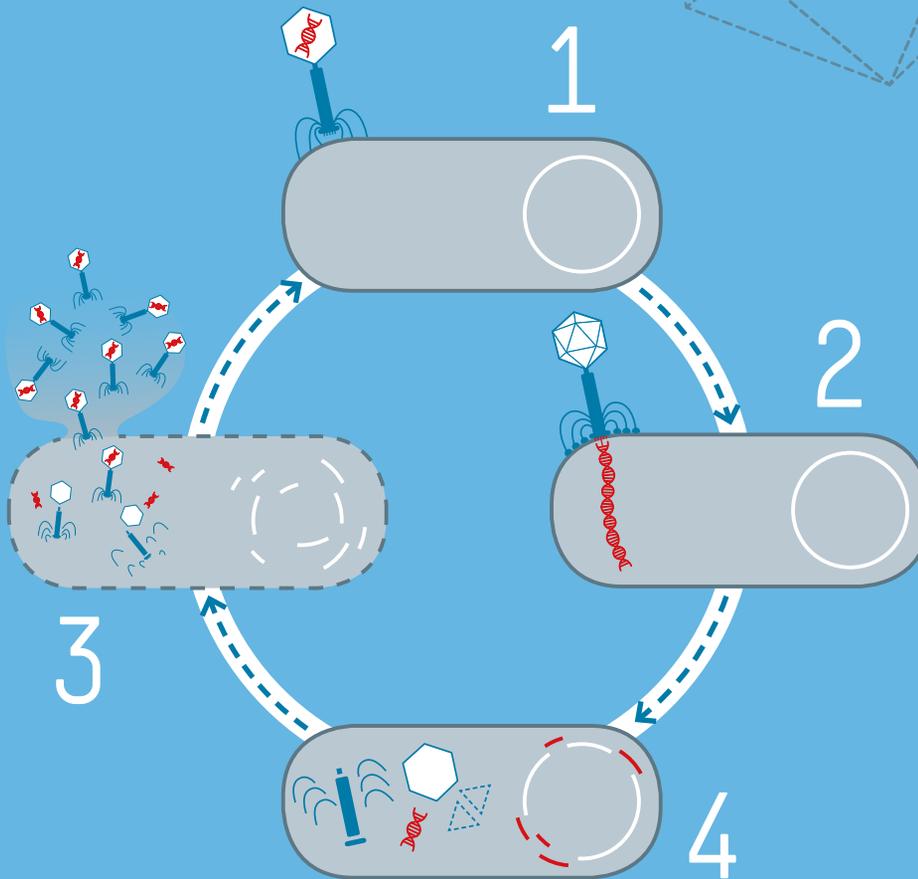
Phages

Bacteriophages are viruses that infect only bacteria. They are not capable of replicating in animal or human cells, so they pose no danger to humans. There are more phages on Earth than all other organisms combined. Phages are found everywhere bacteria live, so also in the human intestinal flora and on the skin. From a global standpoint, they contribute significantly to regulating the incidence of bacteria.

The head of a phage is shaped like an icosahedron, a sort of die with 20 faces and 12 vertices. It contains the genetic material and is perched on a long tail. The phage uses the tail fibers, which are shaped like spiders' legs, to attach itself to its host cell. Bacteriophages cannot self-replicate – they use bacterial cells for this. Every phage species is specific to a certain bacterial strain.

Phages recognize suitable hosts based on special receptors on the host's surface. In order for a phage to infect a bacterium, the bacterial receptors and the phage tail fibers must fit together like a lock and key.

After the phage attaches to the bacterium (1), it injects the genetic material from its head into the cell (2). The bacterium then begins to produce phage components (3). The phages are subsequently assembled and released (4). Some 50 to 100 new phages can be created from one bacterium.



Graphic © Vierthaler und Braun

► Félix d'Hérelle successfully treated the first shigellosis patients with a phage solution as early as 1919. In 1936, together with his friend Georgi Eliava, he founded the Eliava Institute of Bacteriophages, Microbiology and Virology in Tbilisi, Georgia, which seeded the spread of phage therapy in the Soviet Union. In World War II, Red Army soldiers were successfully treated with phages. Soviet researchers later continuously refined those methods, but after the Soviet Union collapsed, the old knowledge about phage therapy was forgotten.

