BAM

Bundesanstalt für
Materialforschung
und -prüfung

BAM Report
2022/23

Shaping transformation together

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2022/23

Dear readers,

Whether we discuss restructuring the energy system, the sustainability of the economy, or the changes that our cities and mobility are undergoing: The word transformation is probably one of the most frequently used at the moment, along with “Zeitenwende”. It is beyond questioning: We are facing a new reality that cannot be reinterpreted. Instead, it is up to us to actively shape it.

But can we at all protect our economy and at the same time focus on preserving resources rather than exploiting them? I firmly believe we can. Producing would then mean, for example, finding solutions that help us shift towards a circular economy. BAM, whose mission is to promote the German economy, is already broadly contributing to the green transformation: By performing basic research that is quickly translated into application, not least thanks to our diversity and specialisation, which allow us to develop an overarching perspective. After all, finding solutions to manage change also means changing your way of thinking.

For example, we are involved in the development of smart quality assurance tools for modern hydrogen technologies, sustainable battery materials for powerful e-batteries or safe designs for even larger and more efficient wind turbines. We will only succeed in the long term if we embrace change. At BAM, we are in the process of pooling our expertise in further cross-disciplinary and cross-sector competence centres, testing new holistic cooperation formats and welcoming key stakeholders from industry, science and politics to our growing network. The new BAM Report 2022/23 presents a selection of current BAM projects, ideally providing a linking point for further collaborative projects and initiatives that will help us to safely shape the transformation process together. Let’s start talking about how we can address the challenges ahead of us – together!

Yours
Prof. Dr. Ulrich Panne

President
Bundesanstalt für Materialforschung
und -prüfung (BAM)

PS: This year, we are publishing our annual publication online only, as a small contribution to increasing our sustainability.

"Materials science – a key discipline in transformation

On 18.11.2022, Federal Minister Robert Habeck visited BAM, which is assigned to his ministry as a senior scientific and technical federal institute. The Minister informed himself about the two competence centres on hydrogen and wind energy. "The transformation of our economy is an urgent task of our time. For this, we need innovations, especially in the field of sustainability and environmental and climate protection," Habeck said in an address to BAM employees. "Materials science is a key discipline in the transformation, and BAM's work on hydrogen and wind energy in particular is helping to advance the transformation in Germany."

