

# Fraunhofer

magazine

4/19

## Leaps and bounds in quantum technologies



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# Let us shape the future!



Prof. Reimund Neugebauer  
© Fraunhofer/Bernhard Huber

What does the future hold in store for us? This question is on many minds in the weeks bracketing the turn of the year. But let's not gaze into crystal balls here. We do not wish to predict the future. We want to shape it.

**This issue of Fraunhofer magazine** ushers readers into 2020 with a 22-page section devoted to a "future machine" – that is, a machine with the potential to transform our future. The Fraunhofer-Gesellschaft and IBM are bringing the first quantum computer to Germany – an open research platform accessible to companies of every size. Slated to go online in 2021 and to be operated by a consortium of seven Fraunhofer Institutes led by Prof. Manfred Hauswirth, it will be the launch pad for unimagined possibilities in application-oriented quantum computing research in the EU. Combined with another tomorrow technology, artificial intelligence, this "future machine" is bound to bring great leaps in performance.

Quantum systems can calculate in parallel to reckon with a vast number of possibilities simultaneously. This ability sets them apart from conventional digital computers. A system that can allow for so many possibilities at the same time is far better equipped to learn, and to grasp and chart the most complex connections and relationships with extreme efficiency. Hence, the combination of quantum computing and artificial intelligence will be nothing less than a key future technology that will maintain our competitiveness in international high-tech markets.

I am aware of the naysaying. As the story goes, Europe has been left behind. China is said to have already invested over ten billion euros in quantum research. This has yielded the first quantum satellite, the inceptive prototype of a communication link secured with quantum cryptography. Be that as it may, it was European quantum pioneers who set the stage with their research, providing a platform for China to build on. In an interview on page 30 of this magazine, Prof.

Andreas Tünnermann states with confidence, "Germany is at a very good vantage point." And I can promise that Fraunhofer is stepping up to shoulder its share of the responsibility. This is yet another change that we are going to shape in a positive way with the first quantum computer. It is not too late for us Europeans to rise to this challenge. Quantum communication will surely help us assert our fundamental right to the security and sovereignty of our data.

We can look forward to people soon experiencing the advances brought to us by quantum technologies, particularly in medicine. And we will soon see quantum sensor and quantum imaging applications making their way to the market.

**So, what does the future hold in store for us?** Allow me this occasion to offer my clear answer: The future holds boundless possibilities in store for us. I look forward to seizing them with you in 2020.

Yours sincerely,

Reimund Neugebauer  
President of the Fraunhofer-Gesellschaft

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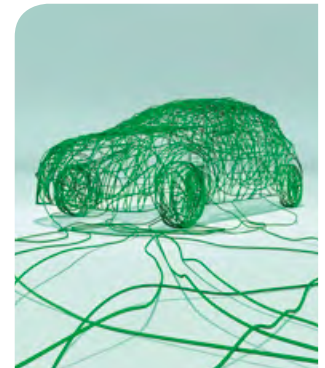


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**Cement factories account for almost eight percent of global CO<sub>2</sub> emissions.** If the cement industry was a nation state, it would come third behind China and the United States as an emitter of greenhouse gases. By comparison: Germany contributes 2.2 percent to global CO<sub>2</sub> emissions.

**8%**

# Navigating the human body with AI in the driver's seat



A surgeon threads the catheter from an incision in the groin all the way to the brain. © Fraunhofer IPA



Each year, some  
**270,000**  
people suffer a stroke  
in Germany.

Doctors often perform a thrombectomy to treat stroke, inserting a thin catheter through a vascular incision in the groin, and then threading it through the aorta all the way up to the blocked blood vessel in the brain. A tiny basket-like mesh called a stent retriever opens like a net at the point of occlusion to ensnare the clot. Then the surgeon reels in the catheter, hauling out the clot caught in the net – 45 minutes to three-and-a-half hours later, depending on the surgeon's aptitude and experience. A thrombectomy is clearly a skill acquired with long training and much practice. Merely maneuvering the catheter through the body to the blood clot takes 10 to 90 minutes of concentrated effort.

The Fraunhofer team aims to speed things up with a computer-controlled catheter. "The physician will still perform the actual procedure to remove the blood clot with a stent retriever, but a self-navigating catheter is going to take over the complicated task of steering past all those hard-to-traverse anatomies," says Johannes Horsch, a research fellow in the Project Group for Automation in Medicine and

When stroke strikes, every minute matters. A surgeon wielding a catheter has to act quickly to clear clots obstructing major blood vessels. Any delay puts patients at risk of serious brain damage. But few specialists are qualified to perform this tricky procedure. Seeking a speedy yet reliable way of steering catheters to clots, Fraunhofer researchers have struck upon a smart solution – artificial intelligence.

Biotechnology PAMB at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA. This automated intervention with a catheter is not only a viable option for strokes. It can also serve in endovascular surgery for heart attacks or liver tumors.

**These navigation skills are also acquired** via deep reinforcement learning (DRL), a method scientists apply to train neural networks. It is similar to the way humans learn – by experience. An algorithm generates the data to train the neural network independently, by practicing this procedure over and over again on a computer model. It rehearses with a simulated vascular tree and catheter to gain virtual experience.

"This virtual model allows us to simulate every movement the catheter could possibly make and train the neural network up to a certain level. "In the tests so far, we've achieved a 95 percent success rate with the simulation model – in this simplified scenario, the catheter was indeed able to navigate autonomously to the vascular occlusion," says Horsch.



## Dispelling fears to save lives

Time is of the essence for victims of a sudden cardiac arrest. But few people feel confident enough to administer chest compressions. The new Rescue Aid resuscitation mat is here to overcome that reluctance.

Every minute counts in the event of acute circulatory arrest. "People are afraid of making a mistake, so they do nothing or administer the chest compressions too timidly," says Dr. Holger Böse, scientific and technical manager of the Fraunhofer Institute for Silicate Research ISC's Smart Materials Center in Würzburg. "A proper cardiac massage can significantly improve the survival rate. And Rescue Aid makes resuscitation that much easier," says Böse. The mat helps would-be rescuers get over their inhibitions and fears by taking physical contact out of the equation. Developed by students at the University of Applied Sciences in Munich, the silicone mat took shape in the course of a Fraunhofer science-plus-design competition called Form Follows Future.

It is easy to use: The rescuer places the resuscitation mat on the victim's upper body. A star-shaped array of deformation sensors integrated in the mat gauges the applied force. Connected by wires to electronic components and LEDs in a box on top of the mat, the sensors convey pressure levels via color-coded lights. A green light tells rescuers they are applying the right amount of force; a red light means they are pumping too hard. With this LED chain, rescuers can keep an eye on pressure levels and adjust their compression force accordingly. An audio signal marks time, setting the rhythm for chest compressions. This tone generator is also housed in the electronics box.

The lights tell rescuers if they are applying enough force.  
© Fraunhofer ISC

Böse and his team established Rescue Aid's merits in tests with a CPR dummy. Available now as a demonstrator, the mat is to be optimized and adapted to fit people large and small.

The sensors are made of a soft foil to rule out injuries. This is a major improvement over the few competing products on the market. Their rigid sensors can be a real pain in the palm of the rescuer's bottom hand. Equipped with affordable technology and streamlined electronics, this resuscitation mat can be manufactured at remarkably low cost. "We can certainly see Rescue Aid becoming a fixture in first aid kits," says Böse.



## Eco-friendlier and more efficient

A new ceramic heat shield reduces aircraft fuel consumption and pollutant emissions. The Fraunhofer Institute for Material and Beam Technology IWS in Dresden developed the process for coating aircraft turbines.

Engineers Dr. Maria Barbosa and Dr. Laura Toma succeeded in applying an extremely thin layer of ceramic shielding – it measures around one fifth of a millimeter. They accomplished this remarkable feat with an innovative suspension spraying process. An aircraft turbine coated with this material can operate at temperatures that are up to 150 degrees higher than usual. That makes this turbine more efficient, durable and able to run with less cooling. "The improved engines burn fuel more efficiently and emit fewer pollutants, so they are eco-friendlier," says Dr. Barbosa.



Dot your i's, cross those t's: A pen could take the struggle out of learning to spell. © Stocksy/Flonline

## A smarter sort of pen pal

A pen that catches spelling mistakes on the fly? That would surely top many a young student's wish-list. Researchers at the Fraunhofer Institute for Integrated Circuits IIS in Erlangen, Germany, are determined to make that wish come true.

Equipped with sensors, this prospective smart pen will do more than merely correct spelling mistakes. "The idea is for the pen to be an intelligent tool that also helps children improve handwriting automaticity and penmanship on their own," says Julia Knopf, professor of German Primary Education at Saarland University. She is taking part in this joint project with industry partners.

**The principle sounds simple enough:** The sensors track the writing as the author puts pen to paper, and then sends it to a tablet in real time for assessment. Putting it into practice is not quite that simple, however: "An important part of the study deals with the question of when and by which methods the feedback on spelling should be given and what the didactic exercise scenario looks like," says Knopf. Once the concepts for these handwriting exercises have been developed, they will be tested at various schools, probably starting in 2022.

## Goodbye, greasy smudges

Pristine stainless steel door handles, fittings and refrigerators sure look sleek. But a human touch or two is all it takes to go from snazzy to grubby. Fingers and palms leave greasy smudges that are hard to clean. A new nano enamel developed by researchers at the Fraunhofer Institute for Microstructures of Materials and Systems IMWS promises to put an end to those unsightly blemishes.



The new coating shrugs off grease and water. © iStock

**This innovative nano enamel** is water- and oil-repellent. It contains special particles that adhere to stainless steel to roughen and enlarge its surface. A fingertip or hand touching a refrigerator door coated with this paint only brushes up against the peaks of this raised surface. Skin oils do not penetrate to its valleys, so those little dabs here and there are hardly noticeable.

"How big are the individual particles in the various paint systems? Are they distributed uniformly? What effect do additives have? – that's what we're looking into," says Dr. Jessica Klehm, a research fellow at Fraunhofer IMWS. This analysis is the only way of assessing the coating's quality. If the nanoparticles aggregate to form larger particles, the transparent coating could become opaque. On the other hand, if the particles are too small and the surface too smooth, the oily film could stick to it across a larger area, defeating the coating's purpose.

The researchers have already found a front-runner among the investigated options. The production of this coating system is to be ramped up to industrial scale next year.

### Editorial notes

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



**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:**  
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**Layout & lithography:** Vierthaler & Braun  
**Cover image:** Sven Döring on behalf of Fraunhofer

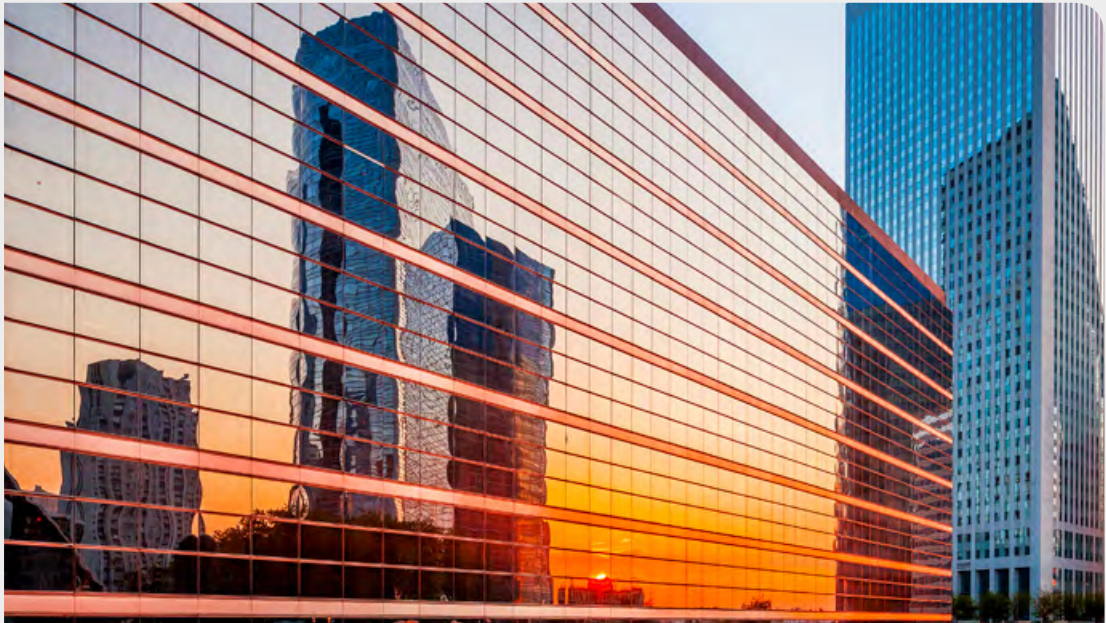
**Printed by:** H. HEENEMANN GmbH, Berlin  
**Translation:** Burton, Van Iersel & Whitney

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Munich 2019





Roller blinds could also be coated with the new solar cells. © Alessandro Saffo/MATO



## A cloth cut for power

A truck tarp that generates electricity? That could come to pass with a new breed of textile-based solar cells. And when it does, refrigerated trucks could produce the electricity needed to power on-board generators. Even roller blinds could be transformed into solar collectors.

“We can apply pliable solar cells directly to technical textiles with various coating processes,” says Dr. Lars Rebenklau, group manager for system integration at the Fraunhofer Institute for Ceramic Technologies and Systems IKTS. These scientists have found a way to use textiles for the substrate in place of the glass or silicon in conventional solar modules. “That may sound simple, but it’s not. The textile industry’s machines are huge – they make fabrics that are five or six meters wide and a thousand meters long,” adds Dr. Jonas Sundqvist, group manager for thin-film technologies. What’s more, these textiles have to withstand temperatures of around 200 degrees Celsius during the coating process. And the solar cells have to live up to lofty expectations for fire safety, stability and affordability. “That’s why we opted for a glass-fiber fabric that meets all these requirements,” says Rebenklau.

**Another challenge** was how to get the layers that make up a solar cell – the bottom electrode, the photovoltaic layer and the top electrode – to bond with the fabric. The fabric’s surface is a veritable mountain range compared to these wafer-thin layers, which are just one to ten micrometers thick. The researchers had to iron

out these towering peaks and deep gorges. A levelling layer applied to the surface of the textile did the trick.

They designed all production processes from the bottom up with practicality in mind – that is, for easy integration into standard textile industry production lines. Their solution for applying layers is a case in point: the roll-to-roll method, a common industry practice, serves to apply the two electrodes made of electrically conductive polyester and the photovoltaic layer. The solar cells are also laminated with an additional protective layer to make them more robust.

“We produced an initial prototype to demonstrate that our textile-based solar cell works,” says Rebenklau. “Its efficiency rating ranges between 0.1 and 0.3 percent as it stands.” He and his fellow engineers are now pursuing a follow-up project to push its efficiency beyond five percent, the tipping point for this textile-based solar cell’s commercial viability. Silicon cells with ratings ranging from 10 to 20 percent are far more efficient. However, this new type of cell is intended to be a smart add-on that augments rather than competes with conventional cells.

Fabrics have to withstand **200°** during the coating process.



The weird, wonderful quantum world

# The future is now





# Quanta can assume different states



Dr. Erik Beckert from the Fraunhofer  
Institute for Applied Optics and Precision  
Engineering IOF holding an entangled  
photon source. © *Sven Döring*





■ ■ ■

at the  
same  
time.

That is not  
all they have ■ ■ ■

Marta Gilaberte Basset is working  
on new technologies for applied  
quantum imaging. © Sven Döring













■ ■ ■ in common with those  
multitasking quantum  
engineers at  
Fraunhofer.

Prof. Andreas Tünnermann, director of Fraunhofer IOF, is one of the leading lights in the field of applied quantum technology. © Sven Döring





# Welcome to the world of quanta,

where nothing seems logical, but everything

appears possible. A new era is dawning

with quantum technologies helping us

to better understand and order our world.

Fraunhofer is bringing science to applications.

By Mandy Bartel

# When will the quantum computer arrive?

Three questions for Prof. Manfred Hauswirth, Fraunhofer FOKUS, on the quantum computer initiative with IBM

Quantum mechanics is slippery, defying intuitive grasp. Albert Einstein called it “spooky.” He was born in 1879. Yet here it is in the here and now, a ghost knocking at the door of everyday reality. In a rare consensus, experts agree that quantum technology is poised to change the world. Take the field of medicine: Quantum sensors could shed new light on brain functions. Quantum imaging could revolutionize diagnostic procedures. Quantum computers could yield new insights into molecular chemistry to fast-track drug discovery and slash their production costs.

The mind boggles at the potential of applied quantum mechanics. Who knows where this technology will take us? Will we be able to better protect the climate with the means to measure and predict climate change far more accurately? What marvelous products might emerge once we are able

to develop and test materials faster and at lower cost? Will gridlocks be but a bygone annoyance once quantum computers send every traveler down the best path? And will quantum technology help create a secure and sovereign digital infrastructure for business and private citizens?

Expectations are high; investments are soaring. The German federal government has earmarked 650 million euros for research into quantum technologies until 2021. And the EU’s Quantum Flagship initiative has a budget of one billion euros for European research over the coming ten years. Fraunhofer and IBM will be bringing the world’s first commercial quantum computer to Europe to serve as an open research platform. They aim to ramp it up in Germany by late 2021. Prof. Reimund Neugebauer, president of the Fraunhofer-Gesellschaft, expects it to give a “decisive boost for German research and companies of all sizes” with “full data sovereignty based on European law.”

Europe has taken up the quantum computing challenge. China, meanwhile, is said to have already invested over ten billion U.S. dollars in quantum development. This has yielded the world’s first quantum satellite, launched in 2016 to distribute quantum keys in space. It was designed by a doctoral student who learned his trade with one of Europe’s quantum pioneers, Prof. Anton Zeilinger, group leader at the Institute for Quantum Optics and Quantum Information in Vienna and president of the Austrian Academy of Sciences. In 2017, China also completed a prototype for a 2000-kilometer, quantum-encrypted communication link between Beijing and Shanghai.

## 1 What is this project all about?

In partnership with IBM, we are going to install Europe’s first commercial quantum computer at a location in Germany. The aim is to develop applied quantum computing solutions for a range of fields and assess their viability. We would like to see companies of all sizes involved in this project.

## 2 Why does this matter?

It is early days yet for applied research in quantum computing. We need to define quantum algorithms and then convert them for easy use in applications programming. That requires expertise on the part of industry, so we want to fast-track efforts to build a knowledge base here in Germany. This initiative will also enable us to pursue quantum computing under full data sovereignty according to European law, without being dependent on large Internet corporations from overseas.

## 3 When do you expect to see the first results?

A quantum computer is to be installed in Germany in 2021. But even optimistic forecasts suggest it’s going to take another 10 to 20 years before businesses can use quantum computers.



“For the rest of my life, I will reflect on what light is,”

said Albert Einstein, who had his doubts about quantum theory.



# Five

sectors destined to be changed by quantum technology

1  
Medicine and health-care  
Deeper insights into biological processes, more efficient drug discovery, more powerful diagnostics

► Is Europe fated to yet again bring up the rear? No, says Prof. Manfred Hauswirth, executive director of the Fraunhofer Institute for Open Communication Systems FOKUS, located in Berlin, Germany. He is sanguine about Europe's chances: "In Germany and Europe, we not only have the necessary expertise in the processes of quantum physics; we also have an in-depth understanding of the potential applications. And we understand all the major production and industry processes. That's what counts right now, with research focusing on potential applications of quantum technology. We're still very much at the start of developing genuinely practical uses."

## Quantum computing looms large on the horizon

Yet progress has been promising so far, with headlines of recent months dominated by a story that first broke at the end of September 2019. Google reportedly used a 53-qubit quantum computer to perform a random sampling calculation in just over three minutes, thereby achieving the grail of "quantum supremacy." As the story goes, the world's most powerful supercomputer would have required 10,000 or so years for the same operation. IBM was quick to question the science behind Google's assertion, insisting that the conventional supercomputer's potential is far from exhausted.

## Welcome to the quantum world

Quantum physics is not something most of us encounter in our daily lives. Everything we can experience first hand – the big stuff of our macroscopic world – obeys the laws of conventional physics. Sub-atomic particles defy these familiar principles. The laws of quantum physics rule on the atomic scale, where strange things happen. This is a world where elementary particles, atoms or even molecules can behave like particles or like waves. They can even exist in several states at once. Two particles can become entangled, so that one always possesses the complementary information on its twin, irrespective of the latter's location. This uncertainty about a particle's actual state goes to the heart of quantum physics. Rather than being in one state or changing between a variety of states, particles exist across several possible states at the same time in what is called a superposition. Nothing is fixed and anything is possible, so we are dealing with probabilities here – or, more precisely, with probability waves. We cannot know the exact position or state of a particle until we observe or measure it, which destroys the quantum state.

1900

**The dawn of quantum physics**  
Max Planck postulates quantum theory: light consists of tiny, discrete packets of energy known as quanta

1913

Niels Bohr first formulates a quantized model of the atom

1915

Albert Einstein postulates the theory of general relativity and posits the existence of **photons as particles**

1924

Louis-Victor de Broglie postulates **wave-particle duality**

It would take IBM's supercomputer just two-and-a-half days – rather than the purported 10,000 years – to solve the problem. What's more, IBM argued, the problem lacked practical relevance. As this spat between two rivals shows, there is much more at stake here than an argument over numbers.

This is not just about prestige. Analysts at Morgan Stanley predict that the market for high-end quantum computers will reach 10 billion dollars by 2025, double what it is now. The circle of quantum computer manufacturers is growing steadily. Alongside IBM and Google, there is also Microsoft, the Chinese Internet giant Alibaba and startups such as Novarion, Rigetti and D-Wave. Yet the various manufacturers rely on different physical principles for the realization of the quantum hardware. Scientists distinguish between universal quantum computers, which can perform arbitrary quantum algorithms, and quantum annealers, which are less complex, but limited to very specific tasks.

Researchers at VW have been using a D-Wave quantum annealer since 2017 to better simulate traffic flows. And BMW is investigating whether quantum annealers can help optimize its production robots' performance.