Help for cystic fibrosis patients

Exactly one hundred years after bacteriophages were discovered, Holger Ziehr, together with two partners, launched Phage4Cure. Funded by the German Federal Ministry of Education and Research, this project is aimed at developing a phage-based drug for cystic fibrosis patients. People with

this genetic disorder have a viscous mucus in their lungs that is an ideal breeding ground for bacteria. One such bacterium is *Pseudomonas aeruginosa*, which is now resistant to most antibiotics.

The phages used in the project stem from the DSMZ-German Collection of Microorganisms and Cell Cultures in Braunschweig. This collection also includes many phages that are specific to antibiotic-resistant bacteria. They were isolated from such sources as wastewater from clinics and municipal wastewater treatment plants.

Using more than 130 clinical samples from patients, the Fraunhofer ITEM researchers test which phages are most effective against the *Pseudomonas* bacteria. "There is no broad-spectrum phage that covers all *Pseudomonas* strains," explains Holger Ziehr. "So we created a cocktail of three different phages." ►

Phage therapy was a success as far back as 1919 – then it was forgotten again.

CO₂

How do my eating habits affect the environment and climate? Fraunhofer ISE has organized campaign weeks during which employees who eat in its cafeteria each day are given answers to this question through food labeling, identification of ingredients' origins and the CO₂ footprint of their meals.

Ready for a

Use these pages of Fraunhofer Magazine to note down your own thoughts about sustainable development.

A large rectangular area with a light green background and a repeating pattern of wavy, overlapping lines. This area is divided into 15 horizontal sections by thin, dark green lines, serving as a template for handwritten notes.

A vertical column on the left side of the page, consisting of 15 horizontal lines, providing additional space for notes.

The phages can be filled into vials in a sterile filling unit directly on the Fraunhofer ITEM premises and then shipped. © Fraunhofer ITEM



► The phages are manufactured on the second floor of the institute. This is the realm of Dr. Sarah Wienecke, who is responsible for phage production. When she starts a new batch, she places a flexible disposable plastic container on a heated shaking table, fills it with ten liters of clear nutrient solution and adds *Pseudomonas* bacteria from a safe production strain. The gentle rocking and pleasant warmth cause the bacteria to grow. When the nutrient solution has reached a certain turbidity due to the bacterial growth, Sarah Wienecke puts the phages in.

After just a few hours, the turbidity disappears and the nutrient solution becomes clear again. The phages have done an excellent job. They infected the bacteria, then replicated inside them and caused them to burst. Now the entire nutrient solution is full of phages. The biotechnologist then filters out the coarse components and uses other standard biotechnology methods to wash the phages. To produce the phages as investigational drugs, there are already clean rooms at Fraunhofer ITEM equipped with appropriate facilities that allow for production in compliance with stringent regulatory requirements.

Clinical studies begin in 2021

At Fraunhofer ITEM's headquarters in Hannover, Dr. Sabine Wronski then uses the phages to develop an aerosol that cystic fibrosis patients can inhale. Additional preclinical testing is underway at Berlin's Charité hospital, where the phages are tested on living lung tissue samples taken from portions of human lungs, for example following a tumor operation. Berlin is also where the first clinical studies are set to take place in 2021, at the Charité Research Organisation – initially on healthy study participants, then on patients.

The Phage4Cure team is also charting new regulatory territory, working closely with the German Federal Institute for Drugs and Medical Devices (BfArM) in the approval process. After all, there are as yet no specific rules for therapeutics that, like phages, can self-replicate. The process is guided by the requirements for biologic drugs, such as therapeutic antibodies. The quality parameters developed in this project can then serve as a template for approving additional phage therapeutics for clinical trials.

Phage therapy as a covered benefit?