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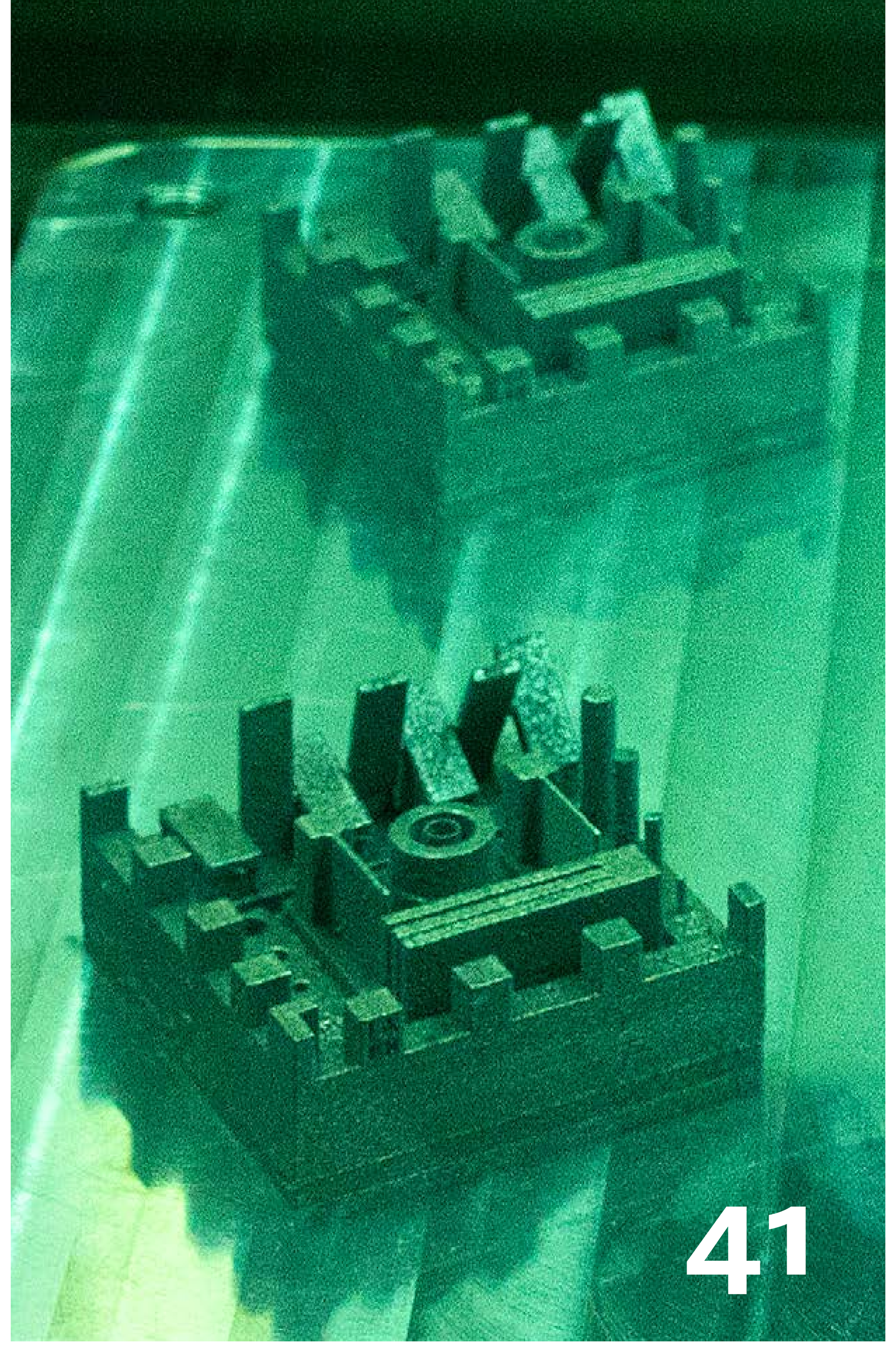