**Universal quantum computers are technically very challenging to build and operate.** What sets these computers apart is that their performance doubles in power with each added qubit, thereby increasing in exponential rather than in linear fashion. In other words, two qubits yields four possible combinations, three qubits eight, and so on. The quantity of qubits matters, but equally important is the quality of qubit entanglement and its coherence time. The latter determines how long the quantum system remains stable enough to compute before noise masks the information. Most universal quantum computers, such as Google's 72-qubit Bristlecone, only work under special laboratory conditions. ▶

$$i\hbar \frac{\partial}{\partial t} |\psi(t)\rangle = \hat{H} |\psi(t)\rangle$$

1925

Erwin Schrödinger describes matter waves as probability waves and postulates the **Schrödinger equation**, one of the fundamental equations of quantum mechanics

1935

The thought experiment **Schrödinger's cat**

1938

Otto Hahn discovers **nuclear fission**; the first atomic bomb soon follows

1927

Werner Heisenberg formulates the **uncertainty principle**: the position and momentum of an electron cannot be determined simultaneously

1950s

Scientists put macroscopic quantum systems to practical use, ushering in **the first quantum revolution**

1953

European countries establish **CERN** (*Conseil Européen pour la Recherche Nucléaire*) to investigate subatomic particles

1954

The first **microwave oven**



# 2

**Logistics and transportation**  
Optimized route planning, better-informed decisions about where to locate logistics centers, better power grid management

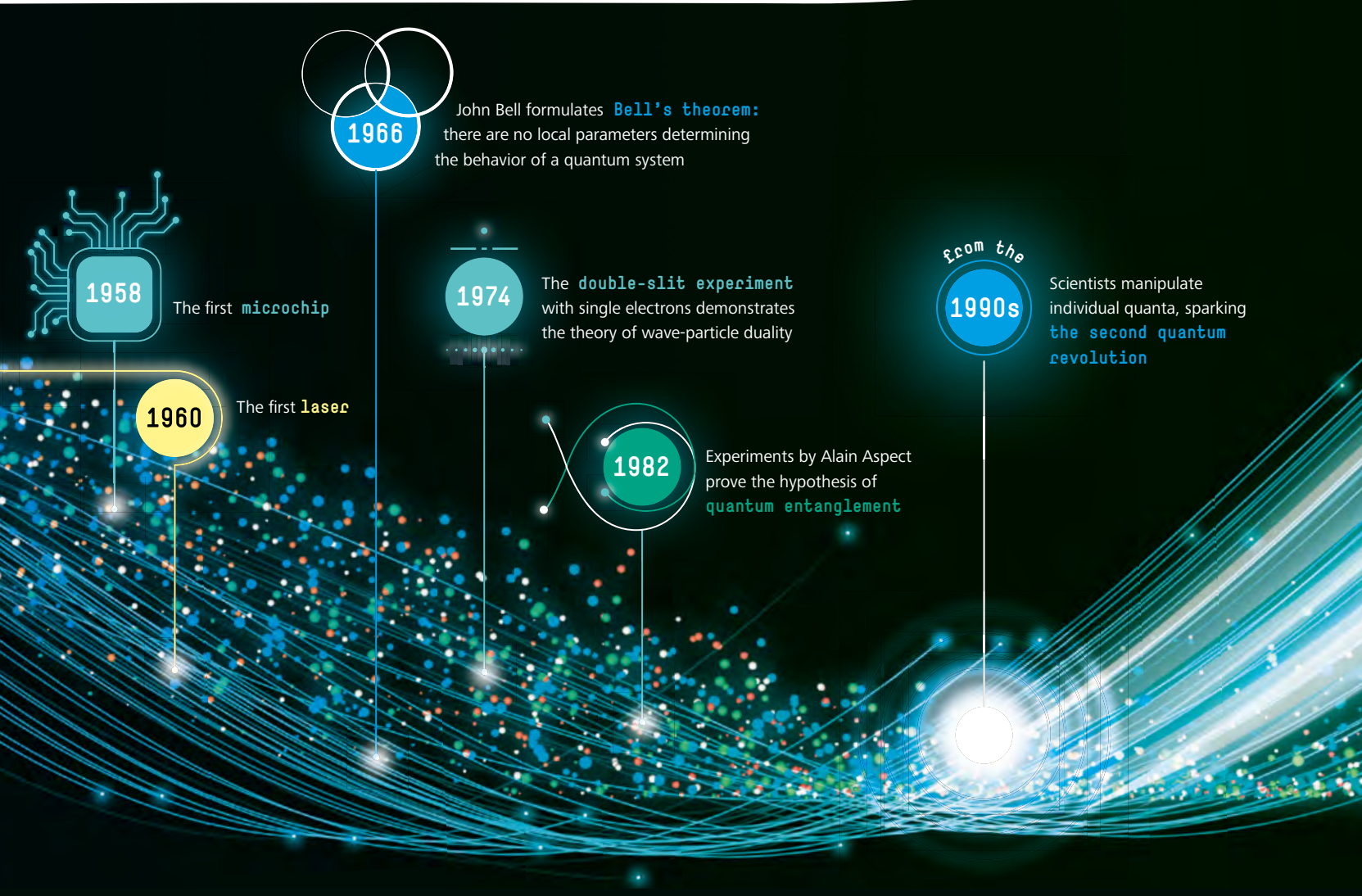
► In January 2019, IBM unveiled the IBM Q System One, the world's first commercially viable quantum computer – meaning that it works outside a lab. A consortium of seven Fraunhofer Institutes in Germany has been tasked to look into real-world applications for quantum computing as of 2021 in a bid to drive the advance of applied quantum science in the EU. “We want to find out just what kind of applications there are for quantum computing in industry and how to write the necessary algorithms and translate them for specific applications,” explains Hauswirth. The initiative also aims to keep entry barriers low by sharing insights with companies to fast-track the industry's efforts to build a knowledge base in quantum computing.

There are still high hurdles to clear on the path to upscale the performance of available quantum computers. The priority now is to find ways of shielding the fragile quanta

from ambient influences that interfere with the computing process. For example, qubits have to be cooled to a temperature approaching absolute zero – around minus 273 degrees Celsius, which is colder than outer space. They also require a vacuum and have to be shielded against electromagnetic radiation. Vibrations and parasitic effects of electromagnetic waves used to manipulate the qubits and read out the information they carry can also cause problems.

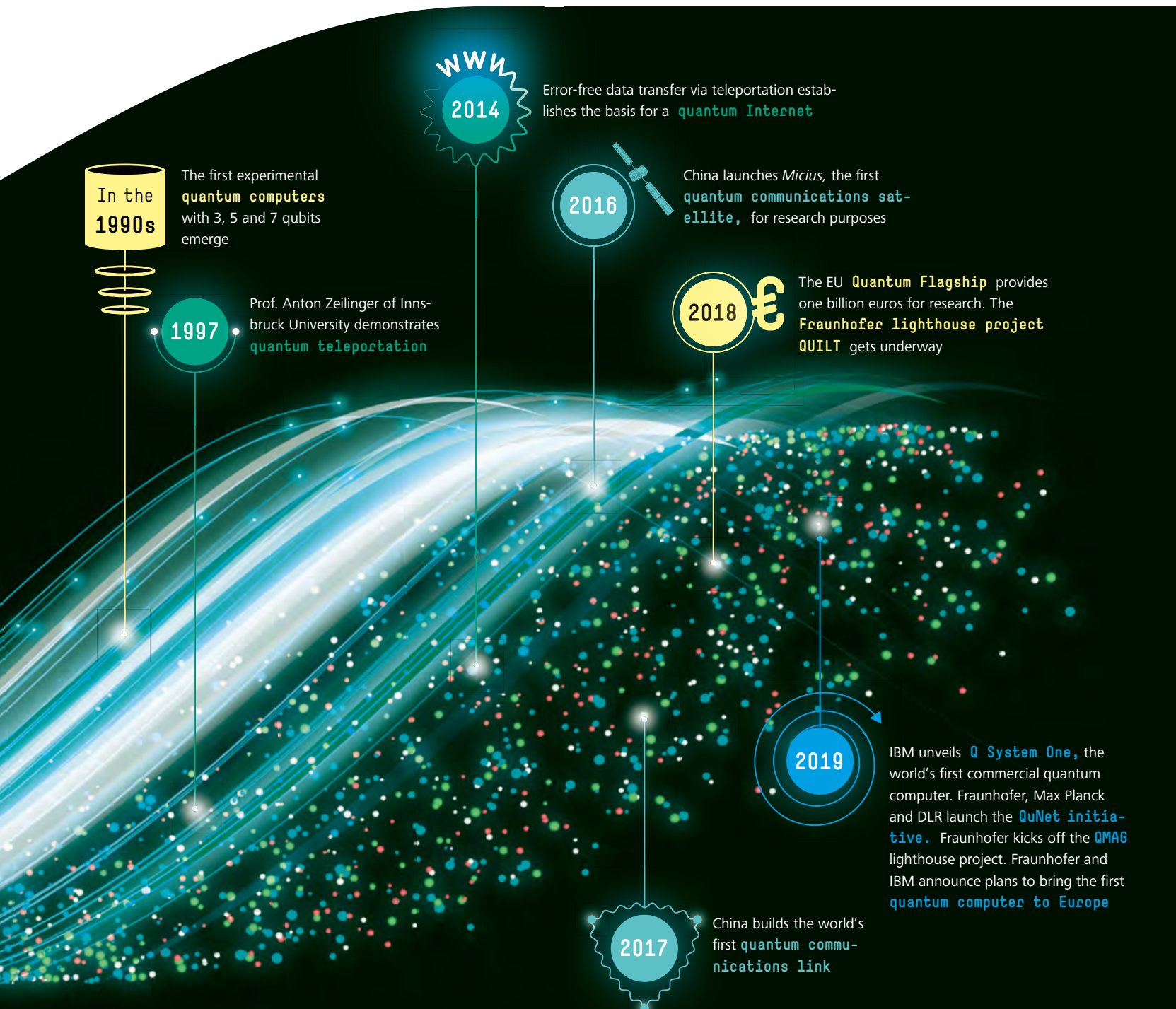
## Solving complex problems

What kind of real problems can quantum computers solve? “In a few years from now, quantum computers will provide highly efficient means for prime factorization. That will leave current cryptographic systems vulnerable, which is why major research into post-quantum cryptography is underway,” says Hauswirth. Quantum computers will be able to tackle even



more complex problems a few years down the road: "Today's financial technology, for example, has trouble managing billions of cash flows in parallel and in real time within the confines of a very tight regulatory girdle. Sequential processing is still prone to errors, but quantum computers would help get around this."

Prof. Anita Schöbel is director of the Fraunhofer Institute for Industrial Mathematics ITWM in Kaiserslautern. She and Hauswirth are mainly responsible for quantum computing at Fraunhofer. Pointing to an application in the works at her institute, she says, "We're working on projects that use stochastic partial differential equations such as the ▶



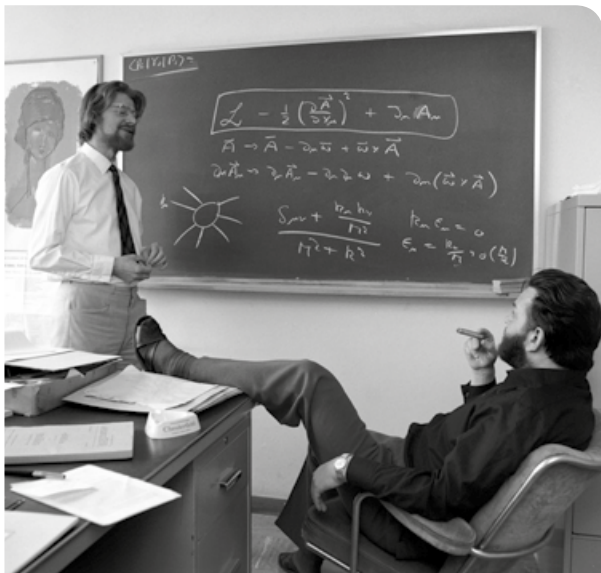


► Fokker-Planck equations. These serve to develop lithium ion batteries and wind turbines, calculate granular flows and determine prices in quantitative finance. These equations can be converted into quantum mechanics equations for quantum computers to crunch the numbers, probably much faster.”

### The race to develop quantum AI

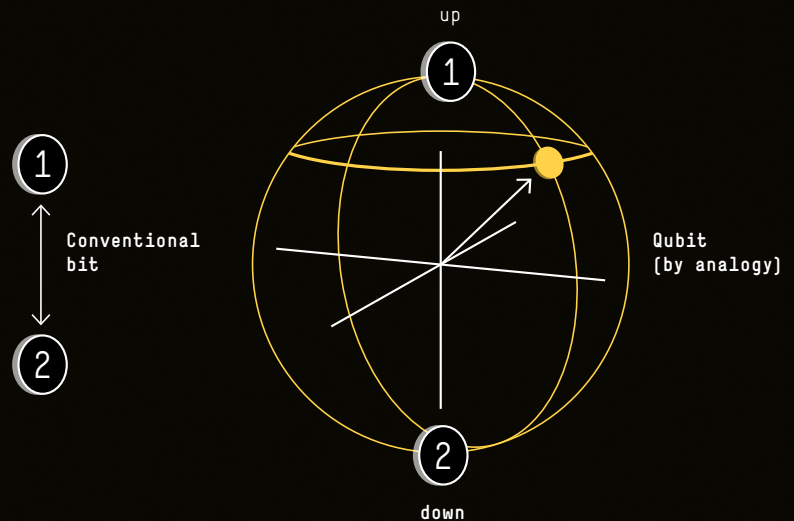
Quantum computing is expected to be the springboard for a huge leap forward in artificial intelligence (AI). A new interdisciplinary research field called quantum machine learning (QML) has emerged at the intersection of these two key technologies. Explaining how the two are connected, Prof. Christian Bauckhage from the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS in Sankt Augustin says, “From a mathematical perspective, a lot of AI problems are really problems of combinatorial optimization, which serves to do things like calculate the best delivery routes. If these problems are highly complex with lots of variables, it is very difficult, if not impossible, to find the best solution in a reasonable length of time using today’s digital computers. A quantum computer, by contrast, would be able to solve them in a flash.”

Quantum pioneer John Stewart Bell (left), originator of Bell's theorem, with colleague Martinus Veltman at CERN in 1973. © akg-images



# How does a quantum computer work?

A conventional computer works with bits; a quantum computer with qubits. Like bits, qubits can have a value of 0 or 1. Unlike bits, they occupy a superposition of overlapping quantum states, so they can also have any combination of the two. A qubit does not take on a definite value until it is measured. Adding one qubit doubles the system’s performance so that 50 qubits, for example, would yield 2 to the power of 50 (250) possible combinations. This way, big problems and complex tasks are computed in parallel rather than in linear fashion.



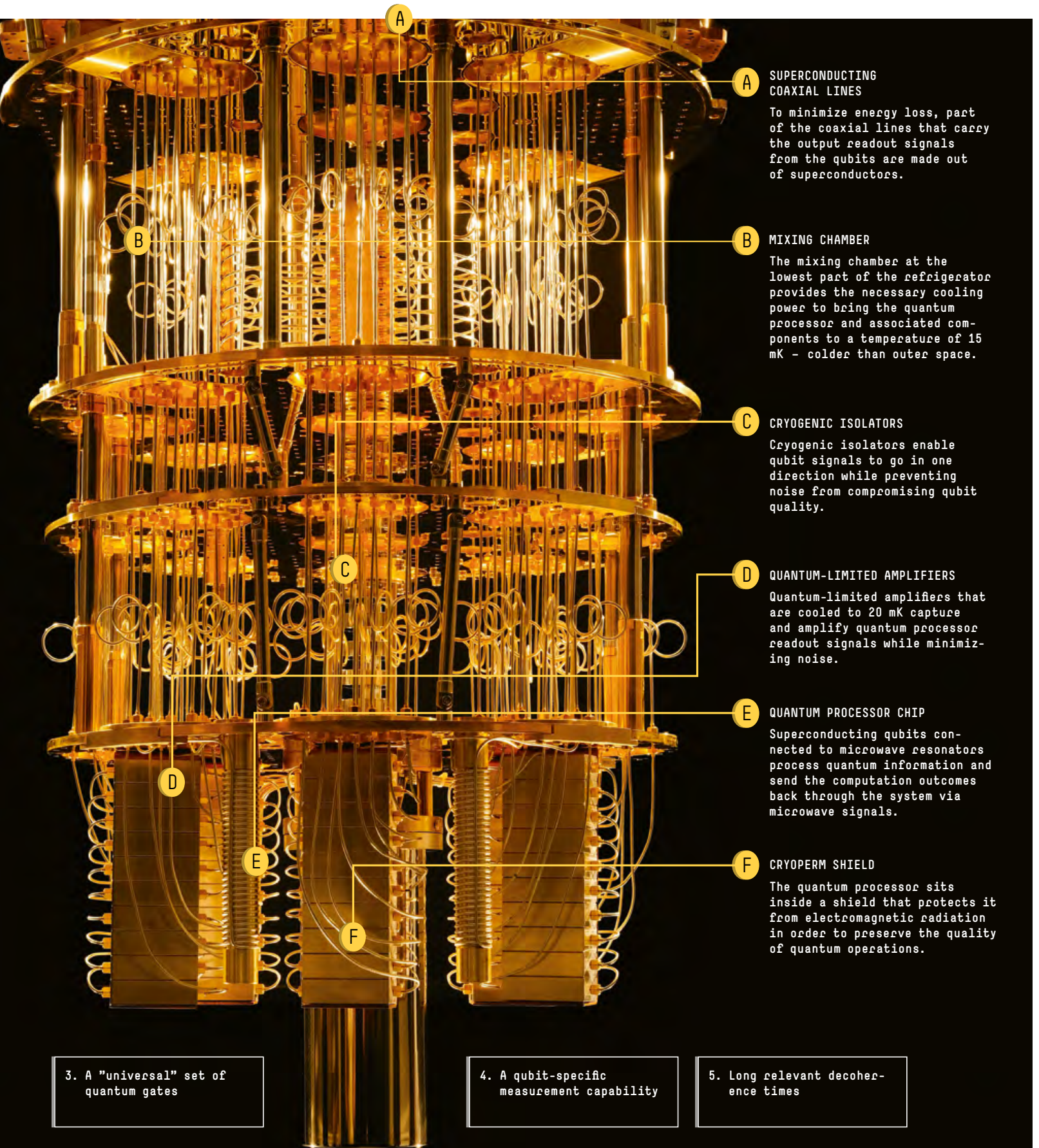
A qubit can be pictured as a rotating particle whose axis of rotation only assumes a fixed position when it is measured. Calculations are performed by correlating qubit states.

## 5 David Di Vincenzo’s\* five criteria for a quantum computer

1. A scalable physical system with well-characterized qubits

2. The ability to initialize the state of the qubits to a simple fiducial state

\*Pioneer of quantum information science and professor of theoretical physics at RWTH Aachen



**A SUPERCONDUCTING COAXIAL LINES**  
 To minimize energy loss, part of the coaxial lines that carry the output readout signals from the qubits are made out of superconductors.

**B MIXING CHAMBER**  
 The mixing chamber at the lowest part of the refrigerator provides the necessary cooling power to bring the quantum processor and associated components to a temperature of 15 mK - colder than outer space.

**C CRYOGENIC ISOLATORS**  
 Cryogenic isolators enable qubit signals to go in one direction while preventing noise from compromising qubit quality.

**D QUANTUM-LIMITED AMPLIFIERS**  
 Quantum-limited amplifiers that are cooled to 20 mK capture and amplify quantum processor readout signals while minimizing noise.

**E QUANTUM PROCESSOR CHIP**  
 Superconducting qubits connected to microwave resonators process quantum information and send the computation outcomes back through the system via microwave signals.

**F CRYOPERM SHIELD**  
 The quantum processor sits inside a shield that protects it from electromagnetic radiation in order to preserve the quality of quantum operations.

3. A "universal" set of quantum gates

4. A qubit-specific measurement capability

5. Long relevant decoherence times



### 1 What is this project about?

Six Fraunhofer Institutes and other partners in science are investigating how quantum technologies can benefit imaging applications and are developing initial demonstrators to this end.

### 2 Why does this matter?

Conventional medical imaging is somewhat limited. By contrast, quantum imaging will provide insights into previously inaccessible realms of the body using low-radiation light that does not destroy cells and tissue. It will also make the imaging of material surfaces more reliable, faster and cheaper.

### 3 When do you expect to see the first results?

We've already built initial demonstrators for life science applications and for detection in the barely accessible terahertz range. More are to follow by late 2021.

# How are you going to make quantum imaging work in the real world?

Three questions for Prof. Andreas Tünnermann, Fraunhofer IOF, on the lighthouse project QUILT



► Quantum computers can process large datasets in a single step and identify patterns in the data that conventional computers are unable to detect. Moreover, they might be better capable to cope with by incomplete or corrupt data. In a few years, this fusion of quantum computing and artificial intelligence could have repercussions that echo in practically every area of our lives. QML could help enhance logistics, improve power grid management and optimize investment portfolios in the finance sector. It could also expedite training for large neural networks. Bauckhage and his team at the Fraunhofer Cluster of Excellence Cognitive Internet Technologies are working on a QML project to develop quantum algorithms for problems of combinatorial optimization that are fundamental to machine learning and AI. "We want to be at the forefront of the coming revolution in quantum computing and provide industry with solutions as quickly as possible."

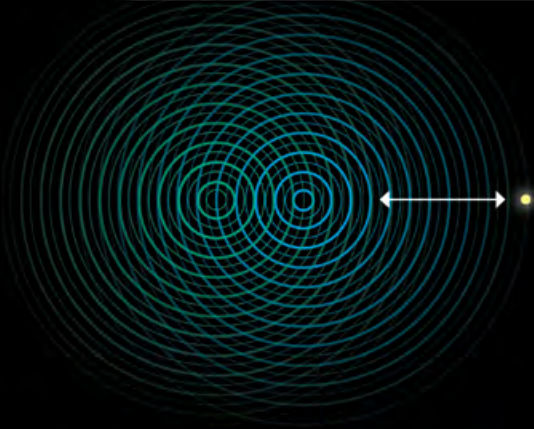
**Fraunhofer is pursuing a similar goal** in a project called PlanQK. Together with 14 partners, Fraunhofer FOKUS is seeking to develop a platform for quantum artificial intelligence. This will create a joint forum for AI and quantum computing specialists, developers, users, customers, service providers and consultants to share their knowledge of QML algorithms and applications. One example of a scenario with practical implications is banking fraud, which QML could help detect and even predict. In September 2019, this project won a competition for economically impactful innovations in artificial intelligence sponsored by Germany's Federal Ministry for Economic Affairs and Energy (BMWi).