The PhagoFlow project, which involves treating wounds infected with antibiotic-resistant germs, demonstrates just how important phage therapy has become. The project is funded by the Federal Joint Committee (G-BA), the body that makes legally binding decisions as to which benefits anyone insured under Germany's statutory health insurance scheme is entitled to. "Prof. Josef Hecken, Chairman of the Federal Joint Committee, personally advocated for PhagoFlow," says Holger Ziehr. The project is expected to provide indications as to whether and how phage therapy could be included in the service catalog of the statutory health insurance organizations.

Many patients with gunshot wounds that have not healed despite treatment with antibiotics are treated at the German Armed Forces hospital (BwK) in Berlin. For PhagoFlow, Fraunhofer ITEM is collaborating with the military doctors. Once again, the German Collection of Microorganisms and Cell Cultures is responsible for choosing suitable phages. Fraunhofer ITEM produces the phages on a large scale and provides them to the BwK pharmacy. The pharmacists then select the appropriate phages for each patient based on a microbiological analysis of their wound secretions. Treatment entails simply putting the phage cocktail into the non-healing wound – just as was done for the Red Army soldiers more than 70 years ago, except that the quality standards for the cocktail are different today.

The initial successes in these publicly funded projects have awakened industry interest, too. Fraunhofer ITEM has already signed and sealed the first major contract with a pharmaceutical company. Holger Ziehr is very pleased with the resulting momentum: "Phage therapy is on its way to patients in Germany – at last." ■

"Phage therapy is on its way to patients in Germany – at last!"

Prof. Holger Ziehr

Use these pages of
Fraunhofer Magazine
to note down your
own thoughts about
sustainable development.

Ready for a

A large rectangular area with a light gray background and a repeating pattern of thin, wavy lines. This area is divided into horizontal sections by thin, light gray lines, serving as a template for taking notes.



“For me, sustain-
ability means
being generous
with my respon-
sibility for the
future rather
than generously
squandering
resources.”
Hartmut Plaum,
Fraunhofer
UMSICHT

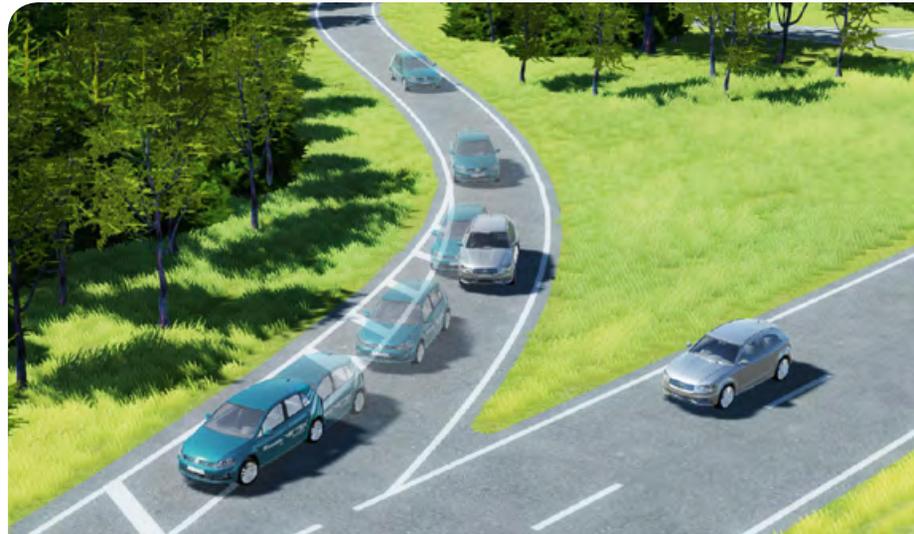
A vertical column of horizontal lines on the left side of the page, providing additional space for notes.

Putting safety to the test

Self-driving cars from Tesla, Waymo and Uber have already covered millions of kilometers. But there are still risks. Now Fraunhofer is offering new solutions in the race to create intelligent systems for autonomous driving.