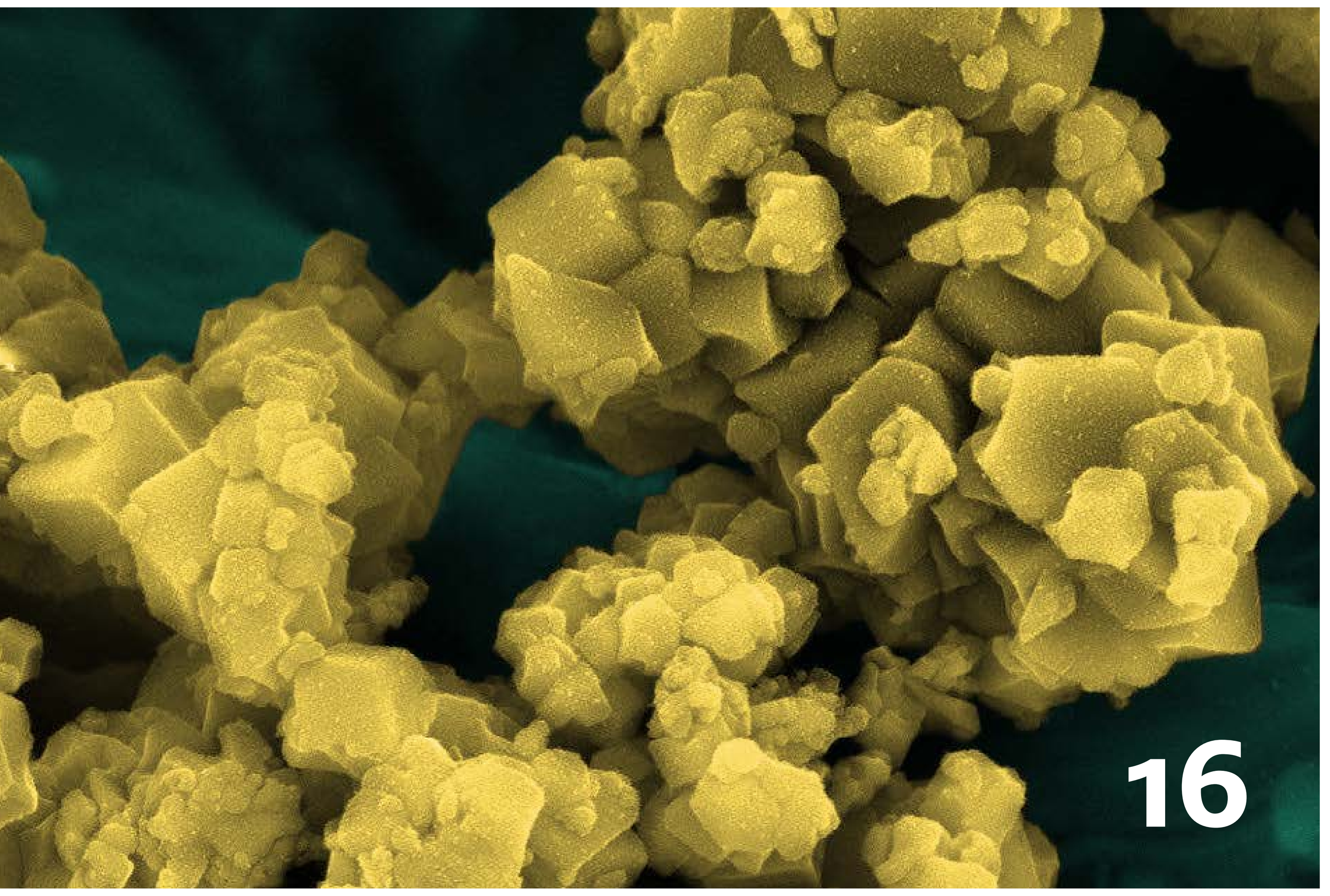
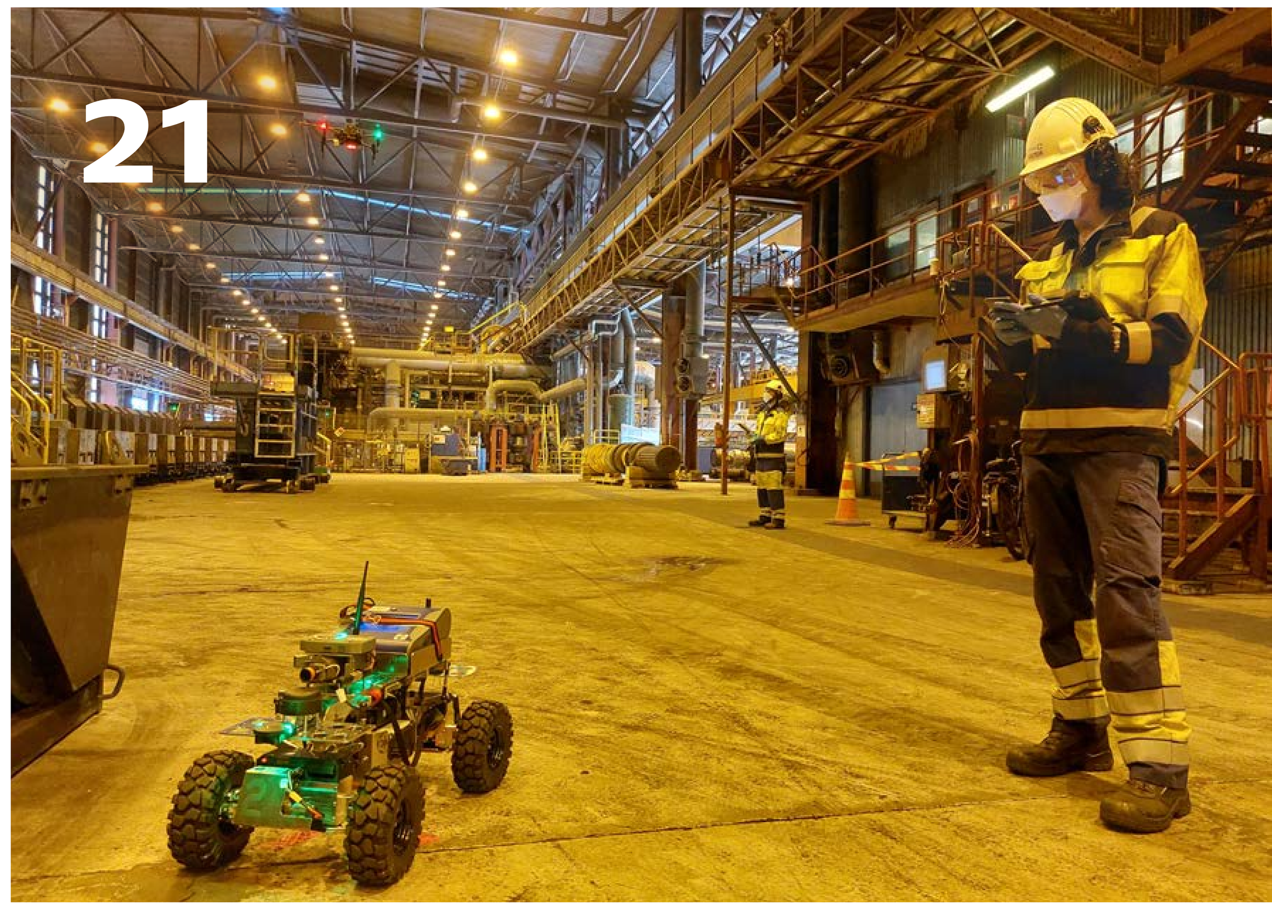
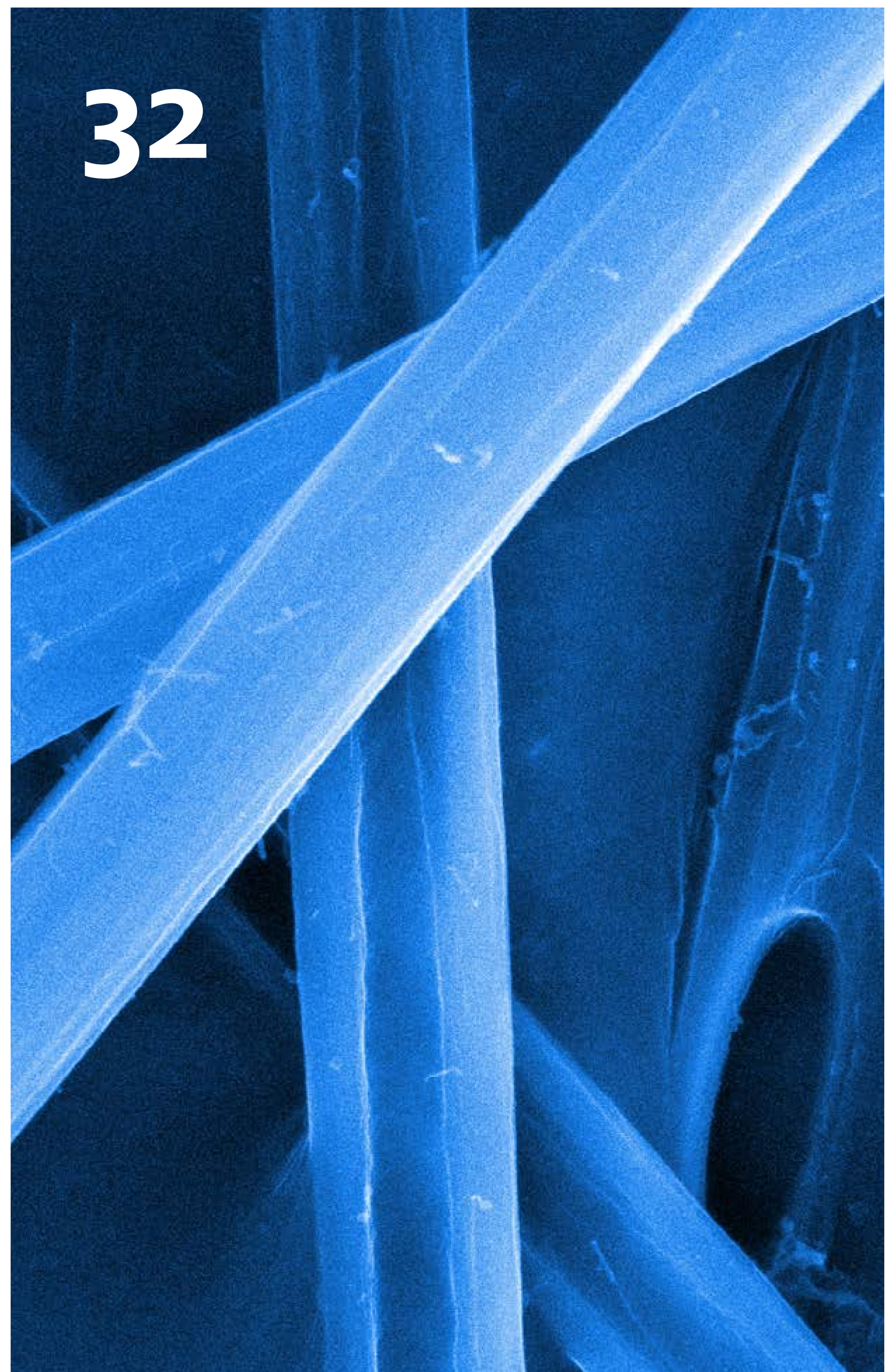