**Applied quantum computing** is clearly taking shape in the real world. Will we all have a quantum home computer or a quantum processor in our smartphones in a few years? "Quantum computers will only ever be able to solve very specific problems, so they won't replace conventional computers. It's likely that cloud-based models will prevail – that is, quantum computing as a service (QCaaS). We'll probably also see hybrids of quantum computing and conventional high-performance computing," says Hauswirth. By then, quantum technologies will have made inroads into other aspects of daily life. ■



Physicist and Nobel laureate Erwin Schrödinger (1887–1961) is noted in the annals of science for his groundbreaking quantum research, but his thought experiment with a cat has become a staple of popular culture.

# The mysteries of quantum physics explained



## Wave-particle duality

Elementary particles such as photons or electrons, and even atoms and molecules sometimes behave like a wave, at others like a particle. A conventional particle can only occupy one position, but a wave propagates in space and can overlap other waves.



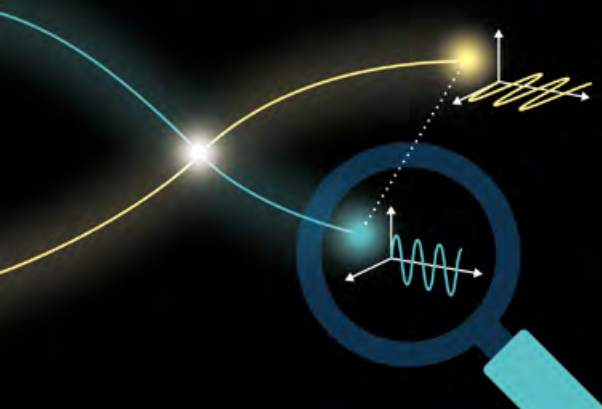
## The quantum tunnel effect

The wave-like properties of particles allow them to move through energy barriers as if passing through walls. Humans consist of particles, so the theoretical probability of each particle in the human body possessing the ability to cross the rectangular potential barriers of a wall is greater than zero. Be warned, though: Attempts to demonstrate this ability could prove painful.



## Schrödinger's cat

Perhaps the most famous thought experiment for explaining quantum physics involves a cat and a flask of poison gas. The two are placed in a box containing a radioactive source and a mechanism that breaks the flask when it detects a radioactive particle. The probability that the poison gas will be released is given at any moment. The process of radioactive decay is an ideal randomizer for determining this moment in time. In other words, without any interaction with the outside world, Schrödinger's "quantum" cat is in a state of superposition, entangled with the state of a radioactive particle. The cat is therefore both dead and alive, its state remaining indeterminate until someone opens the lid to a look inside the box.



## Quantum entanglement

Einstein once described this effect as "spooky action at a distance." The properties of entangled particles are always complementary. And, although they may be light years apart, they are inseparably linked to one another. If, for example, a state of vertical polarization is observed in one of a pair of photons, then the other must be horizontally polarized. And this despite the fact that its state has not been previously ascertained and no signal has been exchanged between the two particles.



# Not quite so spooky after all

A glimpse of the wonders to come in the world of quantum mechanics is to be had at Fraunhofer IOF at Jena. Its scientists are exploring ways of harnessing entangled photons to enable secure communication and enhanced imaging.

By Mandy Bartel

**E**rik Beckert brandishes a shiny golden device bristling with fibers and wires. A photon source with a nonlinear crystal, this device generates 300,000 entangled pairs of photons per second. Fraunhofer IOF's quantum research focuses on correlated light particles which may show "spooky action at a distance." Twin photons' properties always complement each other regardless of the distance between the two, so measuring the first tells you the state of the second. This turns out to be a useful feature for powerful physical encryption to foil hackers, plug data leaks and prevent snooping and thievery by industrial and economic spies.

Beckert, an engineer and self-taught quantum mechanic, explains the entanglement precept thus: "We use entangled photons to generate secure quantum keys on a physical basis and transmit them via satellite to our communication partners on Earth with as little interference as possible. Any attempt to intercept the communication is detectable because it disrupts this entanglement." The first quantum ciphering satellite of European origin to be equipped with this photon source is expected to launch into space in 2022. Its development owes a great deal to the efforts of Beckert, his Jena team and other partners.

The future of quantum encryption has arrived, with financial service providers, telecoms and government agencies taking such a keen interest in the technology. Fraunhofer, Max Planck, the German Aerospace Center DLR, the German Federal Ministry of Education and Research and industry partners embarked on a major campaign to make quantum encryption a reality. Called QuNET, this project aims to erect a high-security communications network over the next few

years by connecting government sites via unhackable links. It will also provide the underpinning for quantum communication infrastructure spanning Germany. Beckert believes quantum cryptography could be the ticket to secure online banking further down the line.

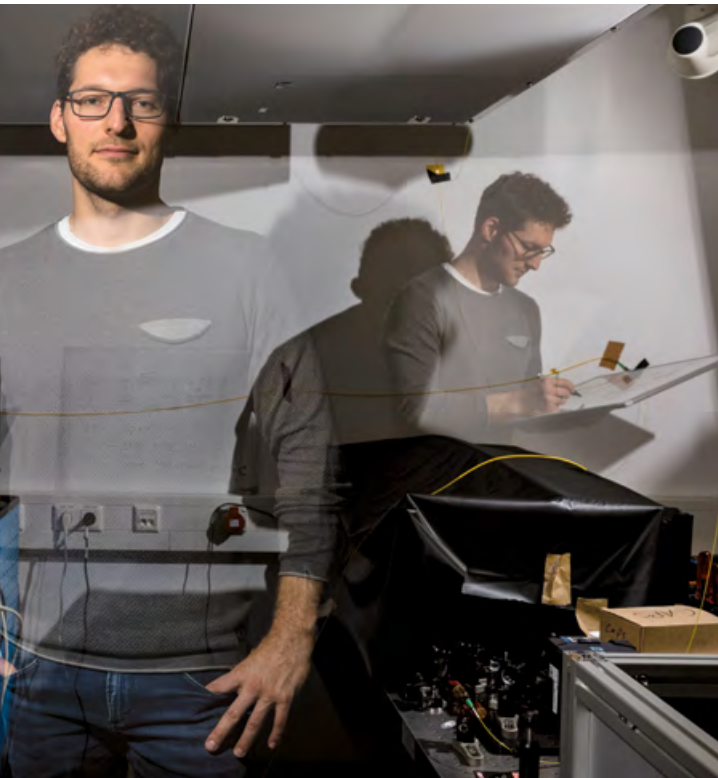
Efforts are already underway to make quantum communication affordable for the mass market. Called UNIQORN, this project involves 17 partners from across Europe. Researchers at the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, HHI in Berlin are doing their part by developing miniaturized, quantum-enabled components that will be easy to install in home routers. One of the scientists' goals is to slash the costs of quantum communication by 90 percent to put it within reach of cash-strapped consumers.

## Entangled photons - a revolution in imaging

Two of Beckert's colleagues at the IOF, Dr. Markus Gräfe and Marta Gilaberte Basset, are pressing entangled photons into service for quantum imaging, a field that scientists just recently began to explore. "Medical researchers have been stymied by the problem of human cell samples being so sensitive to light. UV light, especially, damages cells. This limits the amount of time available for investigation," says Gilaberte Basset. Quantum imaging with minimal doses of radiation could allow scientists to observe and analyze tissue cells with a high resolution and non-destructively. They could even monitor cell processes that take several minutes or many hours.



**3** Finance  
Enhanced  
portfolio  
management,  
risk analysis  
and fraud  
detection and  
prediction;  
secure commu-  
nications and  
data transfer  
for online  
banking and  
the like



Dr. Markus Gräfe and his team are working with entangled photons to make the invisible visible.  
© Sven Döring

# Can quantum encryption secure our communication?

Three questions about QuNET for Prof. Martin Schell, Fraunhofer HHI

## 1 What is this project all about?

Fraunhofer is working with the German Federal Ministry of Education and Research (BMBF), the Max Planck Society and the German Aerospace Center (DLR) to connect government organizations via an impenetrable quantum-based communication network. The BMBF is funding the project.

## 2 Why does this matter?

Security is a prerequisite for a digital society. Quantum encryption better protects against eavesdropping and attacks. We need to develop skills of our own in Germany so as not to relinquish the field to others.

## 3 When do you expect to see the first results?

The project is to run for seven years. The first step is to develop the hardware and technological underpinning for multi-user operation in heterogeneous networks. The quantum network is to be ramped up in 2026 jointly with the industry and federal network operators.

Blue laser beams flash this way and that among the Jena lab's elaborate apparatuses as Gräfe explains the gist of their research: "We use entangled photons covering the entire optical spectrum from infrared to ultraviolet in our microscopic systems. This enables us to make objects visible even at wavelengths that had been invisible to date. To put it simply, the light beam that probes the object is not the same light used by the camera to take pictures. While one set of photons is sent to the object to be detected at invisible wavelengths, the twin photons in the visible spectrum are captured by a camera. The entangled light particles carry the same information, so this generates an image despite the fact that the light reaching the camera has never 'seen' the actual object."

Quantum effects of this nature fascinate physicist and space researcher Marta Gilaberte Basset. "The quantum world is difficult for our imagination to grasp. Nonetheless, we experience its laws in action every day in the lab. At the end of the day, this is all about allowing for the existence of two different entities." Basset believes in the viability of practical applications, for example, high-quality imaging to help diagnose cancer. She is exploring that possibility in her doctoral thesis.

## Entangled emoting with a smiley

The IOF research team documented its enthusiasm for applied quantum mechanics with the world's first quantum video. Their choice of subject was inspired: They filmed a smiley without actually pointing a camera at it. It seems

this emoticon was an accurate reflection of the researchers' state of mind when they achieved this milestone in quantum imaging.

Real-world applications are a top priority for the Fraunhofer IOF team. Markus Gräfe says that integrating quantum technology into today's microscope systems is a key challenge. He wants to do this in a way that brings down the barriers for industry: "Nobody wants to fuss with several systems or work with one oversized system. This is why we're engaged in discussions with microscope makers such as Carl Zeiss and are working together on practicable solutions." Fraunhofer IOF is also pooling its research into quantum imaging with the expertise of five other Fraunhofer Institutes. This lighthouse project goes by the name of QUILT – Quantum Methods for Advanced Imaging Solutions. Several companies have joined the consortium's industry advisory board in a bid to keep its efforts to develop quantum-based imaging, spectroscopy and analytics solutions on an application-oriented track.

Gräfe, Gilaberte Basset and their Fraunhofer colleagues have already achieved tangible results. One is a portable demonstrator microscope for life-science applications. Another is the first quantum spectrometer for the midrange infrared band developed by a research team at Fraunhofer IPM in Freiburg that is also taking part in QUILT. Medical science is not the only field that stands to benefit from quantum technologies. Similar approaches could work in fields such as materials science. Automakers, for example, would welcome better detectors that inspect paint layers in the terahertz range in far greater detail. ■



# Quantum sensors: new opportunities for medical technology

Photons are one, but not the only, way of taking measure of the quantum world. Electrons are another. A research team at Fraunhofer IAF is using these tiny particles to develop ultra-precise quantum sensors.

By Mandy Bartel

The principle behind quantum sensors seems simple: Electrons orbit atomic nuclei which spin like a top. In this context, “spin” is an angular momentum intrinsic to quantum mechanics. This spin produces a magnetic dipole around the electron that other magnetic fields attract or repel. This creates the world’s smallest magnet.

The Fraunhofer Institute for Applied Solid State Physics IAF has chosen to use diamonds for its quantum magnetometer. Explaining the method’s finer points, the institute’s quantum expert Jan Jeske says, “We measure the states of electrons in a very specific defect in the diamond lattice, a so called nitrogen-vacancy (NV) center. This NV center enables us to optically measure the electron spin. A magnetic field shifts the energies of the spin states, which we measure by a change in brightness. This is how the sensor works. Diamond is well suited for this, because it is very stable even at room temperature and allows for long coherence times. To create the NV centers, we first add nitrogen atoms to the diamond, and then generate a neighboring vacancy.”

## Improved diagnostics for diseases

Such quantum sensors harbor the potential for enormous progress in medical engineering. For example, they can help diagnose cancer faster and more accurately. The Freiburg research team is looking to improve today’s MRI technology by combining a diamond-based polarizer with biomarker molecules to be injected into the patient prior to an MRI scan. This imaging

method could be 10,000 times more sensitive than conventional scans. Quantum sensor technology will also help combat one of the most frequent causes of death, cardiovascular diseases. Given the tools to measure minute magnetic fields in metabolic processes taking place within heart tissue, physicians can better identify risks. The IAF researchers engaged in the MetaboliQs project are developing a diamond-based polarizer which will offer 160 times higher efficiency and 40 times faster polarization at room temperature than before, at just a quarter of the cost.

Quantum sensors are a gateway not only to advances in medical diagnostics; they are also opening new doors for industry and manufacturing. For example, with their ability to detect the tiniest cracks or deformations in materials by their magnetic field signature, these sensors enable manufacturers to test microelectronic and nano-electronic components in a non-destructive manner. The Fraunhofer-Gesellschaft launched the QMAG lighthouse project – a collaborative effort of six Fraunhofer Institutes and two universities – in 2019 to optimize magnetometers for this sort of application.

With concerted research efforts like this underway, we will surely see quantum leaps in many fields over the next 10 to 20 years. This work is giving us a better understanding of matter in all its facets, and the tools to put it to good use. Scientists can now measure, analyze and calculate states and interactions at the atomic level with remarkable accuracy. To measure more is to know more. And to know more is to know better what to do with this knowledge. The future, an adventure in the making, has already begun. ■



# Room temperature – are we there yet?

Three questions for Prof. Oliver Ambacher, Fraunhofer IAF, about the QMAG lighthouse project ▶

## 1 What is this project all about?

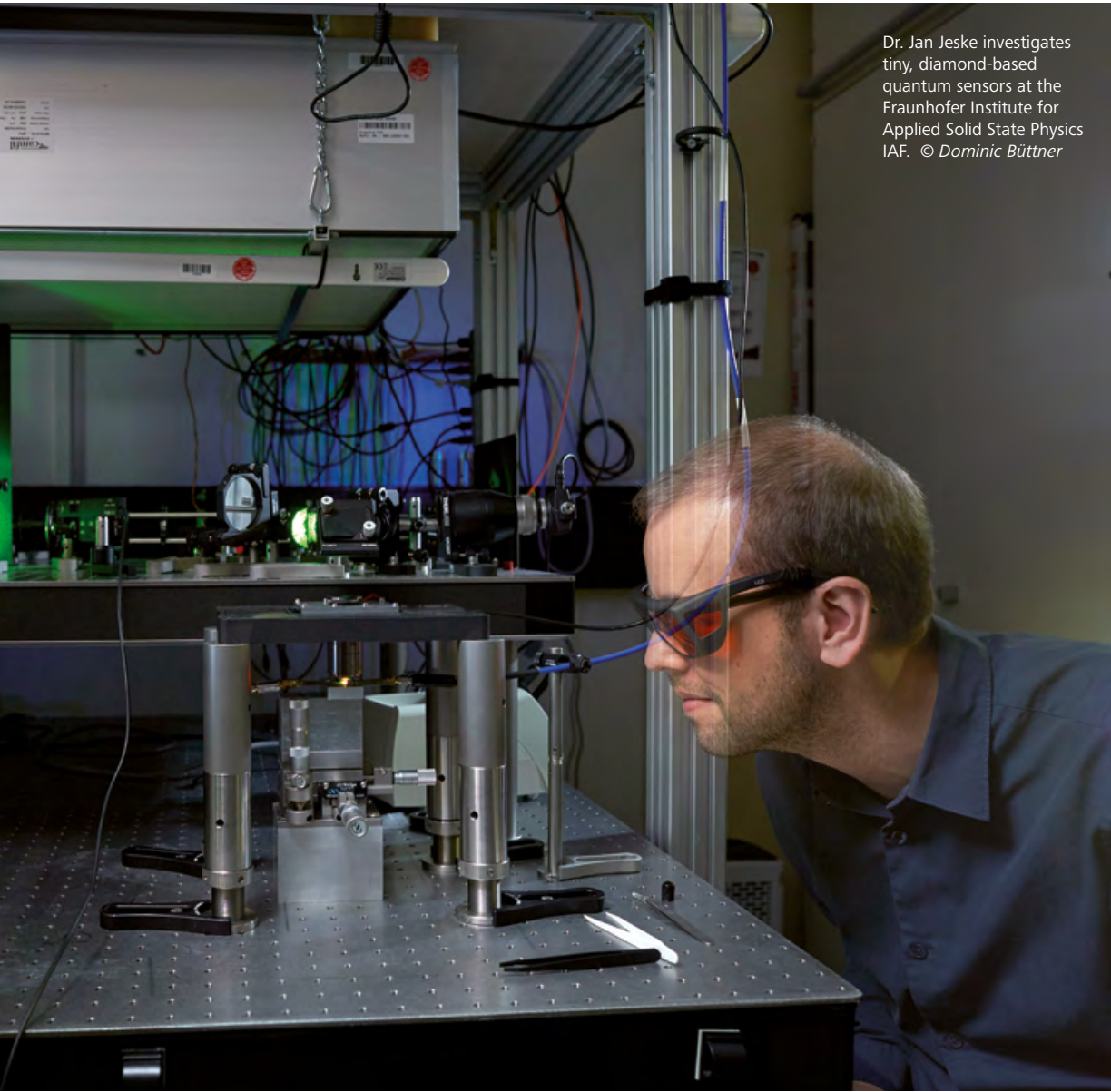
QMAG has six Fraunhofer Institutes developing quantum sensors for industrial applications. These high-resolution, ultra-sensitive magnetometers will be able to measure very small magnetic fields at room temperature. The QMAG research team is building and testing two demonstrators based on different methods to make that happen.

## 2 Why does this matter?

The benefits of quantum magnetometers are manifold. They can serve to optimize microelectronic and nano-electronic circuits and shed new light on physical effects. They are quicker and more accurate at detecting damage in materials. And they can measure processes with far greater precision when paired with nuclear magnetic resonance (NMR) spectrometers.

## 3 When do you expect to see the first results?

Two complementary quantum magnetometers that work at room temperature are expected to be up and running by 2024. We also want to set up a customer-centered lab for the applications discussed above.



Dr. Jan Jeske investigates tiny, diamond-based quantum sensors at the Fraunhofer Institute for Applied Solid State Physics IAF. © Dominic Büttner



## Quantum technologies

# “Germany is at a very good vantage point”

One of the leading minds in the field of quantum technologies at Fraunhofer, Prof. Andreas Tünnermann heads up the Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena.

Interview by Mandy Bartel

### **Mr. Tünnermann, do you recall when and where you first encountered quantum mechanics?**

That was a long time ago. As far as I'm aware, my first encounter with the quantum world took place in the sixth or seventh grade when I had to hand in a paper on the external photoelectric effect. The photoelectric effect was one of the key experiments serving to establish quantum theory. Einstein was awarded the Nobel Prize in Physics in 1921 for his explanation of this effect, with which he proposed that light consists of quanta called photons. The quantum world has always fascinated me, and photons remain the focus of my life as a researcher today. I am a laser man.

### **What fascinates you about the quantum world?**

People learned to control larger ensembles of quanta and put them to use in applications in the '50s and '60s. This is known around the world as the first quantum revolution. It gave rise to the laser, and then to the photonics industry, a new line of business that radically changed our society. Just think of the Internet, which would be inconceivable without photonics. The first quantum revolution also laid the foundations for microelectronics. The world as we know it would stand still today without these components. Now we are asking ourselves, “What is the practical added value of being able to control a single quantum? Can it be made to create value of similar macroeconomic significance [*as photonics and microelectronics*]?”

### **You launched several major quantum initiatives on behalf of Fraunhofer in recent years. How did quantum research get underway at Fraunhofer IOF?**

We have been researching quantum systems and their applications since the institute was founded. For example, we work on lasers and investigate the interactions between light, or photons, and matter. To this end, we collaborate with world-class groups. In many cases, these groups owe their ability to conduct original research into quantum technologies to our components and systems for controlling light. We have been looking into specific questions of the second quantum revolution for more than ten years now, jointly addressing aspects of quantum imaging, quantum sensor technology, quantum communication and quantum computing with partners.

### **What are the most exciting quantum projects underway now?**

Quantum communication is an important topic for our society because data security and data sovereignty are fundamental rights. We want to further the cause of data sovereignty in Europe with QuNET, a project we are currently pursuing with partners to develop the underpinning for secure data transmission and storage. This is where quantum technologies serve to generate keys and share data among the various partners in a communication network. One example of another communications project is Space EPS. Working with the Institute for Quantum Optics and Quantum Information Vienna, we developed and optimized a photon source for a communications satellite on behalf of the European Space Agency. The first prototype measured several square meters – the size of a large conference table. It had hundreds of discrete optomechanical components. We streamlined the design, shrinking it to the size of a shoebox. The next stage of development is to bring it down to the size of a pack of

4 Materials science Simulation of novel materials at the molecular level, faster development of materials, more precise testing methods



Quanta have accompanied 'laser-man' Prof. Andreas Tünnermann throughout his career as a researcher.

© Sven Döring

cigarettes. We're on the verge of that now, but my personal goal is to end up with a matchbox-sized format. *(laughs)*

**In what field will quantum technologies have the most enduring impact on our lives?**

Certainly in medicine, as quantum imaging can vastly improve diagnostics. We will need less light to take a picture with future quantum technologies. As I mentioned, there are many other fields, not least communication.

**The four major fields of research are quantum computing, communication, imaging and sensors. Which do you think is most likely to be the first to yield marketable applications?**

I am optimistic that marketable real-world applications will soon emerge in communication, imaging and sensors. We are already pursuing projects with companies to this end.

**China launched the first quantum satellite into space back in 2016, and Google appears to have recently established its quantum superiority. Has Europe already lost the race for quantum supremacy?**

No. I believe we are actually at a very good vantage point. Advances in European research made the project in China possible in the first place. In Europe, we are thriving on excellent basic research conducted with a great deal of continuity. Just think of the funding furnished by the DFG [German Research Foundation] over many decades in this field. It served to establish remarkably competitive university groups to pursue basic research. Applied research is also very strong, especially in quantum communication, imaging and sensors. What we need to do today is join forces with industry to demonstrate the value-adding advantage of quantum technologies over conventional approaches, and create that value.

**What does Germany have to do to keep up in terms of applied science?**

Above all else, we need skilled personnel and we have to invest in their training. Beyond that, we have to bring different disciplines even closer together and merge the knowledge of engineering and physics. And we need a commitment from industry TODAY so we will be able to bring innovative products to market TOMORROW.