By Eva Rathgeber

Driving scenario on the OCTANE simulation platform.
© Fraunhofer IOSB



According to a study by the Capgemini Research Institute, half of drivers say they would like to buy a self-driving car over the next five years – yet the study also revealed that almost two-thirds of drivers are unsure whether they can really trust them. Safety concerns are the biggest problem in autonomous driving – yet they might be the best opportunity German companies have to claw back the lead from high-tech companies in the U.S. and China. That’s because people all over the world associate German engineering with outstanding reliability. The Fraunhofer-Gesellschaft is currently working on a series of solutions aimed at improving the safety of self-driving cars.

The great race to complete the last 20 percent of this technological journey has only just begun, according to Professor Mario Trapp: “We may be lagging behind the U.S. and China in traditional AI, but Germany leads the way in making AI safe,” says the director of the Fraunhofer Institute for Cognitive Systems IKS in Munich, which was created just last December on the foundations of the former Fraunhofer ESK.

Automakers are determined to protect their vehicles against cyber attacks and ensure failsafe operation of onboard electronics through redundancy and other methods. But they also understand the critical importance of ensuring that autonomous vehicles do not cause accidents. Typical error rates accepted by industry for traditional vehicle systems is generally of the order 10^{-8} , which means only one critical error is permitted per 100 million operating hours. A standard car is driven for around 200 to 300 hours a

year, so it generally takes a long time for an error to occur. Autonomous vehicles are still a long way off reaching this level of reliability, however: “Today’s self-driving cars perform fantastically well in good weather and traffic conditions. But we still face huge challenges when it comes to translating these experiences to the real world of rain, storms, snow and difficult, unpredictable traffic situations,” says Trapp. Many experts therefore argue it will take until at least 2035 before the first fully autonomous cars are approved for general road use.

Another complication is the fact that the we expect far more from the AI of an intelligent car than we do from a human driver or other AI systems such as voice assistants. That’s understandable, because if a voice assistant fails to understand us several times in a row, it’s annoying – but if a car fails to correctly identify a cyclist, it could be deadly. There is even consensus that an autonomous vehicle’s AI should be safer than the average human driver by at least a factor of ten. Considering that 90 percent of all traffic accidents are caused by human error, this shows how much potential AI has to make our streets safer.

Five components of all-round safety

In the “Safe Intelligence” project, Fraunhofer IKS is working on ways of ensuring and validating the safety of AI in autonomous vehicles. Its software engineers are faced with the challenge of unifying two contradictory worlds: the creative design freedom of smart software development and the restrictive realm of safety. ▶

“Germany leads the way in making AI safe.”

Professor Mario Trapp

Use these pages of
Fraunhofer Magazine
to note down your
own thoughts about
sustainable development.

Ready for a

10 000
individuals have
been counted

Several initiatives
are underway to
protect insects.
Employees at
Fraunhofer
UMSICHT have
planted a meadow
with more than
35 species of
flowering plants
and grasses.
Fraunhofer HHI
and ICT are
home to aparies.
The roof of the
Fraunhofer Munich
headquarters is
a take-off and
landing pad for
bees – around

► Their starting point is to look at a safe system and ask how much AI it can realistically encompass. Three key aspects underpin their development work: First, no harm may come to humans. Second, a car stuck in the garage is no use to anyone – meaning that a car needs to work reliably while also being safe. And third, this all has to come at a reasonable cost.

“It’s easier to use AI for functions we can monitor, such as fixed routes taken by local public transport or specific situations such as freeway traffic or transporting goods by truck. But as soon as you introduce challenges such as detecting pedestrians, nobody can currently offer the reliability we need,” says Trapp. Scientists train artificial intelligence to recognize what people look like, but it’s difficult to fully understand what exactly the AI is learning. Attributes such as short or long skirts and trousers or yellow raincoats might play a role, but there are clearly all sorts of other yellow objects that don’t contain a person – and there are people the AI will simply fail to identify as such. Add factors such as obstacles that limit visibility, and things get even more complicated.