BAM and its five focus areas

The Bundesanstalt für Materialforschung und -prüfung (BAM) integrates research, assessment and consultation in technology and chemistry under one umbrella. Within the context of our legal and socio-political responsibilities, we identify needs that will shape safety requirements in technology and chemistry in the future. Our work is focussed on the five focus areas of Energy, Infrastructure, Environment, Materials and Analytical Sciences.

Energy | Infrastructure | Environment | Materials | Analytical Sciences

ENERGY

Hydrogen digital

Hydrogen is set to decarbonise heavy duty vehicle, ship and air traffic in the future. BAM is developing and testing technology for safety and efficiency in a digitally networked research filling station.

The operation of a hydrogen filling station places particularly high demands on safety: The fuel gas is delivered in transport vehicles at up to 500 bar and stored on site as compressed gas in pressure vessels. Before a vehicle can be refueled, the gas must be compressed up to 1000 bars and then cooled to minus 40 degrees Celsius. These processes put special stress on the materials of compressed gas storage tanks, pipelines, compressors and refrigeration systems.

Presentation of the project at the Hannover Messe 2022

Maintenance means downtime

To ensure the operational safety of hydrogen filling stations in Germany, all components are maintained and inspected at regular intervals. For this purpose, individual parts may need to be removed and inspected; the inspections themselves are very time-consuming. Currently, the inspections are therefore associated with downtimes of several days and correspondingly high costs. The filling station is not available to customers during this time.