**Why should companies start exploring quantum technologies today and what should their priority be?**

There's no question about it – companies need to know if quantum technologies will create more value for their given line of business than the solutions out there today. It is important to get ahead of the curve at an early turn, and develop evaluation criteria that steer them to the right business decisions. ■

IT and security  
5  
More powerful computers for previously unsolvable problems, encrypted communications networks



# Researchers take the taste test

Everyone knows the importance of cutting down on fat, sugar and salt. Fraunhofer IVV is helping to get the right balance between taste and healthy eating - and research into chocolate is particularly popular just before Christmas.

By Josef Seitz

Some dads bring work home with them – but this particular family has no complaints. The fruits of this dad’s labor are something his three kids are happy to sample: a mix of fatty acids, saturated and unsaturated micellar proteins from lupines and other pulses, and oils from rapeseed and sunflowers, all combined into a chocolate taste sensation!

Christian Zacherl strolls into the pilot plant for chocolate production at the Fraunhofer Institute for Process Engineering and Packaging IVV in Freising. The lab coats hanging to the right of the door – liberally spattered with chocolate brown patches – make it perfectly clear what this food technologist and business development manager for food will be working on again today. There are machines aplenty, including a drum roaster, an agitated bead mill, a laboratory conch, a tempering machine, a three-roll mill and coating tanks. But perhaps the day’s most important tools are the humble spoons, which are already laid out ready for use. Together with his colleagues, Zacherl will be taste-testing just how close the institute has come to reaching its goal.

**Fraunhofer IVV embarked on two Europe-wide research projects at the start of 2019.** Their goal is to achieve a one-third reduction in the saturated fat content of chocolate fillings and the popular chocolate spreads people have on bread for breakfast. The scientists are hoping to replace palm oil, which is believed to adversely affect the cardiovascular system, with oils that are regarded as healthier and that can be produced by more sustainable means. The idea is that fields of rapeseed and sunflowers located closer to consumers could eventually replace the palm oil plantations that are so controversial from an environmental standpoint, with native oils taking the place of oils from the rainforest. Known as oleogels, these can be tailored to have a texture as close as possible to that of the original fats while simultaneously optimizing the fatty acid profile.

**Those are the benefits for people’s health, the climate and the environment** – at least in theory. But Zacherl

insists it cannot succeed in practice unless we get one crucial factor right: “It has to be tasty. If it’s healthy but doesn’t taste good, then there’s no point.” Large-scale consumer tests began in late 2019, but at the time of this interview the food technologist at Fraunhofer IVV in Freising was busy sampling a spoonful of chocolate spread from the first of several pots. “Standard chocolate spread with palm oil” says the label, and it tastes like the popular brand Nutella. A row of other pots awaits his appraisal. The “chocolate spread with rapeseed oil” still has a very fatty-looking surface texture. The “choc-

“If it’s healthy but doesn’t taste good, then there’s no point.”

Christian Zacherl





Tasty spoonfuls: (left to right) Christian Zacherl with his IVV colleagues Karin Agulla, Irene Buchmann, a researcher in the working group on chocolate technology, and Yvonne Guckenbiehl, a doctoral student in the working group on chocolate technology. © Fraunhofer

olate spread with oleogel” appears on the labels of several pots containing spreads of different consistencies depending on the number of times they went through the bead mill. The scientists focus on the key questions of texture, color and taste, which may be nutty, oily – or even rancid.

Zacherl studied food technology at the Technical University of Munich (TUM). He has been working at Fraunhofer IVV since 2005, carrying out research, development and tasting, and steadily acquiring new jobs that reflect evolving trends in the food industry. Reducing salt content in foods is currently the number one concern in France and Spain, while Germany is more focused on reducing sugar and energy density. From pizzas with high fiber content to burgers with 30 percent fewer calories, Zacherl insists that the team can produce just about anything. Supermarkets recently started selling one of the most radical products of the latest trend in food creation: Beyond Meat looks like meat and tastes like meat, but it contains no meat at all and is produced to vegan standards. But the Fraunhofer food technologist is still far from satisfied with the products available to consumers, arguing that they contain too many additives and that the ingredients are not regional enough. “Right now we’re working on replacing

soya in these kinds of meat alternatives,” he says. This is something close to his heart, because Zacherl enjoys cooking and good food and has followed a vegetarian diet for years – with one major exception.

In the IVV’s pilot plant for chocolate production – that down-to-earth facility with its drum roaster and coating tanks – the tasters continue to dip their spoons in the chocolate spreads. The flavor and mouth feel get closer and closer to the original as they move from pot to pot. So why do we have such a thing for chocolate? “Cocoa butter is the most expensive fat,” says Zacherl, stating the plain facts first. But soon the food technologist gives way to his enthusiasm, rhapsodizing about the melting point that allows a solid product to release its aromas in the mouth, “fruity, nutty, metallic – there are just so many different nuances!” He clearly understands the tremendous pleasure people get from chocolate, yet the Fraunhofer expert still takes the opportunity to pass on a tip on healthy eating: “In my book, healthy means balanced, regional, home-made and enjoyed in good company.” And a good example is the major exception that this vegetarian allows himself in his own diet – namely a goose at Christmas! ■

## Top chocolate consumers

Germans consume **11.1 kilograms of chocolate per capita per year** – the equivalent of one bar every three days. That makes Germany Europe’s leading nation of chocolate lovers, followed by the Swiss with a per-capita consumption of 9.7 kilograms, Estonians on 8.83 kilograms and the British on 8.09 kilograms. Surprisingly little chocolate is eaten in the neighboring country of Austria. Austrians consume an average of just 830 grams a year per person.

**The most popular kind of chocolate in Germany** is milk chocolate (47 percent). Nougat comes next, with dark chocolate in third place.





# Revolution one drop at a time

A decade of research, a successful spin-off – and a major leap forward for the pharmaceutical industry.

By Eva Rathgeber

“We can massively increase the number of experiments while also cutting costs.”

Andreas Traube,  
Fraunhofer IPA

Imagine a world where made-to-measure antibiotics get the job done without the blanket approach of a broad-spectrum antibiotic, where cancer specialists identify optimal substrate compositions by testing different concentrations of anti-cancer drugs on a patient’s cell cultures, and where scientists have the technology to grow viable living cells in a precise and controlled manner. These are just three examples of what I-DOT can do – and some argue the potential it offers is nothing short of revolutionary, especially for the pharmaceutical industry.

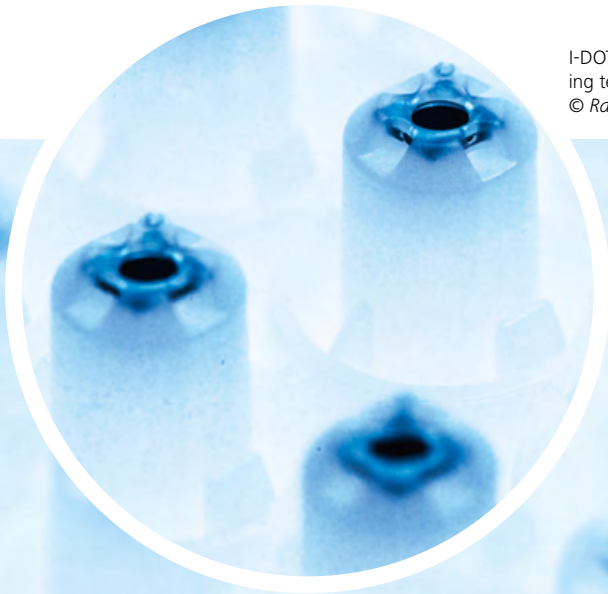
These four letters have played a major role in Andreas Traube’s career. A full decade of research went into creating the “Immediate Drop on Demand Technology,” or I-DOT for short. Now a head of department at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Traube has been fascinated by one particular question ever since he became a scientist: what’s the best non-contact, pipette-free method of dispensing tiny samples of liquid for biological analysis? From the start, his main focus was on the microtiter plates used for bioassays. “In biology, any contact is bad because it can result in contamination,” he says. The topic not only dominated his work, but also appeared in a number of theses at Fraunhofer IPA. Tobias Brode, now head of the medical engineering and biotechnology business unit at the IPA, attracted particular attention with his thesis and was asked to join the Fraunhofer team of scientists working on the I-DOT process.

“It’s great to track the evolution of a project from its inception right through to product commercialization,” says

Traube. The principle behind the non-contact I-DOT method is simple: applying a pulse of compressed air to the top of the source well dispenses a nanoliter droplet through the hole or ‘nozzle’ in the bottom of each well into, or onto, the desired target. Using a set of eight dispensing heads arranged in parallel, each individual nozzle can dispense up to 600 of these approximately one nanoliter drops a second, enabling volume throughput of between 10 and 1,000 nanoliters.

**Competitive advantage:** “Using I-DOT, we can transfer tiny doses of many different liquids extremely quickly,” says Traube. “So we can massively increase the number of experiments while also cutting costs.” Conventional high-throughput methods of bulk experimentation currently rely on pipetting robots, but these are unable to handle the quantities below one microliter that offer such key costs benefits. Conventional methods involve 3,600 pipetting steps: I-DOT slashes the number of steps required and uses just one fifth of the material.

Dispendix GmbH was founded in 2016 as a spin-off of Fraunhofer IPA and was acquired by Swedish 3D bioprinting company Cellink at the end of 2018. Cellink acquired Dispendix’s product range and technology with the aim of gaining a key competitive edge in microtissue production. The company’s cooperation with Fraunhofer continues apace, and the license agreement based on I-DOT patents will run until 2028. The two organizations are combining forces to work on the development of further technologies, particularly in the fields of single-cell analysis and digital dosing. ■



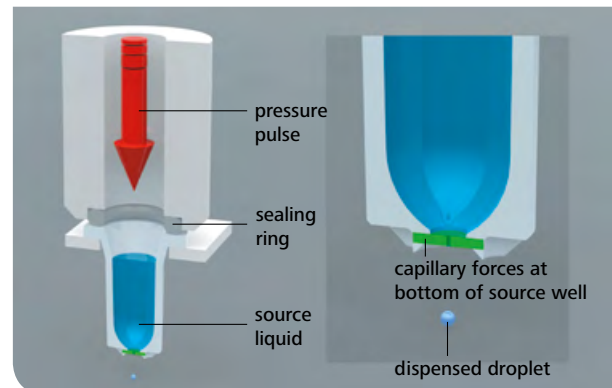
I-DOT sample vials: the non-contact, pressure-based dispensing technology uses tiny openings in the bottom of each well.  
© Rainer Bez/Fraunhofer IPA



It's easy to program the I-DOT using the built-in touchscreen.  
© Dispendix GmbH



Automated loading of the I-DOT. Standardized interfaces make it easy to integrate the I-DOT into complex biological processes.  
© Heike Quosdorf/Fraunhofer IPA



The non-contact I-DOT method works by applying a pressure pulse to the top of the source well to dispense a nanoliter droplet through the hole in the bottom of the well onto any target. © Fraunhofer IPA



# Leaving behind those in need?

The EU has issued a new directive to make medical devices safer – but it could end up jeopardizing care for children and patients with rare diseases. Fraunhofer ITEM is striving to minimize that risk.

By Christine Broll

One in every hundred babies in Germany is born with a heart defect. In many cases, their survival depends on artificial heart valves, stents, catheters and pacemakers specifically designed for infants. Yet these devices may soon be in short supply as a result of the EU's Medical Device Regulation. The new legislation states that all commercially available medical devices must be reassessed by May 2024 to demonstrate compliance with the latest standards. That includes everything from scalpels and endoscopes to hip implants, pacemakers and heart-lung machines. The med-tech industry association BVMed warns this will be an insurmountable hurdle for around 30 percent of medical device manufacturers' products – and that the consequences will be particularly dire for younger patients such as newborn babies.

The EU has launched three major projects to mitigate this impact. One of these is the Medical Device Obligations Taskforce (MDOT), which is headed by the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM in Hannover. Project manager Dr. Ulrich Froriep sees the new EU regulation as a double-edged sword: "If I have a common disease, then I will have access to very safe medical devices in the future. But if I have a rare disease, I may soon be in the unfortunate position of finding that the remedy is no longer available in Europe."

**The new regulation came into effect throughout the EU in May 2017** – and the consequences are starting to bite. The changes to the criteria medical devices must meet to obtain approval were triggered by the scandal of low-quality breast implants that first hit the headlines in 2009. The french company Poly Implant Prothèse (PIP) had been selling breast implants made from cheap industrial-grade silicone. Many of the silicone shells ruptured soon after being implanted, leading to infections. Some 30,000 women were affected in France alone.

All notified bodies now have to be redesignated – yet by the end of October only four of the existing 58 notified bodies had been certified to review medical devices: two in Germany, one in Italy and one in the United Kingdom. Medical device makers must therefore prepare themselves for a long wait and be prepared to provide considerably more data and documents than before. In particular, the EU has toughened up the requirements for technical documentation and manufacturers' quality management systems. The regulation includes a new risk classification system that requires clinical trials for a far greater range of devices.

"It's a huge challenge for the German med-tech industry, which primarily consists of small and medium-sized enterprises," says Fraunhofer researcher Froriep. "The companies are looking closely at which clinical trials they can afford for which devices."

The High-Performance Center Translational Biomedical Engineering, in which Fraunhofer ITEM has joined forces with partners including the Hannover Medical School, is taking action on many levels to preserve patients' access to medical devices. One of their goals is to develop accelerated test methods for manufacturers. "We're also working with industry associations in the political arena to raise awareness among key decision-makers and get improvements on the table," says the head of the High-Performance Center, Professor Theodor Doll from Fraunhofer ITEM. "We're involved in two projects on an EU level that are seeking to develop open innovation test beds for medical devices."

Project manager Ulrich Froriep hopes that the EU project MDOT will create a platform that will help med-tech companies with the conformity assessment process for medical devices. Fraunhofer ITEM embarked on the project in January

Could maximizing safety for patients with common diseases come at a price for everyone else?



A healthy newborn – but one in every hundred babies in Germany is born with a heart defect.  
© Dina Giangregorio/  
F1online

### European market leader

The German med-tech industry leads the field in Europe and enjoys major success in markets worldwide. Exports make up 65 percent of sales in the industry, with companies investing an average of nine percent of their revenue in research and development. The med-tech industry is dominated by SMEs and employs over 200,000 people in Germany, twice as many as the steel industry. The med-tech industry association BVMed estimates that the Medical Devices Regulation will lead ten percent of companies to abandon the market.

2019 together with 12 partners from six different countries. The EU commission has provided funding to the tune of 8.3 million euros.

The project team envisages an online platform that will help manufacturers navigate the complexities of the new regulation. The platform should be easy to use, with companies simply having to enter which medical device they intend to bring to market to get a detailed breakdown of the tests and data required for conformity assessment.

The project team also hopes to facilitate collaboration between individual manufacturers by following the example of the EU's chemicals regulation REACH – or rather the way in which the chemicals industry handled this regulation, which came into force in 2007. "The big chemicals manufacturers worked together to meet the REACH requirements by forming consortia to evaluate the safety of new substances," says Froriep. "In the case of medical devices, manufacturers could carry out joint tests on different materials, for example, or perhaps share their existing data for a fee."

### "We're likely to see a new wave of medical tourism"

To show how the platform might look, the partners are currently developing three demonstrator technologies in the fields of inhalers for premature babies, active neural implants and coatings for hip replacements. The part of the project dedicated to inhalers for premature babies is headed up by Gerhard Pohlmann at Fraunhofer ITEM. "Inhalers provide a gentle way of administering surfactant to the immature lungs of premature babies, which is essential for their survival," says Pohlmann. "Surfactant is conventionally delivered in liquid form via a tube, which is very stressful for the infant." With such a small market volume, the high cost of conformity assessments for these highly complex devices has so far been out of reach of individual SMEs – but the MDOT project now offers a realistic path toward obtaining approval.

**High-risk devices are the focus** of the second EU project Fraunhofer ITEM is involved in. The TBMED project focuses on devices such as synthetic corneas for the human eye, synthetic bone substitutes and automatic insulin pumps. The goal is to strengthen SMEs' innovative capabilities and help them keep pace with international competitors. Fraunhofer ITEM is in charge of biocompatibility testing in the project, for example toxicity testing in cell cultures.

Despite these projects and initiatives, Froriep still worries that Europe may lose ground: "If innovative devices become available in the U.S. before they reach Europe, then we're likely to see a new wave of medical tourism." ■



# The ecological impact of Christmas trees



## 01: Growth phase

**10**  
years

### Time factor

It can take ten years for a tree to grow tall enough to be used as a Christmas tree.



**12 min.**  
of labor per tree

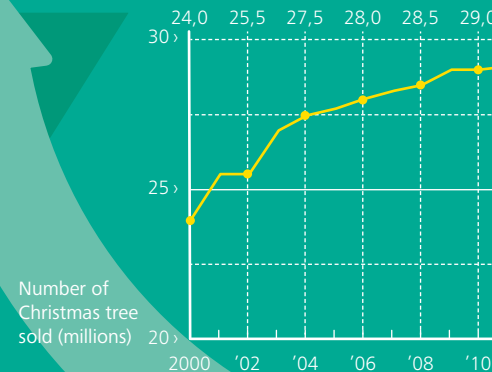
### Labor factor

The producer invests an average of around 12 minutes for each tree they produce. The labor required for each hectare comes to 80 hours a year and primarily consists of manual work.

45 m



Dortmund



Number of Christmas tree sold (millions)



## 04: Disposal issues

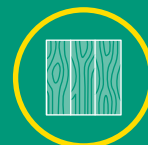
Local authorities across Germany are in charge of collecting Christmas trees. What happens then differs from place to place. In Berlin, they are fed into biomass power plants to produce electricity and district heat. In Leipzig, Christmas trees are composted and converted into humus, while in Munich some trees are made into chipboard. Just like garden waste, it is prohibited to dispose of trees in the forest. Unsold trees are often given to zoos.



Turned into energy



Composted



Furniture/  
building materials



Zoos



Do not dispose of  
trees in forests



## 02: Transportation issues

### Bought locally

Enthusiasm for buying locally is on the rise – and Christmas trees are no exception. Almost one in three trees are now purchased directly from the grower. Less transportation is good for the climate.



30%  
street vendors



27%  
directly from  
producers



24%  
supermarkets/  
hardware stores

### Bought online

Buying Christmas trees online is still a niche market, but it is steadily becoming easier for consumers, with an increasing range on offer. Nowadays it's even possible to have a pre-decorated tree delivered straight to your living room!



<1%  
of Christmas  
trees are bought  
online

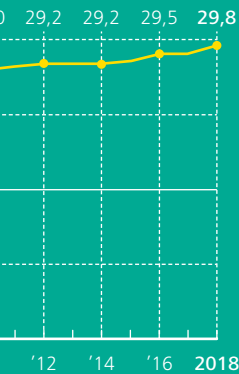
### German Christmas tree records

In 2018, Dortmund took the honor of having Germany's tallest Christmas tree, followed by Frankfurt and Munich.



### People love having a tree

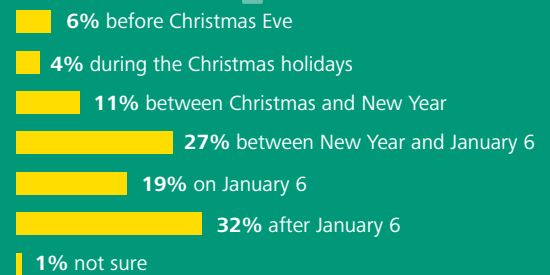
Almost 30 million Christmas trees were sold in Germany in 2018.



## 03: A tree every year

### Useful life

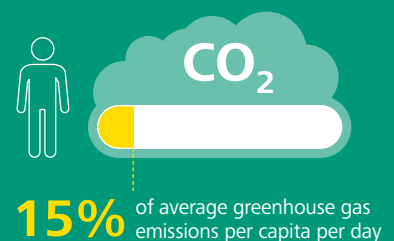
Some ten percent of German households take down their Christmas tree before Christmas Eve or during the Christmas holidays. However, many people follow the tradition of leaving the tree up until Epiphany.



### Alternatives Plastic tree

Over a third of modern-day Christmas trees are made of plastic. Artificial trees release more CO<sub>2</sub> into the atmosphere than natural Christmas trees due to a combination of manufacturing, transportation and disposal emissions. However, if an artificial tree is used year after year, it ends up having a smaller carbon

footprint than a natural tree after 4–7 years. Transportation is the crucial issue when it comes to the carbon footprint of natural Christmas trees. But, to put it in perspective, a Christmas tree is equivalent to just 15 percent of average greenhouse gas emissions per capita per day.



32% artificial  
Christmas trees



68% natural  
Christmas trees





Pieces of this car puzzle – especially the electronic components – could make space travel more affordable. © Volkswagen AG





# Space applications for car parts

Space missions are an expensive business. Satellites and probes contain a plethora of custom parts that require extensive testing prior to launch. But that might soon change thanks to a joint project by Fraunhofer INT and the European Space Agency (ESA) that aims to use off-the-shelf auto parts for spaceflight applications.

By Mehmet Toprak

**S**afety is paramount, so the first step is to clear the lab. Now the Cobalt-60 irradiator can be switched on – and the test can begin. For the next 24 hours, the irradiator will bombard a roughly A4-sized circuit board with high-energy gamma rays. If it survives this radioactive onslaught, the board will have a good chance of moving on to the next stage of functional tests and analyses and ultimately qualifying for a very special mission. What started out as an off-the-shelf component for a mid-range car might end up on a journey into space!

This is just one example of the tests that will be kicking off the RACOCO project at the Fraunhofer Institute for Technological Trend Analysis INT. RACOCO stands for “radiation characterization and functional verification of COTS components for space applications.” COTS refers to the “commercial off-the-shelf” components the project has been set up to investigate. Deploying COTS components could slash the cost of space missions, so the first task is to identify which ones might be up to the job. The INT researchers opted to focus on vehicle parts due to the auto industry’s stringent safety and reliability standards. And even the most minor changes in auto parts production are documented, so transparency in the manufacturing process is high. ▶

In the RACOCO project, Fraunhofer is hoping to identify off-the-shelf components from industrial manufacturing that are suitable for spaceflight.