“Obviously you could design the system to be more cautious so that it always drives very slowly or even performs an emergency stop in those kinds of cases. But then it ends up being too cautious, so your safety figures are good but the reliability and cost are not where you want them to be,” says Trapp. To tackle these uncertainties, Fraunhofer IKS engineers have developed a safety architecture they call four-plus-one, which works on five different levels. The first level focuses on continuing to improve AI methods with the goal of teaching the AI to understand what it knows and what it doesn’t – in other words to correctly assess its level of uncertainty. “You can’t rely on the current confidence

values of the AI – it generally rates itself far too highly,” says Maximilian Henne, a research fellow at Fraunhofer IKS.

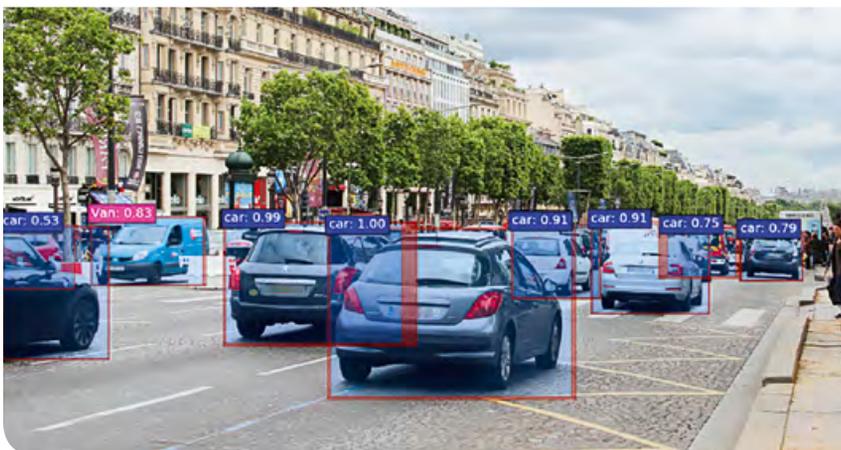
One of these methods is known as out-of-distribution detection. This involves teaching the AI to identify new examples that are conceptually very different from the training data and to use specific methods to quantify the degree of deviation. The second level focuses on observing AI software as a “black box” and carrying out specialist error analyses. The third component is adaptive safety management. This involves improving the AI’s ability not only to assess the current safety risk but also to adapt itself to this risk so that it can achieve the best possible results without endangering safety. The fourth component – continuous safety management – is about learning systematically from field trials, not only to improve the product rapidly, but also to systematically expand the knowledge required to make cognitive systems more reliable and thus to improve safety processes.

“AI generally rates itself far too highly. You can’t rely on the current confidence values.”

Maximilian Henne

Proof of safety through virtual testing

To prove that their self-driving cars are ready for market, U.S. companies in particular – such as Waymo, Tesla and Uber – have already tested their vehicles over millions of kilometers of American roads. According to unanimous expert opinion, however, this high number of worldwide test drives is nowhere near sufficient to guarantee the safety of autonomous vehicles. What’s more, test drives are both time-consuming and logistically complex; even small adjustments to the parameters can have hard-to-predict consequences in complex systems, making new test drives necessary. Various Fraunhofer Institutes are therefore working on methods of furnishing proof of safety on the basis of virtual simulations. ►



Using a neural network to identify and classify other road users. © Fraunhofer IKS

27%

“Does your day-to-day work contribute to sustainable development?” “Often” was the answer given by 20 percent of polled Fraunhofer staff. Four percent responded with “always.” Fraunhofer staff are working towards sustainability day in and day out – in numbers

Ready for a

Use these pages of Fraunhofer Magazine to note down your own thoughts about sustainable development.

Large area with horizontal lines for writing notes.

Vertical lines on the left side for writing notes.