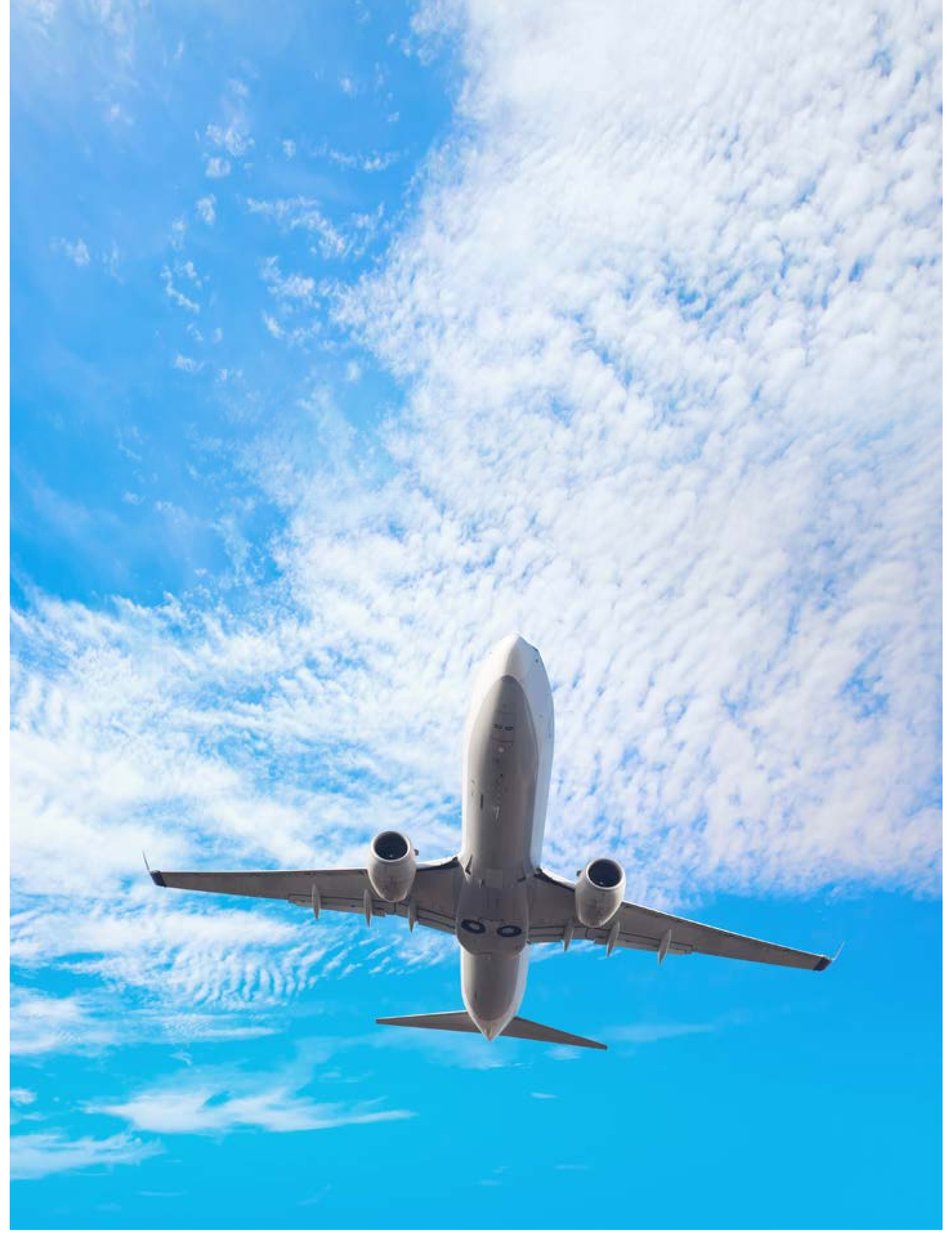
"With a digitalisation of the entire processes, the maintenance times could be intelligently controlled and at the same time the economic efficiency, reliability and availability of hydrogen filling stations could be significantly increased," says Robert Bock from the hydrogen competence centre H2Safety@BAM. "In order to test digitally supported quality assurance for widespread use, we are setting up a unique research filling station for hydrogen at BAM's test site 50 kilometres south of Berlin," adds his colleague Torsten Kehr.

Digitalisation shortens inspections

For the first time, all components of the filling station will be networked with each other. Data on pressure, temperature and component condition will be recorded via sensors and then visualised and evaluated in a digital twin. “In this way, we can also test innovative monitoring concepts for the buffer tanks and other components. In the medium term, this will enable inspections to be initiated only when they are really needed,” says Torsten Kehr. At the same time, the results will be incorporated into standards and regulations so that the digital approaches can also be applied in a quality-assured and legally compliant manner.