Dizzy new heights? In the future, ESA hopes to equip its satellites and space probes with industrially manufactured components. © SpaceX

**“We hope to boost efficiency by streamlining testing.”**

Dr. Michael Steffens,  
Fraunhofer INT

► The next step is to test the components. Can they withstand constant bombardment with cosmic radiation in Earth’s orbit or out in space? Or does that rapidly impair their performance? And could the impact of a single high-energy particle – the kind of perilous single-event effect that can be caused by factors such as solar winds – be enough to cause a defect? There are broader goals, too, says Fraunhofer researcher Dr. Michael Steffens, who is in charge of making COTS components “flight-ready.” “One of our key goals is to boost efficiency by streamlining testing.”

### **Killing two birds with one stone**

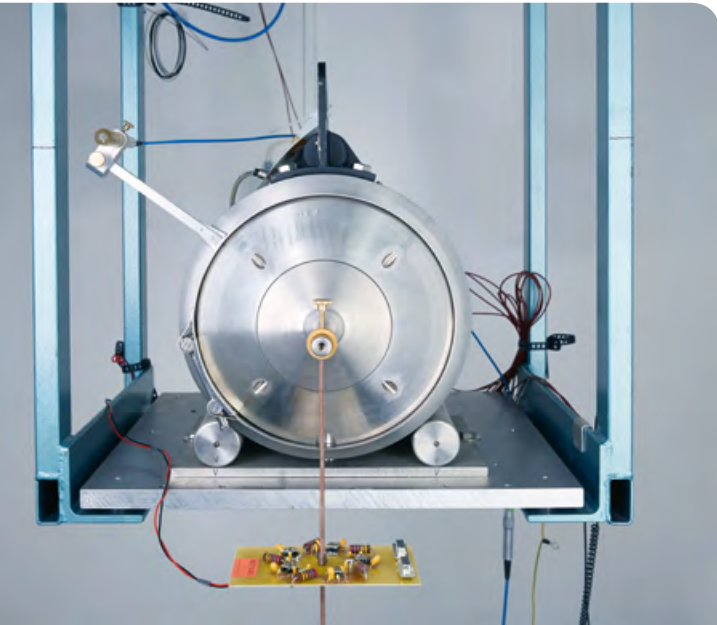
Steffens heads up a team of 12 that plans, designs and conducts tests at the INT in Euskirchen, not far from Cologne. Work on the project is in full swing in the “Nuclear Effects in Electronics and Optics (NEO)” business unit – and there are plenty of resources available in addition to the Cobalt-60 source, including various lasers and a plethora of high-grade measurement and lab equipment.

The impetus for this ambitious project came from the European Space Agency (ESA), which brought the INT scientists on board. The Fraunhofer team’s point of contact is Gianluca Furano, who has spent the last 17 years working as a computer engineer in ESA’s Data Systems division – roughly the same amount of time he has spent delving into the use

of COTS components in space. Getting Fraunhofer involved in the research project was an easy decision for ESA to make, says Furano, not just thanks to the NEO team’s high-tech equipment, but also due to their expertise. “Our productive partnership with Fraunhofer stretches back many years,” says Furano. “When it comes to irradiation testing, our INT colleagues are the best!” Steffens also acknowledges their prowess in this area, though in more modest terms: “We are the leading European player in the field of dosimetry, which refers to the precise study and measurement of radiation dose.”

**The project team hopes to make a decisive contribution** to solving two key spaceflight dilemmas. Previous missions have relied almost entirely on high-reliability or “HiRel” parts which are produced in small batches on dedicated production lines. That not only makes them expensive, but also requires each and every batch to be tested and certified for radiation resistance. Some of the test routines can take years to complete, so what starts out as state-of-the-art technology ends up being something very different by the time it is ready for launch. Put simply, space missions are too costly and make use of obsolete technology.

Working with his team, Steffens hopes to draw on his experience as a solid-state and nuclear physicist to improve this situation – and Furano has high hopes that the project



Endurance test for space missions: the cobalt-60 irradiator bombards the board with high-energy gamma rays for many hours at a time. © Fraunhofer INT



Measurement equipment in the INT lab: Fraunhofer INT researchers are the perfect partner for ESA thanks to their plentiful experience and expertise in dosimetry. © Fraunhofer INT

will succeed: “We want to accelerate testing so that we can take advantage of state-of-the-art technology. That would be a huge boost for our space missions.”

In the fast-evolving world of spaceflight, this boost is exactly what’s needed. Previously, there were just a few major government players who ruled the roost, such as NASA in the U.S., ESA in Europe and Roscosmos in Russia. But now they’ve been joined by a host of new companies with plenty of financial clout. The traditional space agencies have come under particular pressure from Amazon founder Jeff Bezos’s Blue Origin and Tesla boss Elon Musk’s SpaceX. “The market has expanded – and that means we have to step up our activities,” says ESA representative Furano diplomatically.

But how do you speed up testing without jeopardizing the reliability of the results? Zero fault tolerance is par for the course in space applications, because repairing a satellite or probe on its lonely journey through space is obviously not an option. Another complication is the fact that almost all electronic automotive components are highly integrated products that combine a range of very different modules on a single circuit board.

**The Fraunhofer team relies on early indicators to determine if a part has potential.** The researchers start by performing a quick preliminary test on each part.

These tests focus on just one individual component of the module – such as the processor – and target this specific chip with precisely focused gamma rays. If that one chip fails or exhibits a deterioration in performance, then the researchers immediately know they can discard the entire module. It may be good enough for a car, but not for a space mission. “Our full testing process is reserved for those modules that pass the initial test. That makes testing much faster,” says Steffens.

### Dizzy new heights for automakers?

The current boom in space missions promises flights to the Moon and even to Mars, as well as the launch of thousands of new satellites. The sky’s the limit in terms of opportunities – so could automotive suppliers also benefit? The potential certainly exists for them to sell certain electronic modules to vendors in the new space market in the future.

It’s still early days, of course, but both the Fraunhofer team and ESA are keen to push ahead with the project as quickly as possible. ESA manager Furano hopes to see the first tangible results firming up in late 2020. “Then we could see the first satellites and probes containing COTS parts heading into space in early 2021,” he says. Commercial off-the-shelf components could even be used for the planned mission to Mars – even if only as a WiFi hotspot for the scientists at the Mars base. ■

“When it comes to irradiation testing, our INT colleagues are the best!”

Gianluca Furano, ESA



Little bug,  
big potential: Two  
centimeters  
is not much  
in the way  
of size, but  
tiny *Hermetia  
illucens* could  
have a huge  
impact on the  
environment.  
As the stuff  
of tomorrow's  
feed for  
livestock, the  
black soldier  
fly may well  
help save  
rainforests  
and protect  
the climate.

© ddp-images



# From fly larvae to fine food

Humankind clears rainforests to cultivate soybeans and overfishes oceans to obtain fishmeal. Fraunhofer IME has come up with a more sustainable way of sourcing valuable protein. Now if only the soldier fly could break through the yuck barrier.

By Christine Broll

Andreas Vilcinskas spends a lot of time these days talking to investors and bankers, traveling to their haunts in Singapore and London or meeting them at home in Giessen. Wherever these talks take Professor Vilcinskas, he always has to field the same sort of question from the moneymen and women: Should we really be investing our pretty pennies in these ugly bugs?

The professor has a reassuring answer ready: "Insects are going to be the feed of the future for livestock. They also provide a sustainable, climate-friendly way of producing animal protein." Andreas Vilcinskas heads up the Biore-sources department of the Fraunhofer Institute for Molecular Biology and Applied Ecology IME. He is confident that insect biotechnology's time has come. If not now, then when? As a specialist who has had a formative hand in shaping this field of research, he is certainly qualified to address that issue: "Rain forests are being cleared to grow soybeans; oceans are being overfished to produce fishmeal." The production of livestock feed clearly causes great environmental damage. The solution, according to Andreas Vilcinskas, is insects. They provide valuable proteins and fat – yet their ecological footprint is minimal. Insect farms also look to be an excellent business prospect, which appeals to investors.

Andreas Vilcinskas and his team will have a new 30-million-euro building at their disposal in Giessen by mid-2020. Funded in equal parts by the state of Hesse and the German federal government, this facility is to accommodate a hundred scientists. Alongside an array of labs, it will have a greenhouse for rearing insects. This new Fraunhofer Institute for Bioresources is going to research the full spectrum of insect biotechnology. Hexapods are more than just a great source of protein; they are an all but inexhaustible wellspring of natural substances that serve useful purposes in medicine and crop protection.

The larvae of the black soldier fly, *Hermetia illucens*, make good livestock feed. Growing to a length of two centimeters, these flies inhabit tropical and subtropical regions worldwide, including southern Europe and parts of the Balkans. The Indonesian island of Sumatra will soon be home to the world's biggest black soldier fly farm. Construction of a breeding facility is underway with a little scientific help from the entomologists at Giessen. Built to the tune of a half a billion dollars, this plant is going up next to a huge palm oil factory, the leftovers of which are to feed the flies' larvae.

The first priority of Vilcinska's team is to develop a process to break down the pressed shells of oil palm seeds so that flies can digest these waste products. The residual pulp goes into flat boxes, which are then populated with freshly hatched larvae. Growing to a good two centimeters within two weeks, these larvae wiggle their way out of the substrate once they are mature enough to pupate. Come harvest time, fly farmers take advantage of this migratory instinct to simply collect the larvae, which are then freeze-dried. The extracts contain some 40 percent protein and around 35 percent fat. These fractions are mixed to make feed tailored to the nutritional needs of various livestock such as fish, chickens and pigs.

## A natural-born survivor

Sumatran palm oil production is expected to churn out more than a million metric tons of residual plant matter a year. These leftovers will serve as the substrate for growing fly larvae. "Diseases can always be a problem with a stock as big as this," cautions Andreas Vilcinskas. He and his team are developing a pathogen monitoring system with this in mind. "We definitely want to work without antibiotics to avoid polluting the environment." He also wants to maintain the green reputation that insect protein has earned. ►

Harvested larvae are freeze-dried; the extract contains 40 percent protein.





“Learning from insects means learning to win.”  
 Prof. Andreas Vilcinskis is a trailblazer in insect biotech.  
 © Fraunhofer/  
 Piotr Banczerowski

“The larvae produce anti-microbial peptides.”

Prof. Andreas Vilcinskis

► Chances are good his plans will pan out. The larvae of the soldier fly are natural-born survivors with an impressive immune system, perfectly adapted by nature to grow up amid rotting waste and dung teeming with germs. Vilcinskis and colleagues at the University of Dresden and the Max Planck Institute for Chemical Ecology are investigating how these flies manage to keep pathogens at bay. The team found more than 50 different antimicrobial peptides in the insects to explain their larvae’s remarkably robust immune system. Even more remarkable is that the spectrum of peptides produced by these animals changes with their diet. “By optimizing the food used to rear larvae, we can make sure they produce antimicrobial peptides to ward off key pathogens such as salmonella and listeria,” says Vilcinskis. “These peptides end up in the insect meal, protecting it against bacterial contamination.”

### A fly in the food chain – from larvae to chickens to humans

The market prospects for insect protein look brightest in Indonesia and neighboring countries, where people have no qualms about feeding it to animals. Insects also figure prominently in local traditional cuisine. The likes of grilled grasshoppers and fried silkworms have long been popular delicacies for humans.

People in Africa, too, are open-minded about insect-based livestock feed, so farmed soldier flies could go a long way toward enriching the population’s diet with protein. A pilot project in Kenya is a case in point. A startup called Sanergy has set up portable toilets in the slums of Nairobi. The company regularly empties their tanks, collecting human excrement in large barrels that go to an insect farm, where it is mixed with waste from restaurants and fed to black soldier flies. The larvae are processed into chicken feed, the chickens lay eggs, people eat the eggs and then – to put it delicately – the perfect recycling economy comes full circle.

Inhibitions run highest in Europe. Feeding animal protein to livestock had been a no-go since the EU banned the practice

in the wake of the BSE epidemic. Contaminated meat-and-bone meal was thought to cause the spread of mad cow disease. It was not until 2017 that the EU relaxed the regulations and has since allowed fish farms to use insect-based feed. However, larvae reared on waste are still taboo. Andreas Vilcinskis expects the EU to permit insect-based feed for other livestock as well, first for poultry and then perhaps later for pigs.

Companies seeking to commodify the black soldier fly in Europe share that hope. Suppliers in Germany do business on a very small scale, growing larvae for pet fish and reptiles or making cat food with insect meal. Larger companies in Belgium and the Netherlands are investing to plant a footprint in this emerging market.

### At the top of the pyramid, a gourmet eatery

The EU ban on larvae fed with manure or catering waste makes life hard for businesses seeking to turn a profit with fly farms. Rearing larvae with approved feed such as grains is ecologically unsound. This is why Andreas Vilcinskis has opted to go with organic by-products sourced from the food industry, such as pomace – the pulpy leftovers of apples pressed to make juice. To demonstrate that this line of business can indeed create value in Germany, he is setting up a closed system in which fly larvae serve as food for upmarket shrimp. Turning the lowly black soldier fly into pricey black tiger prawns certainly does that. Part of the “Bioökonomie im Ballungsraum” [*Metropolitan Bioeconomy*] initiative, this project is funded by the German Federal Ministry of Education and Research. ■

### Insects’ long march to the table

Europeans are most circumspect about the notion of insects as food, a reluctance born of the BSE epidemic. That is beginning to change. People are now free to dine on edible insects in the EU since Brussels gave its official blessing in 2018. More and more are overcoming their inhibitions to nibble a bit of bug here and snack on a crispy cricket there. And for good reason: insect-based food is healthy and ecofriendly. Foodies can now buy freeze-dried grasshoppers and buffalo worms, and consult cookbooks with recipes on preparing roasted mealworms on a bed of herbs or crickets with honey and sesame seeds. Some supermarkets already offer insect protein bars and frozen insect burgers. Resident expert Andreas Vilcinskis is confident that insect-based products will have gone mainstream in ten years’ time.

# Diving deep with high aims

A state-of-the-art research campus for underwater technologies is in the works at Rostock. Its centerpiece is the Fraunhofer Digital Ocean Lab.

By Mandy Bartel

Christof Schygulla peers out over the Baltic Sea from his vantage point on the shore of the Warnemünde coast. Out in the distance lies the Nienhagen Reef, an artificial seascape this marine biologist knows well. This is where he investigated microorganisms' colonization of reef structures for the University of Rostock, and later red algae seaweed farming. Today, he heads up the Digital Ocean Lab at Fraunhofer IGD in Rostock, a proving ground for underwater technologies to be built along this artificial reef in the years ahead. Once it is operative, business and science organizations will be able to test and further develop autonomous diving robots, underwater drones, and control and image recognition systems in real-world conditions.

## Potential, deep down under

Just five percent of the world's oceans have been explored to date. Some say we know more about the Moon and Mars than we do about the depths of the oceans. Our lack of knowledge is mainly down to the inhospitable conditions below the surface. "Poor visibility, enormous pressure and strong currents complicate the effort and drive up the costs of exploring the oceans. We need new and better technologies to clear these hurdles," says Schygulla. Enormous potential lies dormant underwater, with new resources waiting to be tapped and offshore wind farms to build and maintain.

Other seaborne tasks on the marine biology to-do list include preserving biodiversity and fish populations, finding and exploring wrecks, and protecting ecosystems by clearing lingering hazards such as unexploded mines.

"Opportunities to test new technologies exhaustively in a real-world environment hardly abound, despite huge demand from the industry," says the researcher. The new proving ground caters to many applications. The unexploded ordnance yard, for example, serves to test sensors and image recognition systems designed to accurately detect hazards in the seabed. The cable yard makes a fine testing ground for new cable covers and running cable-laying trials. Robot divers can go on training missions and professional users can learn the ropes in the current yard. There is also an obstacle course and a free area for exploring other scenarios. This subsea installation is just one part of the Digital Ocean Lab, the other being an onshore operations center in the Rostock Fishery Port. It controls and monitors missions and test runs.

The marine lab is embedded in the Ocean Technology Campus Rostock. Born of an initiative that the Hanseatic City of Rostock is pursuing with local partners in industry and science, this campus is set to be the largest of its kind for researching and developing underwater technologies. Many companies and institutions are to settle here under this roof over the next few years, underpinning the city's position as a business hub.

**The support** for the campus from all quarters – business, science and government – certainly delights the marine biologist. Economics is a big factor, but Schygulla's top priority is to protect the oceanic ecosystem. "In marine research, we have to strike a good balance between using and protecting the oceans. This lab is making an important contribution toward optimizing and testing underwater technologies and processes with sustainability in mind." ■

"We have to strike a good balance between using and protecting the oceans."

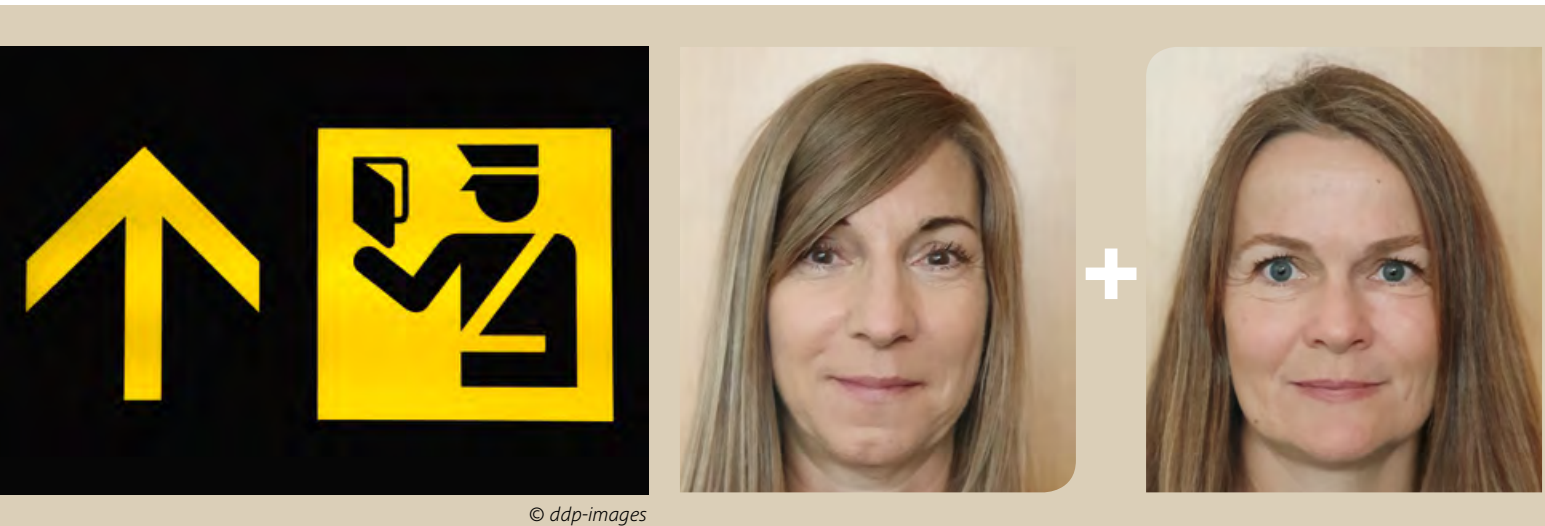
Christof Schygulla

The underwater proving ground's yards serve to test technologies ranging from diver robots to sensor systems under realistic conditions.

© Fraunhofer IGD







© ddp-images

## One face for two

Automated passport checks are de rigueur worldwide. Yet facial recognition systems are vulnerable. That can be dangerous in times of terrorism, transnational crime and mass refugee migrations. The Fraunhofer Institutes HHI and IPK are striving to tighten up security.

By Britta Widmann

“Criminals are able to trick facial recognition systems.”

Lukasz Wandzik,  
Fraunhofer IPK

One passport for two people? It can happen, as a story that starts at a Berlin citizens’ affairs bureau goes to show. The short of it: Apply for an express passport. Verify credentials with an ID card. Pay the €37.50 admin fee. Hand over a picture. Drop by nine days later to pick up a new passport fresh off the federal presses. That is how a political activist who goes by the nom de guerre Billie Hoffmann obtained an official travel document that would have also gotten Italy’s former foreign minister, 46-year-old Federica Mogherini, past automated passport control gate facial recognition systems. As it turns out, Mogherini just happened to also be the EU’s High Representative for Foreign Affairs & Security Policy at the time. The key to this subterfuge was a morphed passport picture. A computer had merged two biometric photos to get one passport made for two people.

### Convenient, but risky

Automated passport checks with cameras and scanners are certainly convenient. They shorten the wait at border

crossings and the lines at immigration. On the downside, this type of authentication is vulnerable to morphing attacks. “Criminals are able to trick facial recognition systems so that two people can use the same passport,” says Lukasz Wandzik, a scientist at the Fraunhofer Institute for Production Systems and Design Technology IPK in Berlin. Wandzik, his colleagues at the Fraunhofer Institute for Telecommunications, Heinrich-Hertz-Institut, HHI and other partners are developing algorithms to detect anomalies typical of morphed images.

**This project goes by the name of ANANAS**, the German acronym for Anomaly Detection for Prevention of Attacks on Authentication Systems Based on Facial Images. Fraunhofer magazine tested the security mechanism with pictures of the author and three coworkers. “Our detector spotted all three morphs despite the non-biometric source images. If the passport checkpoint had been equipped with the ANANAS detector, the author would not have passed the gates with these manipulated images on her ID card,” says Prof. Peter



Turning two into one: a morphed image poses a real threat if two people are able to use the same passport.  
© Fraunhofer / Britta Widmann



Eisert, who heads up the Vision & Imaging Technologies department at Fraunhofer HHI.

This added layer of security comes courtesy of deep neural networks that the researchers trained with morphed and genuine facial images. They can sniff out morphs by the trail of the changes made. "The detection rate for the test databases we created for the project topped 90 percent," says Prof. Eisert.

**Neither the shape of the face nor the hair color** betray any traces of tampering. The telltale signs that give the fake away are often just the subtlest of retouches. "A slightly blurred area here, a duplicate eyelash there, unlikely looking wrinkles or light reflections can point to manipulations," notes Eisert, a computer scientist. Reflections, for example, can reveal a lot about the ambient lighting. If it is inconsistent, casting odd shadows on the skin or bringing out unusual or multiple highlights, the picture could well be a fake.

### What raises suspicions?

Eisert and his team at Fraunhofer HHI want to know if a picture is genuine, but they are also interested in learning the rationale behind the decision. "The problem is that we don't know how the neural network made its decision," says Eisert. So the scientists developed layer-wise relevance propagation algorithms to find answers. Analyzing regions in the facial image that play a part in this decision, these LRP algorithms look closely at suspicious areas to identify and

categorize artifacts generated during a morphing process. And they do indeed detect morphs, as reference tests have confirmed. The LRP software marks the manipulated facial areas.