► For example, researchers from the Fraunhofer Institute for Transportation and Infrastructure Systems IVI are working with project partners from TU Dresden and companies in Saxony on the SePIA project, which aims to develop a complex validation platform for highly automated driving with a focus on electronic subsystems and the overall vehicle. This will be achieved by using real-life driving scenarios with extensive accident data and information from police accident reconstruction reports, as well as vehicle data and video recordings. "In 2019, there were more than 2.7 million traffic accidents in Germany. The most serious ones tended to involve cyclists, pedestrians and motorized two-wheelers such as motorbikes and mopeds," says Dr. Christian Erbsmehl, group manager of Vehicle and Road Safety at Fraunhofer IVI in Dresden. "Our approach allows us to create virtual reproductions of real-life accident situations and test the ability of different vehicle safety systems – either in isolation or in combination – to execute the collision at a lower speed or avoid the accident altogether," he adds. To assess these systems, the scientists use a virtual simulation based on a catalogue of scenarios. They also use a sample hardware/software application environment to test and validate the developed platform.

The Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB has also spent several years collaborating with industrial companies to conduct research in areas ranging from driver assistance to fully automated driving. "Our common goal is to reach a point where we can make a definitive statement on the level of safety," says Miriam Ruf, who heads up the automotive research group at Fraunhofer IOSB. She sees particular difficulty in the fact that the vehicle environment is dynamic and constantly subject to new conditions, from a new brand of electric scooter to a new paint scheme or a new raincoat collection. "And we also can't be sure how people will behave in the future as we see more and more vehicles controlled by AI," Ruf adds. The AI software used in autonomous vehicles must therefore be designed in such a way that it can continue to develop and adapt to a constant stream of new situations once it is on the road.

Fraunhofer IOSB has two test vehicles which its researchers are teaching to drive autonomously. Since 2018, companies have been able to test their autonomous vehicles in real-life traffic situations at the Testfeld Autonomes Fahren Baden-Württemberg in Karlsruhe, a test site for autonomous driving. The Fraunhofer IOSB is responsible for anonymizing the sensor data and also acts as a contact point for businesses and members of the public. One of their latest projects is the OCTANE simulation platform, which is currently being developed through cross-institute collaboration. The platform allows users to simulate and test critical driving situations in a virtual environment and execute them faster or slower than real time. What makes the OCTANE concept so special, says Ruf, is the idea of creating an open source platform with simulation models that can be individu-

ally tailored to the needs of each user in terms of computing time, usability and the quality of the results.

Unsupervised driving is possible – but only in certain situations

There is still no official definition of the safety criteria for autonomous driving, even though this is a necessary condition for approving the sale of autonomous vehicles. "From our perspective, the worst-case scenario would be the IT giants setting the standards," says Trapp. "We're all familiar with their method of launching new software and then gradually finding errors that they rectify on a step-by-step basis. But that approach is no good for cars. This is an area where legislators need to be laying down the law."

Many automakers see their biggest business opportunity at level 5 of autonomous driving, in other words full automation. So far, however, the industry has only reached levels 2 to 3, with approval only granted for partially or highly automated vehicles in which drivers continue to supervise the autonomous system and/or perform certain driving functions themselves.

Experts therefore consider that the most likely first steps will be to use our existing experience to build even better assistance systems and gradually introduce more and more automation into vehicles. Many other areas in which AI is used, such as medicine, are still very much under the control of humans. But in the case of self-driving cars, experts are aware that, in the event of an emergency, people would be unable to simply take over steering within seconds because they would struggle to grasp the context after such a long break from driving.

AI-based fully autonomous driving can already be achieved in certain specialist driving situations and carefully chosen cases, says Professor Trapp: "In contexts that involve limited functionalities, the error rates are already where we need them to be." ■

Display screen in one of the VERTEX test vehicles run by Fraunhofer IOSB: For as long as humans have to continue supervising automated driving, clear human-machine communication will continue to be a safety-relevant system function. © Fraunhofer IOSB



Germany reported 2.7 million traffic accidents in 2019: "Our approach allows us to create virtual simulations of real-life accident situations."

Dr. Christian Erbsmehl

تحت التجهيز

Ready for a

Use these pages of Fraunhofer Magazine
to note down your own thoughts about
sustainable development.

Fraunhofer magazine

100%

- Recycled paper
- Carbon-neutral
- From responsibly managed sources