The research project is part of the Quality Infrastructure Digital (QI-Digital) initiative, through which BAM and its partner institutions want to pave the way for digitally supported and integrated quality assurance. In this context, BAM’s hydrogen filling station not only serves as a development and test environment for modern testing methods, but it also promotes the digital transformation of essential contemporary QI elements: For example, smart standards, digital certificates and calibration certificates are being developed alongside a QI cloud that serves as a platform for these digital tools. In view of the increasing digitalisation of industry and globally networked value chains, QI-Digital is thus helping to secure Germany’s global competitiveness.

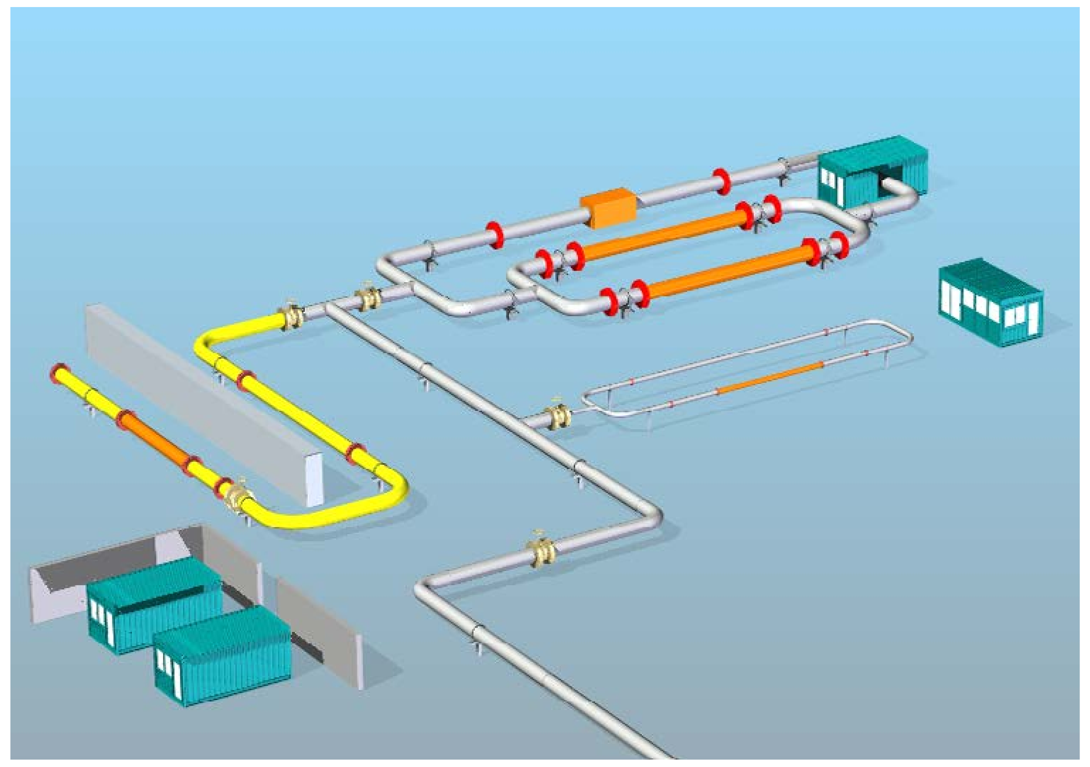
BAM is taking on a pioneering role here in the field of hydrogen. A pilot project, the digital research filling station is being funded with around eight million euros by the Federal Ministry of Economic Affairs and Climate Action.



Hydrogen will help decarbonise air, heavy goods and shipping transport

TEST PLATFORM FOR HYDROGEN PIPELINES

A safe pipeline network is indispensable for the transport and storage of hydrogen and hydrogen-natural gas mixes. Some of the safety-related questions that arise in this respect can only be answered by tests under real conditions. BAM is therefore building a test platform on its test site in Brandenburg at a cost of 3.8 million euros, which includes a range of testing options that is unique in Europe to date. The facility offers industry and gas network operators and manufacturers the possibility to solve safety-related questions and to derive suitable safety measures concerning hydrogen transport with pipelines quickly and in a practical manner. The focus is on investigations that have to be carried out on a real scale and under critical operating conditions. The platform will contain modules for the accelerated preconditioning of pipeline segments, for the investigation of hydrogen quality by means of online gas analytics and for destructive testing.



The platform contains three modules which test the compatibility, quality and safety of hydrogen

500,000

kilometres of gas pipelines deliver energy to Germany's industry and households. This infrastructure plays a key role in the transition to a hydrogen economy: Green hydrogen is expected to replace fossil natural gas gradually in the pipelines. But are the systems, some of which are decades old, suitable for hydrogen?