### AI vs. AI, gatekeepers vs. gatecrashers

Researchers are putting this information to good use by making neural networks more robust and able to spot diverse types of attacks. "Criminals can draw on increasingly sophisticated methods of attack such as AI tools that generate entirely artificial facial images. By optimizing our neural networks, we're trying to stay a step ahead of counterfeiters and anticipate future attacks," says the IT professor.

The demonstrator software suite includes anomaly detection, evaluation tools and merged detector modules provided by the project partners. These interconnected modules use different methods to detect manipulations. "That's what sets this software apart – the various methods that yield a collective result at the end of the process that can be counted on to thwart criminal attacks. You could say that it's better to check twice or thrice for good measure," notes Lukasz Wandzik.

Funded by the German Federal Ministry of Education and Research (BMBF), the ANANAS project will run until May 2020. The aim is to integrate the software into facial recognition systems in place at border crossings, adding morphing detectors to catch fakes and prevent these attacks. ■

A passenger peers at the camera of an airport's automated passport control kiosk. The system compares what the camera sees with the picture in the passport. This ID proofing tool is seeing wider use in smartphones, at points of sales and in other transactional systems.



# Gene therapy as a last hope

How white blood cells are being armed  
for the fight against cancer cells

By Christine Broll

**B**efore opening the special liquid-nitrogen-cooled container, Melanie Müller dons safety goggles and special gloves. She carefully removes a metal box containing a patient's blood bag. The bag holds numerous T cells, a special type of white blood cell. She doesn't know who the sample belongs to, but she knows precisely what fate lies behind the number under which the bag is registered.

The patients whose blood she works with here suffer from severe forms of lymph node cancer or leukemia. Many of them are children. They are considered untreatable, meaning that all standard treatment options have been exhausted. Kymriah®, a gene therapeutic, is their last hope. It is manufactured – individually for each patient – at the Fraunhofer Institute for Cell Therapy and Immunology IZI on behalf of the Swiss pharmaceutical group Novartis.

Kymriah® was the first gene therapy approved for the treatment of cancer. It has been on the market in the U.S. since August 2017, and in the EU since August 2018. So far, Fraunhofer IZI in Leipzig is the sole production site in Europe for the product approved by the European Commission. The complex production process was established there in collaboration with Novartis – initially for clinical studies and now for treating patients. Fraunhofer IZI is also working hard to make gene therapies more economical and efficient. Today, in Germany, treatment with Kymriah® costs 275,000 euros per patient.

## Reprogramming in the cleanroom

The blood bags that the team at Fraunhofer IZI receive are thawed out in the ultrasterile cleanroom with genetic engineering safety level S2. Here, Melanie Müller and the other employees wear full-body coveralls with a hood, shoe covers, two pairs of gloves, face mask and safety goggles so as not

to run any risk of contaminating the patients' blood cells. The cleanroom is where the patients' T cells are genetically transformed, arming them for the fight against cancer cells.

**The T cells are reprogrammed** to enable them to recognize the cancer cells. A non-replicating virus transports a gene that forms a special receptor on its surface – the chimeric antigen receptor, or CAR for short – into the T cells. This is why the reprogrammed cells are called CAR T cells. With the receptor's help, they can now identify cancer cells as the enemy and do what natural T cells normally do with hostile bacteria and viruses: initiate an immune process that kills the enemy.

Following the transformation, the lab in Leipzig propagates the CAR T cells and tests them extensively. After about 22 days, they are sent, deep-frozen, to the patient to save a life.

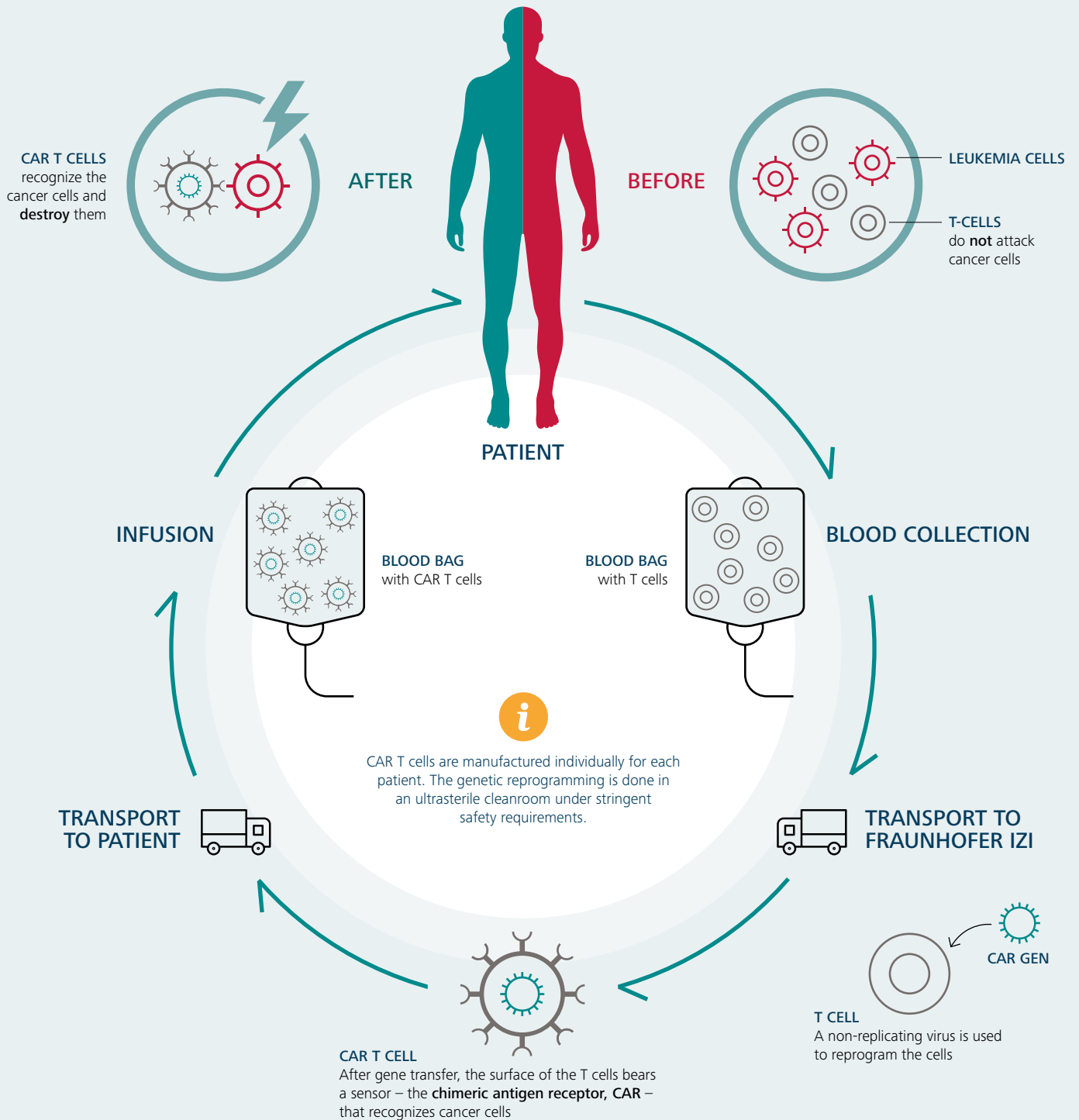
Patients who are currently being treated with Kymriah® in Europe have a long history of suffering behind them. This treatment is approved only for cases in which at least two standard treatments have already failed. It is used for children and young adults up to 25 years of age with pediatric acute lymphoblastic leukemia (pALL), as well as adult patients with a form of lymph node cancer known as diffuse large cell B-cell lymphoma. Those affected normally have a life expectancy of just a few weeks or months.

The CAR T cells are normally administered to patients only once by infusion. This destroys the cancer cells and triggers an intense immune reaction. If this causes the release of too many immunological messenger substances, such as cytokines, a cytokine storm may result – accompanied by high fever and flu-like symptoms. Neurological disorders are also possible. ▶

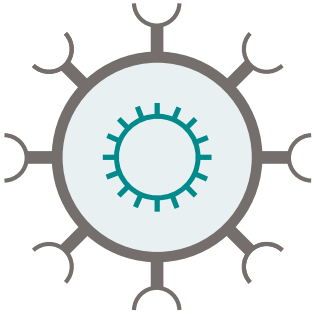
Kymriah® was approved for use in the EU in 2018. In Germany, this therapy costs 275,000 euros – per patient.

# CAR-T cell therapy

In the lab, a patient's T cells are reprogrammed to recognize and destroy blood cancer cells.







► The specialized centers that work with Kymriah® are equipped with intensive care facilities where they use a variety of therapies to battle these and other side effects.

Since the CAR T cells can continue to multiply in the patient's bloodstream, this treatment can also reduce tumor cells over the long term, as the results of clinical studies have shown. In the ELIANA study, 79 patients with acute lymphoblastic leukemia were treated. Of those, 82 percent responded to the treatment, and two years later, 66 percent of the patients treated in the study were still alive.

### Therapies for breast and lung cancer, too

So far, the CAR-T cell therapy is available only for patients with B-cell-based cancers. This is because the CAR construct used for Kymriah® recognizes a very specific target molecule that occurs only in degenerate B cells. However, companies and research facilities around the world are working to develop CAR-T cell therapies for treating solid tumors and other types of cancer.

At Fraunhofer IZI, the department headed by Dr. Gerno Schmiedeknecht and Kati Keibel is pursuing a promising approach – in cooperation with the University Hospital of Würzburg and the Max Delbrück Center for Molecular Medicine in Berlin. The project is being funded through the Proof of Concept Initiative, a platform through which Deutsche Hochschulmedizin, the Helmholtz Association and the Fraunhofer-Gesellschaft are intensifying their collaboration. "Our partners in Würzburg have developed a CAR construct that recognizes a special target molecule that also occurs on certain solid tumors," says Gerno Schmiedeknecht. "The target molecule is called ROR1 and occurs on lung and breast cancer cells, among others. We are currently developing a method to produce CAR T cells that destroy these cancer cells."

By developing this method, the research team aims to make the manufacture of personalized CAR T cells more econom-

ical and efficient. Currently, a non-replicating virus is used to introduce the gene for the CAR construct into the T cells. However, these specialized viruses are extremely expensive and difficult to procure, which is why, for the gene transfer in the project, they use an alternative: a transposon – a jumping gene that can change its position within a genome. "The virus-free transfer method is more economical and highly efficient," Schmiedeknecht says. Upon completion of the project, initial clinical tests with the CAR T cells targeting different tumors are planned for 2021 at the University Hospital of Würzburg.

CAR-T cell therapies save terminally ill patients' lives, but they pose a major challenge for the healthcare system. In Germany, around 50 patients have so far been treated with Kymriah®. In mid-September 2019, Novartis signed an agreement with the National Association of Statutory Health Insurance Funds (GKV-SV) to defray the treatment costs.

### Who's going to pay for it?

But what will happen when CAR-T cell therapies are also approved for the most common tumor indications, breast and lung cancer? Then patient numbers will soar. Will the health insurance companies still be able to bear the costs of several hundred thousand euros per patient? Or will this treatment be reserved for those who can afford it?

Gerno Schmiedeknecht takes a less pessimistic view of this development. "When the first monoclonal antibody therapies came on the market, they, too, were extremely expensive owing to ineffective manufacturing processes," says the department head. "Today, modern manufacturing methods and the approval of the first biosimilars have resulted in significantly lower prices. Currently, manufacturing the CAR T cells still requires a great deal of manual work in the lab. To save time and costs, we are aiming to automate production." Support for this endeavor could come from experts at other Fraunhofer Institutes. After all, process automation is one of Fraunhofer's strengths. ■

"To save time and costs, we are aiming to automate production."

Gerno Schmiedeknecht,  
Fraunhofer IZI

Patients' frozen immune cells arrive in blood bags and are then genetically reprogrammed in the Fraunhofer IZI cleanroom to manufacture the cell therapeutic agent.  
© Fraunhofer IZI

## Gene therapy

In gene therapy, foreign genes are introduced into a patient's somatic cells. There are two types of gene therapies.

1. Gene therapy for hereditary diseases: An appropriate gene is inserted into certain somatic cells to offset an inherited genetic defect. Three such therapies have thus far been approved in Europe. They are used to treat beta thalassemia, ADA-SCID (a severe immunodeficiency) and a rare inherited retinal degeneration.
2. Gene therapy for cancer: A gene transfer enables a patient's T cells to recognize and fight cancer cells. In Europe, two therapies have been approved for different, aggressive forms of leukemia and lymph node cancer: Kymriah® from Novartis and Yescarta® from U.S. company Gilead/Kite Pharma.

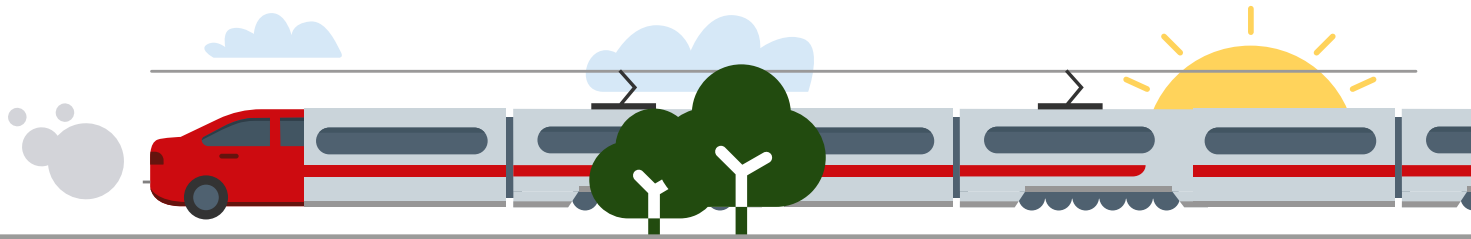
Many other gene therapies are currently being developed, such as one for hemophilia.



In the Fraunhofer IZI cleanroom, the cell-based gene therapeutic Kymriah® is manufactured for each patient individually under stringent safety conditions.  
© Fraunhofer IZI

## Video on manufacturing CAR T cells at Fraunhofer IZI:

[https://www.izi.fraunhofer.de/content/dam/izi/de/Videos/Beitrag\\_CAR\\_T\\_Extern\\_2018.mp4](https://www.izi.fraunhofer.de/content/dam/izi/de/Videos/Beitrag_CAR_T_Extern_2018.mp4)



# Making travel easier with blockchain

It's New Year's Eve. Your plan is to take the subway to Munich central station, jump on a fast train to Cologne and grab a taxi to the party. It's fairly easy to find the cheapest route from A to B and from C to D using an app. But imagine if you could simply click on "book now" and buy a ticket for the whole journey in just one click! It would make life so much easier - but we're not there yet.

By Sonja Endres

**P**rofessor Gilbert Fridgen and his colleagues at the Fraunhofer Institute for Applied Information Technology FIT are on a mission to make traveling in Germany easier. Their plan is to develop an open, decentralized mobility system, known for short as an OMOS. The idea is for all mobility providers to make their data available through a central platform. An algorithm could then use this data to calculate the cheapest journey, allowing consumers to select, reserve and pay for their trip with just one click.

Customers don't have to worry about who bills what.

"This kind of platform has never got off the ground because Deutsche Bahn, Lufthansa, public transport operators and car sharing companies are understandably reluctant to hand over the reins and their customer relationships to a platform operator," says Fridgen. Blockchain technology offers a way to bypass this problem by creating a neutral platform that eliminates the need for an operator. The idea is for customers to access the platform using existing apps such as DB Navigator and Share Now. Depending on the app, preference could be given to a specific mode of transport in the event of a tie between two different journey options. For example, the DB Navigator app would put trains and public transport at the top of the list, while Share Now would prioritize car sharing.

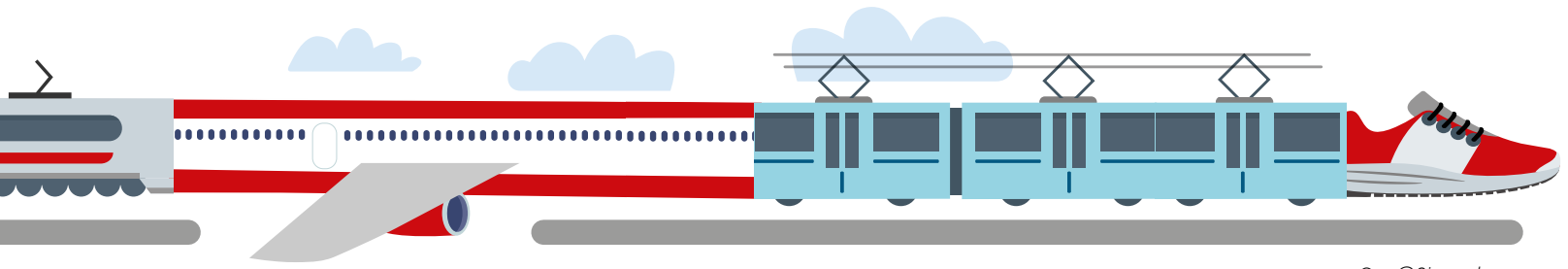
"Blockchain is a bit like a notebook that can be accessed and read by anyone. Deutsche Bahn can see all its train routes in the notebook, but it can also see what options other providers offer, and at what price. That means it can offer customers a package covering their entire journey - such as a taxi to Berlin's main train station followed by a high-speed train to Bayreuth and a car share to their final destination of Kulmbach."

The trip booked by the customer is added to the notebook as a permanent entry that cannot be deleted or modified, together with the details of the services and prices provided by each operator.

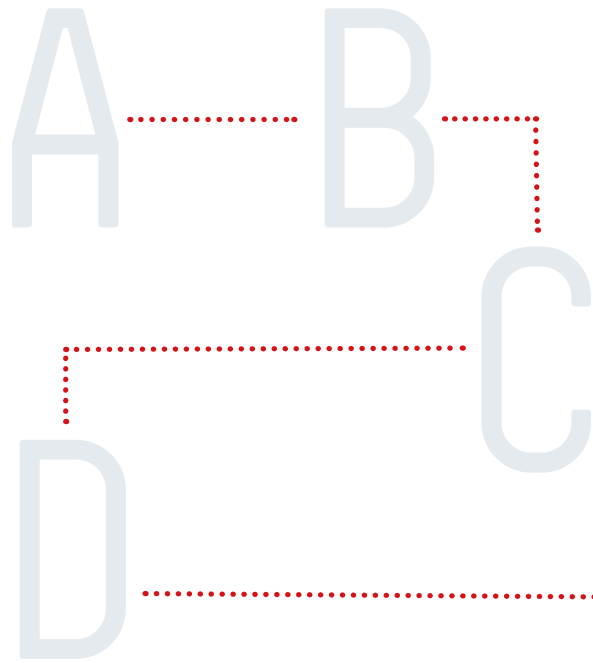
## Easy and convenient

"Deutsche Bahn, the taxi companies and the car share operators sort out the whole billing process between them, leaving customers to simply enjoy their journey. If the customer uses the DB Navigator app, Deutsche Bahn receives the payment and shares it out accordingly. The operators could also agree to allocate five percent of the ticket price to the company that receives the payment, much like the commission paid to a travel agent," says Fridgen.





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### Cheaper and more eco-friendly

Owning a car used to symbolize freedom and independence, the ability to simply jump in and drive off at a moment's notice, alone or with whomever you choose. But the fun of driving in cities like Munich, Hamburg and Berlin has evaporated – and freeways throughout the land seem to get more and more crowded by the day. A combination of tailbacks, roadworks and the endless search for somewhere to park is driving many city dwellers – especially younger ones – to opt for buses, trains and bikes, whether electric or otherwise. These alternatives are also cheaper and more eco-friendly. Younger generations are also less likely to perceive a car as a status symbol, and less likely to buy one in the first place. But mobility can get a lot trickier once they leave the city limits.

The OMOS platform would make journey planning and payment smooth and simple while also offering far more flexibility. For example, if the train is running half an hour late and the car share option is no longer available, the platform can quickly offer alternatives, informing the customer before they even leave the train that a taxi is now waiting for them at the station instead of the car share.

Technically speaking, everything OMOS requires is already in place. Fraunhofer FIT has also conducted a feasibility study on behalf of the German Federal Ministry of Transport – and the results show there is plenty of enthusiasm among consumers for mobility on demand. Owning a car is gradually becoming less and less appealing, and eco-conscious consumers are increasingly willing to consider alternative, more environmentally friendly modes of transportation. OMOS offers the kind of convenience and flexibility that makes it easier to switch, says Fridgen: "If all the mobility providers pulled together, we could see the platform's basic functions up and running within the next couple of years; then it could gradually be expanded."

Businesses are keen to jump on board, and two initiatives have already been set up to establish an open mobility system. "That kind of misses the point, however. To continue the notebook analogy, we don't want a red one, a blue one and a black one! We want one notebook that contains everything. That's why we're talking to those companies and hoping to persuade them to pool their initiatives. If they do, we'll be on hand to offer advice and help them push ahead with their developments and coordinate their work." So far the signs look good – and the next meeting is already in the cards. ■

# OMOS

# “Preventing atrocities”

Whether enjoying a glühwein at a Christmas market, celebrating New Year's Eve at the Brandenburg Gate, or traveling through Germany by train – wherever we are, it's comforting to know that the very best technology is helping protect us against terrorist attacks and violent crimes.

By Janine van Ackeren



Commemorating the victims of the terrorist attack at Berlin's Breitscheidplatz in 2016. © imago images

**O**n July 29, 2019, a psychologically disturbed man propelled a mother and her eight-year-old son onto the tracks and in front of an ICE train as it rolled into Frankfurt am Main central station. On July 28, 2017, customers in a Hamburg supermarket were stabbed with a knife by an asylum seeker. One person died, and a further five were injured. On October 9, 2019, the day of Yom Kippur, the most solemn religious holiday of the Jewish year, a right-wing extremist attempted to storm the synagogue in the east-German city of Halle and shoot assembled worshippers. Having failed in his attempt, he went on to shoot a passerby and a customer of a Turkish fast-food outlet. So how can we make ourselves safer against terrorist attacks and violent crime? It's a question that won't go away.

## How technology can stem violent crime

Smart video surveillance, a technology developed by the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB, could help drastically reduce violent crime. To date, video surveillance has generally had a bad press, with many people concerned about issues surrounding data privacy. This new system, however, offers inbuilt protection. "It automatically identifies whether incidents or activities are suspicious and therefore relevant," explains Dr. Markus Müller, departmental head for video-monitoring systems at Fraunhofer IOSB. If, for example, cameras are recording a harmless scene such as someone with a shopping bag strolling across a square or children playing on the street, then the screens back in the monitoring room remain blank or heavily pixelated, so that nobody is identifiable. If, however, the system recognizes an instance of violence such as a kick or a blow, it activates the monitors and notifies the duty officer.

"The system operates like a digital tracker dog," Müller explains. "Tracker dogs are trained to recognize certain smells. It's only when they detect that smell that they begin to bark. Our system works in a similar way. It only reacts to actual incidents or assaults and ignores any other forms of behavior." In other words, a notification from the system is like someone placing a call to the emergency services. But how exactly does the system recognize that an actual assault has taken place? The answer is simple: artificial intelligence. Researchers at Fraunhofer IOSB have trained the system by repeatedly feeding it with video sequences showing violent acts such as kicks or blows. With each new video, the system becomes even better at recognizing potential assaults.

## Enhanced security at the station

Yet the power of decision remains very much in human hands. As soon as the system identifies a suspected assault and activates the screens, a security officer studies the

images and either rejects the notification as a false alarm or takes appropriate action such as informing the police. "We can't prevent the initial assault," says Müller. "The system's job is to identify incidents as they happen. But what we can do is prevent any further escalation. By identifying an assault and intervening straight away, we can stop it turning into attempted or even actual homicide."

Police in Mannheim are now using the technology in a pilot project to monitor crime hot spots. All in all, the system analyzes video material from a total of 70 cameras – in parallel and in real time. The public response has been extremely positive, with some 80 to 85 percent of people welcoming the new technology. "The crime rate has fallen, Müller confirms. "On average, it takes less than two minutes for the police to arrive at any of the areas under surveillance."

And at railroad stations and similar public spaces, security personnel are able to intervene within a matter of seconds. In the event of an assault, the duty officer can address the assailant directly via loudspeaker: "You are under observation. Security is on its way. Cease and desist!" Evidently, this system will not be able to prevent incidents of the kind that happened in Frankfurt. Had there been police officers on the platform right next to the victims, it is still unlikely that they would have been able to avert the attack. In many other situations, however, the system can substantially reinforce security. "There was a situation one night in a subway station, when a group of people pushed a man down onto the trackbed and then wouldn't let him back up for several minutes," Müller recalls. "With smart video surveillance, security personnel would have been able to intervene right away and prevent any more crimes being committed."

**"We see our technology as helping society:** We want to prevent such atrocities – or, at the very least, stop the terror escalating," Müller continues. Fed with appropriate data, the system can also be trained to recognize specific body positions that are typically assumed by people holding or pointing a weapon. Such positions are significantly different from "normal" body postures. "We believe that smart video surveillance technology could be used to monitor particularly vulnerable locations, such as synagogues throughout Germany. Were this the case, police could have been sent to the synagogue in Halle before a single shot was fired. And then, quite possibly, there wouldn't have been any fatalities."

## Protection against dirty bombs

In a project known as REHSTRAIN (REsilience of the Franco-German High Speed TRAIIn Network), researchers at the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE have developed a technology to counter the threat of so-called dirty bombs, which are ▶

**"The system operates like a digital tracker dog."**

Dr. Markus Müller,  
Fraunhofer IOSB



“We hope that our technology will prevent atrocities – or, at the very least, stop the terror escalating.”

Dr. Markus Müller,  
Fraunhofer IOSB

► contaminated with radioactive material. “Our system detects whether someone in a stream of passersby is carrying a radioactive source and then warns security personnel,” explains Dr. Felix Govaers, deputy departmental head for sensor data fusion at Fraunhofer FKIE. The system is made up of a number of components. Gamma spectrometers, installed in the floor or the walls of a railroad station, are able to detect radioactive radiation and even determine the type of isotope. They cannot, however, localize its source. For this purpose, the network of gamma spectrometers is connected to commercial Kinect cameras, which not only provide images of passersby but also calculate their distance from the sensors. Data fusion software is then used to merge all this data, thereby pinpointing the radiation source and assigning it to a specific person.

When installed at strategic locations – e.g., entrances to stations and airports, ticket barriers, departure gates, or in public buildings – technology of this kind could supply security personnel or surveillance systems with information on a potential dirty bomb attack. Crucially, here too, any decision to intervene remains under human control. Fraunhofer FKIE is currently in discussion with the Düsseldorf company innoRIID, which would like to market the system.

### Defense against dangers from the skies

Let’s imagine a major event, such as the New Year’s Eve celebrations at Berlin’s Brandenburg Gate. A drone suddenly appears in the skies above. Is it harmless? Or is it an airborne weapon controlled by terrorists and carrying explosives – or, more likely, an incendiary device – into the midst of the huge crowd? This scenario shows just how urgently we require systems capable of identifying and defending against drone attacks. In AMBOS, a project to develop defense systems against unmanned aerial vehicles (UAV) for authorities and organizations with security roles, 12 partners from industry, research and higher education have now devised such a system. Funded by Germany’s Federal Ministry of Education and Research (BMBF), the project was coordinated by Fraunhofer FKIE.

The system comprises a radar sensor, cameras, a radio reconnaissance sensor to analyze the radio signal used by the remote controller, and acoustic sensors to detect the sound of an approaching drone. Each sensor plays a complementary role: whereas the radar has a range of several kilometers, it requires a line of sight to the drone – as do the cameras; by contrast, the radio reconnaissance and acoustic sensors do not require a line of sight, but the acoustic sensor has a range of max. a couple of hundred meters and is sensitive to ambient noises. “The system’s great strength is its multimodal character and especially its sensor data fusion software,” explains Hans Peter Stuch, project coordinator and head of the AMBOS

research group at Fraunhofer FKIE. “This not only merges all the data from the various sensors but also monitors the quality of data from each individual sensor.”

### For emergency services charged with ensuring security at major events, the system helps them assess each

situation and react appropriately. Were a drone to approach New Year’s Eve revelers at Berlin’s Brandenburg Gate, security would be able to track its position, altitude, speed and direction of flight on a digital map. Moreover, the system also analyzes this data so as to determine the level of actual threat and suggest possible countermeasures. If appropriate, such measures can be implemented at the push of a button by the head of operations. The initial option is to broadcast an interference signal, which blocks any signal received by the drone from its remote controller. Unless the drone is an autonomous UAV, it will then most likely do one of three things, depending on its configuration: hover motionlessly in the air, land on the ground or return to its takeoff position. The second option to counter a drone is to transmit a pulse of high-energy electromagnetic radiation. This will tangle up the drone’s flight controller, thereby causing, amongst other things, the rotors to stop turning – with the result that the drone will fall from the sky like a stone. The third option is to use a net gun to physically bring the drone down.

The project was brought to a successful conclusion at the end of June 2019 with an evaluation program held in the German town of Mosbach. Drones were flown in a variety of scenarios toward an area under surveillance. The system was able to recognize the danger and, under the control of the operations leader, undertook appropriate countermeasures. “We’re in discussion with a number of police departments and German air traffic control about the core system, which features sensor data fusion, positional graphics and decision support, and which can be combined with various sensors and defense measures,” says Stuch. It is to be hoped that such technology will soon be helping to limit horror scenarios involving drones.

### Twitter scans for greater security

Another critical arena in the fight against terrorism is social media, which is being increasingly used by extremists for communication purposes and for announcing planned attacks. In the future, security forces will be able to turn to another technology from Fraunhofer FKIE in order to search tweets and other social media postings for keywords and thereby narrow down terrorist suspects. This technology combines an analysis of recorded phone calls with a search engine for social media postings. Once a judge has authorized the wiretap, a suspect’s telephone calls are analyzed in a total of three stages: Firstly, calls are scanned to filter out all the intervals in which no speech is to be heard. Secondly,



NewsHawk can help to pick out terrorists and radical groups from a mass of people. © ddp images, Stocksy/F1online

the system compares recorded passages of speech with stored voice samples. This is done with a view to identifying unknown voices – which would otherwise be impossible in the case of callers using a burner phone. Thirdly, the system searches recorded speech for keywords selected by the security forces. Should this further confirm their initial suspicion, they can then use a tool by the name of NewsHawk to analyze suspects' postings on social media or Twitter.

**In the wake of terrorist attacks**, this technology can also be useful for identifying further members of a terrorist cell and thereby hindering new acts of violence. "NewsHawk is like a search engine for Twitter," explains Prof. Ulrich Schade, head of the research group for information analysis at Fraunhofer FKIE. First of all, the tool draws up a chart in which the terms most frequently used in connection with a specific keyword – e.g., the hashtag #Halle0910 – are shown in circles of corresponding size. Clicking on the circle for a specific term reveals all the tweets that also contain this

term. In addition, the search can be further refined so that, for example, only tweets are selected that contain the term X but not the term Y.

Secondly, an analytic tool – specially trained via machine learning for this specific task – is used to scan the corresponding text files for the emotional content of those tweets. For example, a user might express approval of a terrorist attack and call for further acts of violence. Alternatively, they might condemn it. "It's important to take into account the specific language used by each radical group. An Islamist uses different expressions than a right-wing extremist would," Schade explains. Thirdly, the tool analyzes the metadata in order, for example, to ascertain who is following posters who express approval of terrorist attacks. In this way, the tool is able to draw up a network diagram showing who is connected to the perpetrator of a terrorist attack. "For an experienced analyst," says Schade, "it just takes one look at this diagram in order to identify critical nodes." ■

Radar, radio reconnaissance and acoustic sensors for protection against drone attacks

# Gone with the wind

There are 30,000 wind turbines in operation in Germany, many of which are beginning to age. In 2019, 2000 rotor blades had to be discarded; in 2024, this figure will shoot up to 15,000. But where to put these up to 90-meter-long, 15-metric-ton behemoths?

By Sonja Endres

Experts are convinced that, if we want to meet climate targets, we have to increase the number of wind turbines in Germany tenfold over the next 30 years. However, this requires not only installing new wind power generators, but also disposing of numerous old ones – whether due to material fatigue or simply because they are being replaced by larger and more efficient systems.

A study by the Fraunhofer Institute for Chemical Technology ICT predicts that the 15,000 rotor blades that will have to be discarded in 2024 will be joined by another 72,000 in the subsequent three years. We already have environmentally friendly methods for disposing of the steel and concrete in the wind power generators, but recycling the rotor blades remains problematic.

## Firmly bonded and nearly impossible to separate

Rotor blades are not made of steel. “That would be too heavy and inflexible. They are made largely of glass-fiber-reinforced plastic (GFRP) and balsa wood bonded with epoxy or polyester resin,” says Peter Meinschmidt, project manager at the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut, WKI in Braunschweig. This bond is extremely





Around 20 percent of electricity in Germany was generated by wind turbines in 2018.  
© Hans-Peter Merten/MATOfoto

strong. It has to be: The rotor blades reach top speeds of more than 250 kilometers per hour, subjecting them to an enormous force.

For single-origin recycling, however, this is precisely the problem: It is very difficult to separate the individual components of the composite material.

Balsa is one of the lightest woods in the world and is used, for instance, for model construction. It weighs just 40 to no more than 130 kilos per cubic meter – spruce wood by contrast weighs about 500. Holding a block of balsa wood the size of a Rubik's Cube is akin to holding a feather. Laborers effortlessly carry boles out of the plantation on their shoulders.

A rotor blade contains around 15 cubic meters of this wood, which is not only extremely light, but also extremely pressure-resistant. "That's the key advantage of balsa over most plastic foams," explains Meinschmidt. This exquisite wood is cultivated primarily in Ecuador. Previously there was no possibility to recover it when disposing of the old rotor blades. "Although it has hardly any energy content, it is burned as a composite material, usually in cement factories. The cement raw materials have to be heated up to about 1500 degrees Celsius before they coalesce and form cement clinker, so these factories require a great deal of energy. In addition, the melted glass fibers and the ash can later be added to the cement and replace portions of the quartz sand that would otherwise have to be input into the process."

But the number of cement plants in Germany is limited (there are 53 in total), and so is their need for rotor blades as combustion material. "Several rotor blade scrap yards have meanwhile sprung up. There's one near Flensburg, where thousands of rotor blades are already waiting to be scrapped or given a second life abroad. These scrap yards also serve as spare parts depots in case parts of older models become damaged and have to be replaced." However, their capacity is limited and has already been practically exhausted.

But there is still hope for getting the impending flood of rotor blades under control: Meinschmidt and his team – Fraunhofer ICT colleagues and industry partners – have developed a new recycling technology. To recover and recycle the balsa from the rotor blades, the detached blades are

disassembled on the spot. "The conventional approach is to use a band saw to cut the rotor blades into thirds or quarters, but this is a relatively complex process. That's why we came up with the idea to try it with a water jet lance instead. And what do you know: It was much faster and better," says an enthusiastic Meinschmidt. The lance can be mounted on a special vehicle and controlled from there. "The tremendous thrust would make it extremely difficult to guide the lance by hand." Then, while still on site, the 10- to 20-meter-long rotor blade segments are fed into a mobile shredder that breaks them into pieces about the size of the palm of a hand.

Finally, the researchers use an impact mill to separate these pieces into their individual components. To this end, they are set in rotation and hurled against metal at high speed. As Meinschmidt explains, "The composite material then breaks apart because the wood is viscoplastic, while glass fibers and resin are very hard."

### Insulating with rotor blades

At Fraunhofer WKI, the balsa pieces are processed to make, for instance, extremely light wood fiber insulation mats. "Currently around 10 percent of building insulation materials are made from renewable resources, so there's room for improvement here." With a density of less than 20 kilograms per cubic meter, these mats are so far unique on the market and provide similarly good insulation to common polystyrene-based materials.

The recycled balsa can also be used to produce a novel, elastic wood foam. For this, it is ground to a very fine powder and combined with a foaming agent. The foam's stability is created by the wood's own cohesive forces, which render synthetic adhesives superfluous. The foam is suitable for use as an environmentally friendly insulating material, but also as a packaging material that can simply be disposed of in the paper recycling container. This flexible wood foam is also interesting for the automotive industry. "Thermal insulation is a major issue for electric cars. With no combustion engine, there's no exhaust heat to use for heating, so the battery has to supply thermal energy, and the range drops," says Meinschmidt. There are plenty of ideas for recycling the valuable balsa wood from the wind turbines – and thanks to the new Fraunhofer recycling technology, it is now also possible to do so. ■

The sustainable wood fiber sheets are extremely light and insulate just as well as polystyrene.

# Fraunhofer worldwide

## Diamond electrodes break down recalcitrant environmental toxins

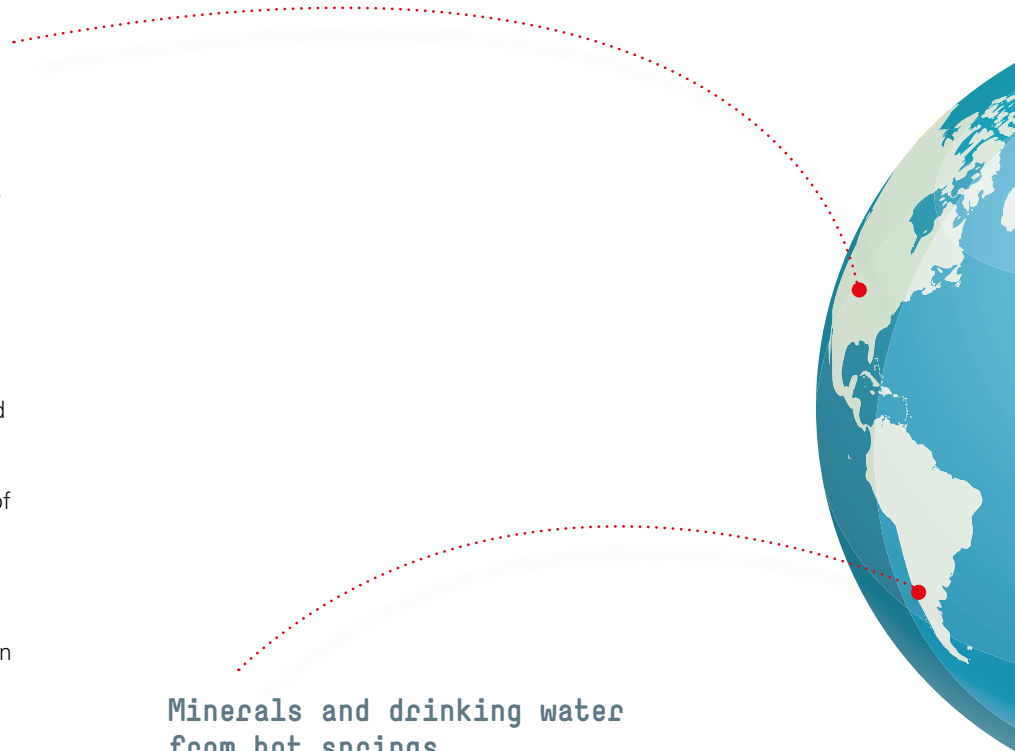


The blessing of longevity can be a curse. Nature is not very good at breaking down polyfluorinated organic compounds. Prized by manufacturers for their ability to repel water, dirt and grease, these tough chemicals resist natural degradation and accumulate in the environment. Leeching into wastewater, they make their way into the food chain for plants and animals to absorb. Traces of these chemicals have been found in human tissue samples across the globe. That is not good news: Per- and polyfluoroalkyl substances, or PFAS for short, have been linked to weakened immune system, impaired fertility and cancer.

“Good ways of banishing these compounds from the cycle of materials have yet to be found. These chemicals are largely immune to bacteria and sunlight. Although they can be filtered out of aqueous solutions with activated carbon, ion exchangers or reverse osmosis, the PFAS are still there and cannot be degraded,” says Michael Becker from the Michigan State University-Fraunhofer USA Center for Coatings and Diamond Technologies CCD. PFAS contamination is a hot topic in the U.S. state of Michigan, whose authorities have discovered elevated concentrations in rivers, groundwater, people and the human food chain.

Becker’s team is developing a process to break down PFAS into their constituent parts with diamond electrodes by way of “electrochemical oxidation.” Added boron atoms transform the diamonds into electrical conductors. The polyfluorinated organic molecules are oxidatively degraded at the anode, either directly or with the help of highly reactive hydroxyl radicals. This process mineralizes these intractable molecules fully, leaving nothing but water, carbon dioxide and harmless fluorides.

The technology has proven its merits in the lab. Now the Fraunhofer researchers are busy optimizing the process for practical application. The Michigan city of Grand Rapids just approved a 300,000-U.S.-dollar grant to develop the technology.



## Minerals and drinking water from hot springs



Water is a scarce commodity in northern Chile. Thermal springs are to be found under the arid ground, but their water does not a great thirst-quencher make. Hot and salty with magnesium, lithium and potassium, it also contains gold and boron.

“Brine is a prized resource. It can serve to produce energy, drinking water and minerals,” says Dr. Joachim Koschikowski, researcher at the Fraunhofer Institute for Solar Energy Systems ISE and coordinator of the BrineMine project.

German and Chilean companies and research institutions have joined forces with Fraunhofer CSET Chile in this project to develop a process to break brine down into its component parts. The energy needed to power this process may

be obtained from hydrothermal sources.

The first step is to force mineral-rich water through a membrane that is permeable only to H<sub>2</sub>O. This produces pure water. The residual solution is rich in minerals that can be filtered out in a second step. Heating evaporates any remaining water through a membrane, which then condenses on a cold surface on the other side. This condensate is potable. The residual solids are minerals that may be separated chemically and put to good use.

“With this BMBF-funded project, we want to not only show that the technology works; we also want to demonstrate its economic viability,” says Koschikowski emphatically. A demonstration plant is to start producing 100 liters of drinking water a day in 2021.

## Shrimp down under, solar power up top



The Mekong Delta is Vietnam's rice bowl, a vast fruit and vegetable garden and a source of fish. Yet 21 million people call this delta home, so land is scarce. Researchers from the Fraunhofer Institute for Solar Energy Systems ISE are working with their German and Vietnamese partners to develop multi-use concepts for this precious land. The project goes by the name of SHRIMPS, an acronym for Solar-Aquaculture Habitats as Resource-Efficient and Integrated Multilayer Production Systems. Commenting on its mission, project leader Max Trommsdorff says, "The goal is to show that solar power generation can be combined with shrimp or fish farms."

Vietnamese aquaculturists are increasingly turning to land-based farms, where the conditions for rearing seafood can be better controlled. "Shrimps are particularly sensitive. They need the water to be held at specific temperatures and protection from predators. Many farmers cover their ponds

with nets or closed greenhouses," says Trommsdorff. Their roofs can accommodate solar modules, so incorporating photovoltaic collectors certainly sounds like a good idea.

Two pilot-scale plants are now going up to demonstrate the technical and economic feasibility of these aqua-photovoltaic systems. One is a covered shrimp tunnel with a roof-mounted one-megawatt photovoltaic system. The other smaller system is going up on supports over fishponds. It will also provide shade, reduce evaporation and keep out predators. Its modules deliver 400 kilowatts output, enough electricity to meet the needs of the farm, which is not connected to the grid.

"As its stands, we expect this aqua-PV to increase the land use rate by close to twofold over a conventional ground-mounted photovoltaic system," says Trommsdorff, succinctly summing up its benefits.



## New agents to fight off the flu



Flu pathogens are quick to multiply and hard to stop. Every cough or sneeze of an infected individual is an airborne delivery system that disperses droplets containing viruses. Anybody in the vicinity who is unfortunate enough to breathe in these droplets also inhales the viruses, which then enter bodily cells via the mucous membranes, multiply, and spread throughout the body.

"Common drugs such as Tamiflu are often ineffective, as influenza viruses have developed resistance," says Dr. Jana Führung from the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM. "What we need is new antiviral agents."

The iCAIR research consortium has ITEM scientists working with the Hannover Medical School and the Institute for

Glycomics at Australia's Griffith University to develop new candidate agents for influenza viruses. They can stop the spread of influenza pathogens by blocking certain molecules on the virus's surface. "These molecules enable influenza viruses to detach themselves from the surface of human cells. If we succeed in switching off this mechanism, the virus can still infect a cell, but it can't go anywhere else. This prevents the pathogen from spreading," says Führung, explaining the antiviral action.