In order to test pipeline steels, they have so far been subjected to elaborate tests in autoclaves: "The laboratory tests performed in these sealable pressure vessels require large quantities of hydrogen, therefore entail a high safety effort and are correspondingly expensive," says Florian Konert, scientist at the hydrogen competence centre H2Safety@BAM. The engineer and the team are developing a faster and more cost-effective testing technique: In the process, they fill a steel sample with hydrogen from the inside and simultaneously subject it to a mechanical tensile load. The method requires only a fraction of the amount of hydrogen. "We are convinced that our approach will simplify testing for metals used as materials in components for the hydrogen economy. In this way, we are contributing to the accelerated market ramp-up phase of hydrogen."

NEW GRADUATE SCHOOL "TRUSTWORTHY HYDROGEN"

BAM and the Brandenburg University of Technology Cottbus-Senftenberg (BTU) founded the joint graduate school "Trustworthy Hydrogen" in 2022. It is intended to ensure the long-term training of excellent young researchers in the field of hydrogen. In this programme, which is unique in Germany, hydrogen experts will be trained for the first time who not only have in-depth technical expertise, but can also develop a holistic view of the entire value chain as well as the framework conditions and safety standards required for market implementation. They gain access to the international networks of BAM and BTU in science, politics and industry. Soft skills in areas such as science communication and policy advice round off the programme. At the end of their three-year training, which ends with a doctorate, the graduates are equipped with all the skills and knowledge to become future leaders in the global hydrogen economy. The first year of training began in the winter semester of 2022/23.

ACCURATE TO THE PER MILLE

BAM is developing new, highly precise natural gas and hydrogen mixes that are accurate to 0.05 per cent. The calibration gases are needed to calibrate measuring devices in a future hydrogen economy and thus to precisely calculate consumption quantities and costs. "Currently, mathematical models are used, but they are not sufficiently validated. In view of the enormous quantities involved, uncertainties in the per-mille range already mean considerable cost differences," explains Dirk Tuma, chemist and metrology expert at BAM. With its high-precision calibration gases, BAM is making an important contribution to the planned decarbonisation of the entire European gas network, which covers more than a quarter of a million kilometres and is to be converted to hydrogen and other climate-neutral energy sources as part of the European Union's Green Deal. In addition to BAM, 17 other renowned institutions from all over Europe, including the national metrological institutes of Spain and Italy as well as the University of Lisbon, are collaborating on the EU-funded joint project Decarb the gas grid.

A special crane delivers the 60-cubic-metre tank

MORE SAFETY FOR LARGE HYDROGEN TANKS

Pressure tanks made of steel and composite materials are used for the safe storage and transport of hydrogen. Due to the increasing demand for the gaseous energy carrier, considerably larger tanks will soon be needed. Strict safety regulations apply to them. They must have a safety device, e.g. a circular "burst disc" made of plastic or metal. If the internal pressure rises – for example due to a fire nearby – the disc bursts and allows the hydrogen to escape in a controlled manner. This prevents a catastrophic failure of the tank, avoiding hazards from fragmentation, for example. The regulations on burst discs are derived from mathematical models and laboratory tests. It has not yet been completely validated whether the calculations can also be applied to very large pressure vessels or huge ship tanks for liquid hydrogen. To clarify this, Martin Kluge and his team are conducting tests on a 60-cubic-metre tank in cooperation with BASF. These are the first systematic investigations at that scale in the world. "With our real-scale experiments, we are obtaining reliable data for the first time so that we can validate the mathematical models. Our goal is to optimally design the safety technology for large-volume gas tanks," says Martin Kluge.

ENERGY

Accelerated wind expansion

Germany wants to increase its wind energy capacity almost ninefold by 2045 in the offshore sector alone. BAM is supporting this ambitious goal with its new competence centre Wind@BAM.

The accelerated expansion of wind energy poses a number of technological challenges: For example, the latest generation of offshore wind turbines, which are up to 250 metres high, place particular demands on rotor blades, steel support structures and the foundations in the seabed. The expansion to depths of up to 40 metres below sea level, but also their longer operating time, place completely new demands on the turbines, e.g. in terms of corrosion protection. Onshore, the towers made of reinforced concrete have to withstand vibrations and wind pressure. Many technical regulations currently in place must be supplemented and procedures must be developed to achieve a longer service life in line with the technical possibilities to ensure that the expansion goals can be met.

Driving innovations forward, using potentials

To solve these challenges, BAM has combined its many years of expertise in the field of wind energy to form the competence centre Wind@BAM in 2022. “Wind@BAM sees itself as an ‘enabler’,” explains Matthias Baeßler, speaker of the competence centre. “On the one hand, we want to ensure that innovations and current findings on the new size dimensions of turbines reach the application stage as quickly as possible, thus supporting the accelerated expansion of wind energy. At the same time, we are involved in reviewing existing safety regulations. We’re identifying aspects that are often overlooked: If wind turbines can be operated safely for longer, for example through the use of intelligent sensor technology, this will be a decisive step forward.” Around 30 scientists are already working on the two solutions in the Wind@BAM competence centre: Making new wind turbines better and existing turbines more durable. For example,

Fluorescence can be used to examine welding seams on the support structures of wind turbines for cracks.