The ITEM team in Hannover is now testing these new agents in infection models developed to this end. They use living human lung tissue and the immune cells contained therein. With these tissue cultures, the researchers can investigate how the lung and immune cells react to a viral infection or treatment. All preclinical trials so far have been successful.



An estimated 690 million packages are delivered in the period before Christmas - around 14 million packages every day. An intelligent assistant cuts packing volume, time and costs.

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# The art of packing

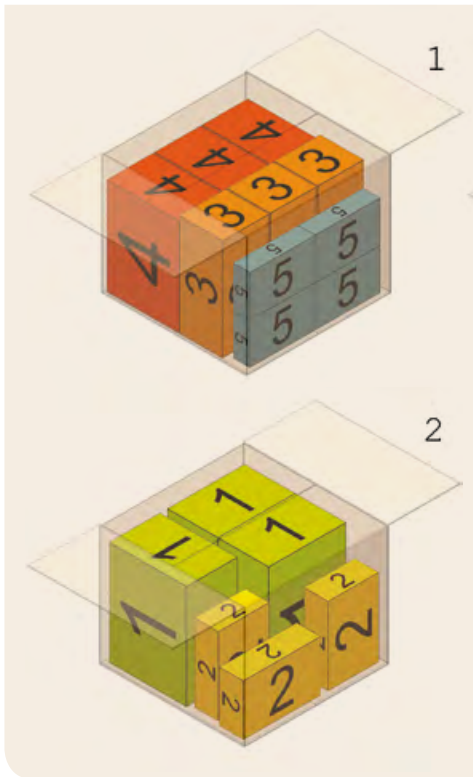
The Christmas season pushes logistics providers to their limits. The Fraunhofer Institute for Material Flow and Logistics IML offers a solution: an optimized and more efficient way to pack boxes using an intelligent packing assistant.

By Winnie Winkler

Online shopping remains popular. It was predicted that 690 million packages would be delivered over the course of the 2019 Christmas shopping season, equating to around 14 million packages every day. Sustainability is also called for. The Fraunhofer Institute for Material Flow and Logistics IML in Dortmund is researching ways to optimize how boxes are packed and how to pack them

more efficiently. In collaboration with Hüdig + Rocholz, a mechanical engineering company, they developed an intelligent packing workstation geared specifically toward the mail-order business and the diverse array of goods it entails. Advantages of this system include faster dispatching, less shipment damage, smaller volume, and therefore less material input and lower costs. The preproduction model is set to be presented at the LogiMAT logistics trade fair in Stuttgart in February 2020. ▶





»PUZZLE® calculates which shipping carton a packer should use and the arrangement of the items in it. PUZZLE® can also keep item types (item color and number) together. © Fraunhofer IML

PUZZLE® and “passt” will soon help reduce packaging, making room for more goods in transporters. © Sina Schuldt/dpa

“passt” is an assistance system that helps workers find the best packing strategy.

► The development of this packing workstation is the result of the collaborative effort of two Fraunhofer IML departments: the Software & Information Engineering department developed the PUZZLE® software to optimize packaging, while the Packaging and Retail Logistics department devised “passt,” a novel assistance system that visualizes the PUZZLE® results.

Fraunhofer IML’s iPackAssist transfer project with Hüdig + Rocholz GmbH is aimed at taking the integration of these two technologies from prototype status to preproduction status. The Fraunhofer IML team headed by Georg Wichmann, Benedikt Mättig and Christian Olms conducted crucial research behind both of these developments. PUZZLE® calculates the package volume and, with the help of the “passt” assistant, provides additional information aimed at helping the employees packing the boxes. Because the assistant provides visualizations, it is easy to understand, which means that employees don’t need to undergo time-consuming training and won’t fail in the day-to-day work environment as a result of language barriers.

The joint transfer project is aimed at helping to develop the interactive packing workstation of the future. Currently, it is up to employees to decide which box format to use for each shipment and how to arrange the items in the box. PUZZLE® determines dimensions, weights and quantities and uses these to calculate the optimum package layout. “passt” is a human-machine interface that guides packers through the packing process.

### How does it work?

The assistance system is comprised of two lighted strips embedded in the table at a right angle to each other, like a coordinate system. These strips indicate where to place the box, and LED lamps light up where the packages can be embedded. Further, different colors are used to provide additional information, such as the maximum load or which group a package belongs to. Because it provides intelligent assistance, learning how to use the system is very easy. ■

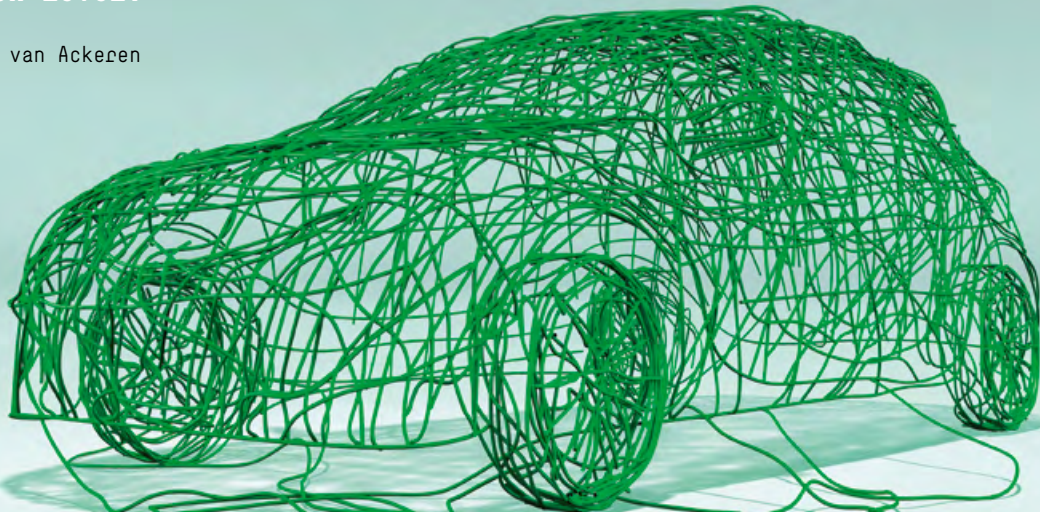


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# Hydrogen gains momentum

The lightest chemical element is increasingly becoming something of a heavyweight. Largely neglected in discussions on climate policy, hydrogen has the potential to take mobility to a new level.

By Janine van Ackeren



**G**ood performance and quiet cruising” was the verdict of the German automobile association ADAC in its October 2019 review of a hydrogen-powered car. It also noted that “it takes just four minutes to fill the tank.”

Could the future belong to hydrogen fuel cell vehicles? According to Fraunhofer experts, we can expect to see up to 1.8 million fuel cell cars on German roads by 2030. Hydrogen could also prove to be a big factor in German automakers’ sales to international markets. South Korea plans to have 1.8 million fuel cell cars on its roads by 2030, while China is aiming for a million. Currently, consumers looking to purchase a hydrogen fuel cell car only have four models to choose from: the Toyota Mirai, the Hyundai NEXO, the Hyundai ix35 and the Mercedes-Benz GLC. There is also a scarcity of hydrogen fueling stations, with only 100 or so available to drivers in Germany as of late 2019. Yet hydrogen-powered mobility is steadily but surely gaining momentum. ▶

► Audi, BMW and other carmakers have announced the launch of various new vehicle models from 2021 onwards. The network of hydrogen fueling stations also looks set to expand, with a total of 400 scheduled to be up and running by 2023, and 1000 by 2030. For some people, traditional SUVs still rule the roost as a status symbol in today's big cities, much like fur coats were once seen as the height of fashion – but hydrogen now has the potential to become the next big thing. Buoyed by support from the German government, the Fraunhofer Institutes ISI in Karlsruhe and ISE in Freiburg have produced a “hydrogen roadmap” for Germany with the help of their colleagues at Fraunhofer IMWS in Halle and Fraunhofer IKTS in Dresden. This makes clear recommendations on how the government can get hydrogen fuel cell cars on the road faster. Providing support for new refueling stations is one of the key proposals, with the authors recommending the use of public funding to get 1000 stations in operation by 2030. They also suggest that “a good way to support the market ramp-up is by incentivizing emission-free mobility in public procurement contexts such as utility vehicles, police vehicles and goods transport.”

### Hydrogen versus electric

What's the best way to power vehicles if Germany and Europe are serious about meeting their climate targets? This was the question tackled by researchers from the Fraunhofer Institute for Solar Energy Systems ISE in their study on the “Industrialization of Water Electrolysis in Germany.” The authors focused primarily on the CO<sub>2</sub> emissions from battery-electric, diesel and hydrogen fuel cell vehicles, commonly referred to as their carbon footprint. “Our studies show that hydrogen fuel cells are the most favorable option for various usage scenarios and vehicle types,” says Professor Hans-Martin Henning, who heads up Fraunhofer ISE. “We therefore see fuel cell vehicles as a key component of future mobility that will co-exist with other climate-neutral means of powering vehicles.” Another question examined in the Fraunhofer study was whether battery-electric or hydrogen-powered vehicles hold the greatest hope for the future. The results revealed that battery-electric vehicles come out on top for short trips and exclusively urban driving, but for distances over 250 or 300 kilometers, hydrogen fuel cell vehicles take the lead.

Meanwhile, experts from the Fraunhofer Institute for Systems and Innovation Research ISI investigated how hydrogen could help us move away from fossil fuels. Their results appeared in a “Gas Roadmap” produced on behalf of the German Federal Environment Agency. “Hydrogen really comes into play in situations where it is difficult to make direct use of electric energy, such as heavy goods transportation, shipping and air traffic,” says Mario Ragwitz, deputy director of Fraunhofer ISI. A glance at the figures for heavy goods vehicles and semi-trailer trucks reveals there are just 230,000 on German roads,

far fewer than the number of passenger vehicles. Yet the potential they offer is huge, because heavy goods vehicles are responsible for half of the road haulage industry's carbon footprint. Powering these vehicles with hydrogen fuel cells could significantly reduce greenhouse gas emissions.

### Hydrogen fuel cell vehicles

Most people are familiar with the idea of using hydrogen as a fuel by generating electrical current in fuel cells. Vehicles carry the hydrogen in a special tank, and the fuel cell converts the hydrogen's chemical energy into electricity to drive the electric motor that powers the vehicle. These systems typically include a small electric battery to handle peak loads. Polymer electrolyte membrane fuel cells (PEMFCs) have become the standard for mobility applications. These offer the kind of high power density and very high dynamics that are required for maneuvers such as rapid braking. “Low-temperature PEMFCs open the door to emission-free mobility for all vehicle classes including buses and heavy goods vehicles as well as rail traffic,” says Professor Christopher Hebling, division director at Fraunhofer ISE. “Our work covers everything from basic development to research into production methods. Our goal is to get fuel cell reliability on a par with that of combustion engines in terms of their mobility credentials, but without increasing the manufacturing costs.”

Currently, vehicles require a whole host of sensors to supply the fuel cell consistently with the right amount of hydrogen. These sensors drive up costs and make the system more susceptible to errors. To address this problem, scientists from the Fraunhofer Institute for Machine Tools and Forming Technology IWU are collaborating with various partners on the Eco-CC project, which aims to develop a cost-effective and reliable measurement and control concept. “The idea is to come up with a concept that makes fuel cell operation as reliable and robust as possible,” says Professor Welf-Guntram Drossel, who heads up Fraunhofer IWU. The researchers have to take numerous parameters and measurement signals into account to get the best results, including pressure, temperature, humidity, electrical voltage, electrical current, gas concentrations, mass flow rates and electrical conductivity. “We combine this sensor data with process models to gradually build up a concept that works,” says Drossel. The scientists hope their new control concept will make fuel cells more cost-effective and efficient.

Hydrogen vehicles can only make a mark in the mobility sector if improvements are made to fuel cell service life, because replacing the fuel cell in a car after just a few years is a costly and unappealing downside for drivers. Researchers at the Fraunhofer Institute for Mechanics of Materials IWM are currently seeking ways to make fuel cells last longer. They are focusing their attention on the ceramic and metal materials

Battery-electric vehicles offer advantages for city driving and shorter distances, but the strengths of hydrogen-powered vehicles come to the fore with distances over 250 kilometers.



used inside fuel cells. The crystal structure of these materials needs to be perfectly formed for hydrogen to diffuse through them as efficiently as possible. If this is not the case, hydrogen tends to accumulate at defective points in the structure such as misaligned crystals and grain boundaries, leading to mechanical stresses which may result in cracks and component failure. Scientists at Fraunhofer IWM use calculation methods based on quantum physics and continuum mechanics to analyze how hydrogen diffuses through metals and ceramics. They also carry out mechanical load experiments to determine what effect hydrogen has on the materials. Using devices such as a permeation cell, they measure the diffusion of hydrogen through thin layers of material. By calculating how much gas penetrates the layer over time, they can draw conclusions on the material structure, identify weak points and make recommendations on how to avoid them.

## The tricky task of storing and supplying hydrogen

Drivers need a safe, readily available supply of hydrogen if they are to use it as a fuel. Hydrogen is conventionally stored at low temperatures (-253 °C) or under high pressures of several hundred bar, but fulfilling these conditions in refueling stations and car fuel tanks is a tricky business. "Fraunhofer IFAM Dresden is developing an easy-to-handle paste in which hydrogen can be chemically stored at room temperature and atmospheric pressure. It can then be released as needed by simply adding water," says Lars Röntzsch from Fraunhofer IFAM Dresden. Another alternative is to use a form of hydrogen that is chemically bound in oil, a type of storage medium known as a liquid organic hydrogen carrier, or LOHC. Researchers at Fraunhofer ISE are investigating how this oil could be integrated in filling station operations. For example, how would a refueling station need to be configured to use this method? And how can the hydrogen be released from the oil when a driver wishes to refuel? Scientists at Fraunhofer IAO have built Europe's first new-generation LOHC storage system, which has a capacity of 2000 kilowatt-hours.

## Safety first!

As well as using hydrogen in fuel cells, it can also be burned directly in the engine. Researchers at the Fraunhofer Institute for Chemical Technology ICT are investigating what safety precautions direct hydrogen combustion engines require. "We're not looking into the properties of hydrogen itself, which are already common knowledge, but rather how hydrogen behaves in each particular system," says Wilhelm Eckl, deputy director of Fraunhofer ICT. "Our aim is to look at all the different possibilities, including the worst-case scenario." This approach is important, because hydrogen is not just a useful and versatile energy carrier, but also highly explosive when mixed with air. ■



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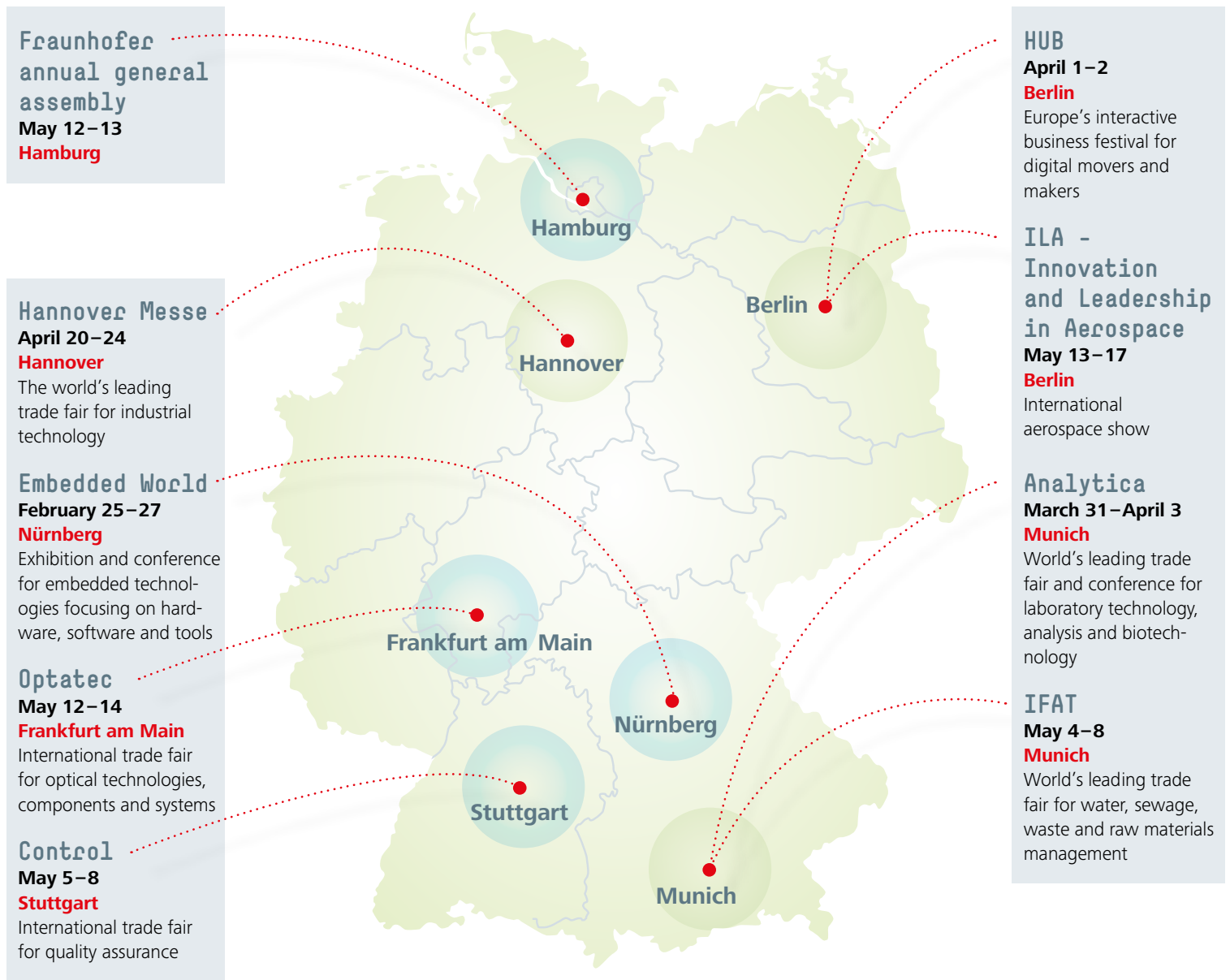
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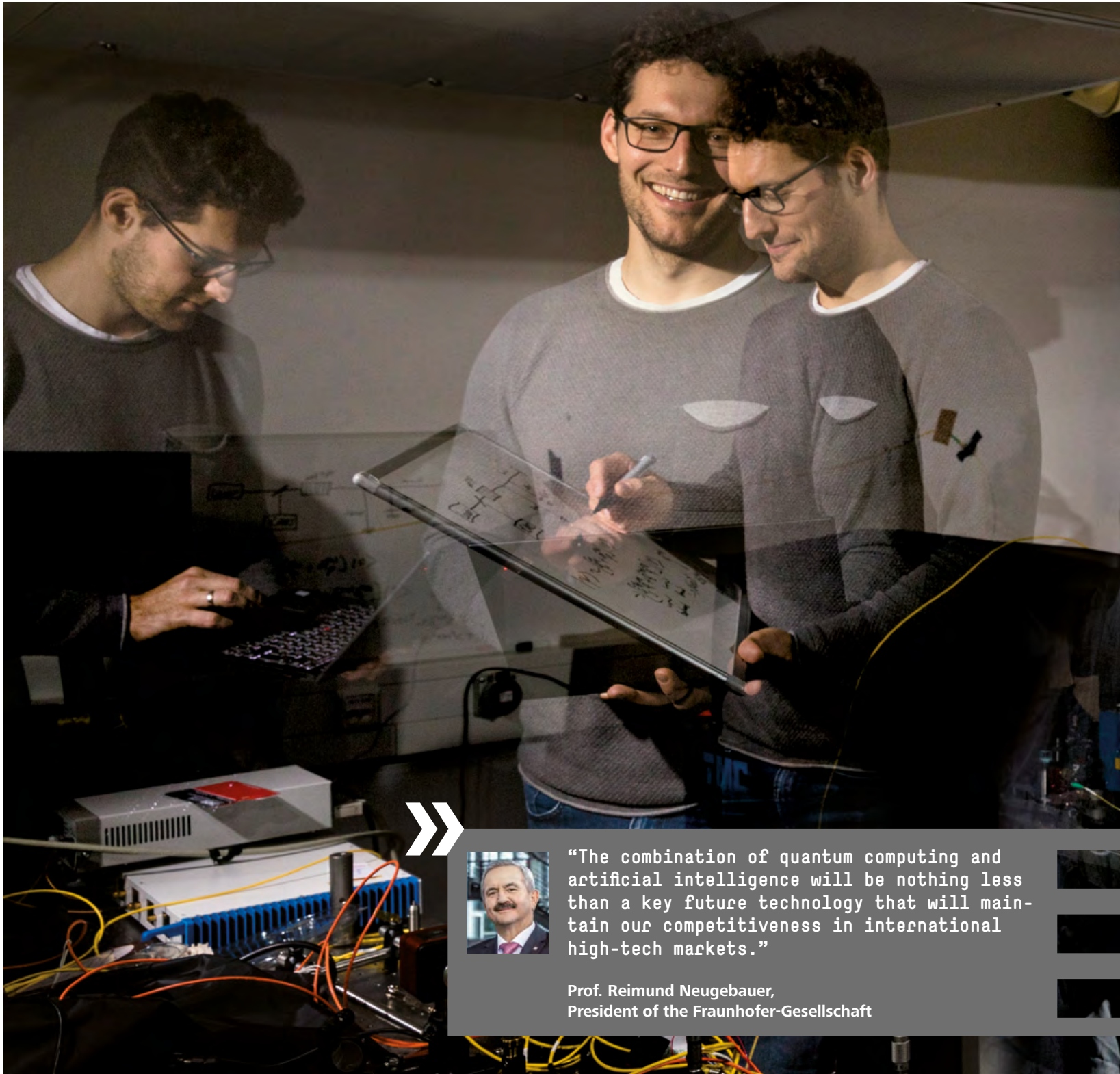
There are currently four hydrogen-powered vehicle models available commercially: two from Hyundai, plus the Mercedes GLC and the Toyota Mirai. Plans are underway to increase the number of hydrogen refueling stations in Germany from the current figure of 100 to 400 by 2023.

# Important events in Fraunhofer's 2020 calendar









“The combination of quantum computing and artificial intelligence will be nothing less than a key future technology that will maintain our competitiveness in international high-tech markets.”

Prof. Reimund Neugebauer,  
President of the Fraunhofer-Gesellschaft