In the large-scale test rig of the Competence Centre, steel components are undergoing stress tests with different loads.

> **What makes Wind@BAM unique: the diversity of materials expertise under one roof.**

they are developing automated welding techniques to enable the use of thinner and at the same time stronger high-performance steels for the new giant towers. One of the benefits: When constructing offshore wind farms, lightweight construction can save large amounts of steel, energy and thus also CO_2.

Intelligent testing and digital monitoring

In order to detect defects in rotor blades as early as possible and thus avoid long downtimes of wind turbines, the Wind@BAM competence centre is developing intelligent testing methods with infrared cameras, drones and artificial intelligence. It tests materials under real conditions on the high seas so that the industry can optimise corrosion protection. And the researchers are developing concepts for comprehensive digital monitoring so that new and existing plants can remain in operation for as long as possible.

"What makes our competence centre unique in Germany is the diversity of materials science expertise on wind energy and the fact that we offer everything under one roof: Research and development, consulting and a wide range of testing options, some of which are unique," says Matthias Baeßler. "Since Wind@BAM also plays a leading role in shaping national and international standards and norms, we always ensure that high quality and safety standards remain guaranteed. In this way, we are also helping to make the German and European wind industry more competitive."

STURDY GIANT TOWERS

Offshore turbines of the latest generation reach gigantic dimensions of up to 250 metres in height. In order for the towers to be able to withstand the high loads of weight and wind, industry uses special steels. These achieve their special strength by adding small amounts of alloying components, such as titanium, niobium or vanadium. At the same time, they allow the load-bearing foundation structures to be erected in a material-saving lightweight construction – which makes the giant towers particularly economical and sustainable. However, it has been known for a long time that a problem arises when the turbines and their foundations are welded together from up to hundreds of individual parts: It is the added added alloying elements in particular that cause the steel to behave differently in the zone around the weld seam due to the high temperatures. This in turn endangers the stability of the entire system. Nina Schroeder at the Competence Centre Wind@BAM is now systematically investigating these metallurgical processes for the first time. She wants to find out in what quantities titanium, niobium or vanadium can be added to the alloys without causing so-called softening zones. Her basic research will later be incorporated into standards and regulations so that the latest generation of offshore turbines can also withstand wind and waves safely.

17 different materials and corrosion protection systems are tested for three years, exposed to the elements

TOUGH TEST ON THE HIGH SEAS

Wind turbines in offshore wind farms have to contend with particularly harsh environmental conditions. Above all, atmospheric corrosion, exacerbated by the maritime weather, takes its toll on the metallic parts above the waterline. Despite extensive research, the key factors for such corrosion processes are not yet sufficiently understood. Even seemingly reliable material systems repeatedly show unexpected problems – because up to now, they have mainly been tested for their corrosion resistance in the laboratory or in climatic chambers. Together with Energie Baden-Württemberg AG (EnBW), BAM started a unique experiment in Germany in 2022: In order to research atmospheric corrosion under real conditions, 17 different materials and corrosion protection systems will be tested for their resistance in a wind farm in the middle of the North Sea for three years. The results should enable the industry to optimally design corrosion protection so that offshore plants can be operated as long as possible, but also economically, safely and sustainably.

IMPROVED MONITORING

Wind turbines are a key element in the energy transition. However, they usually only have a service life of 20 years. The tower in particular, which is often made of prestressed concrete in onshore plants, is exposed to constant vibrations due to the wind. This can lead to fatigue of the concrete and eventually to cracks. In recent years, BAM has already researched how this damage can be detected, e.g. by means of ultrasound and acoustic emission measurements. In a new joint project with partners from science and industry, the methods tested in the laboratory are now to be developed further so that wind turbines can be monitored even better and more efficiently on site over their entire service life. “Our goal is to keep a permanent eye on the condition of the towers,” says Marc Thiele, expert for concrete fatigue at BAM. „In this way, maintenance can be planned better and the potential of existing wind turbines can be used optimally. This should ideally allow them to be operated beyond the intended service life of 20 years and make an even greater contribution to the energy transition.“

ENERGY

Innovative battery materials

Synthetic carbons improve the performance of sodium batteries

Tim Fellinger is an expert in energy materials. In this interview, he explains what it takes to achieve innovative leaps in batteries.

All over the world, laboratories are working to develop better electric batteries. In which direction is the trend going?

The biggest challenge is still to achieve higher storage densities. At the same time, we are confronted with an increasing shortage of raw materials. Many companies and laboratories are therefore working on alternatives to common battery materials such as graphite or lithium-nickel-manganese-cobalt oxides. We are witnessing the renaissance of lithium iron phosphate batteries, but sodium-ion batteries are currently also in vogue because they contain readily available raw materials. Although they have a somewhat lower storage capacity, they work reliably even at low temperatures.

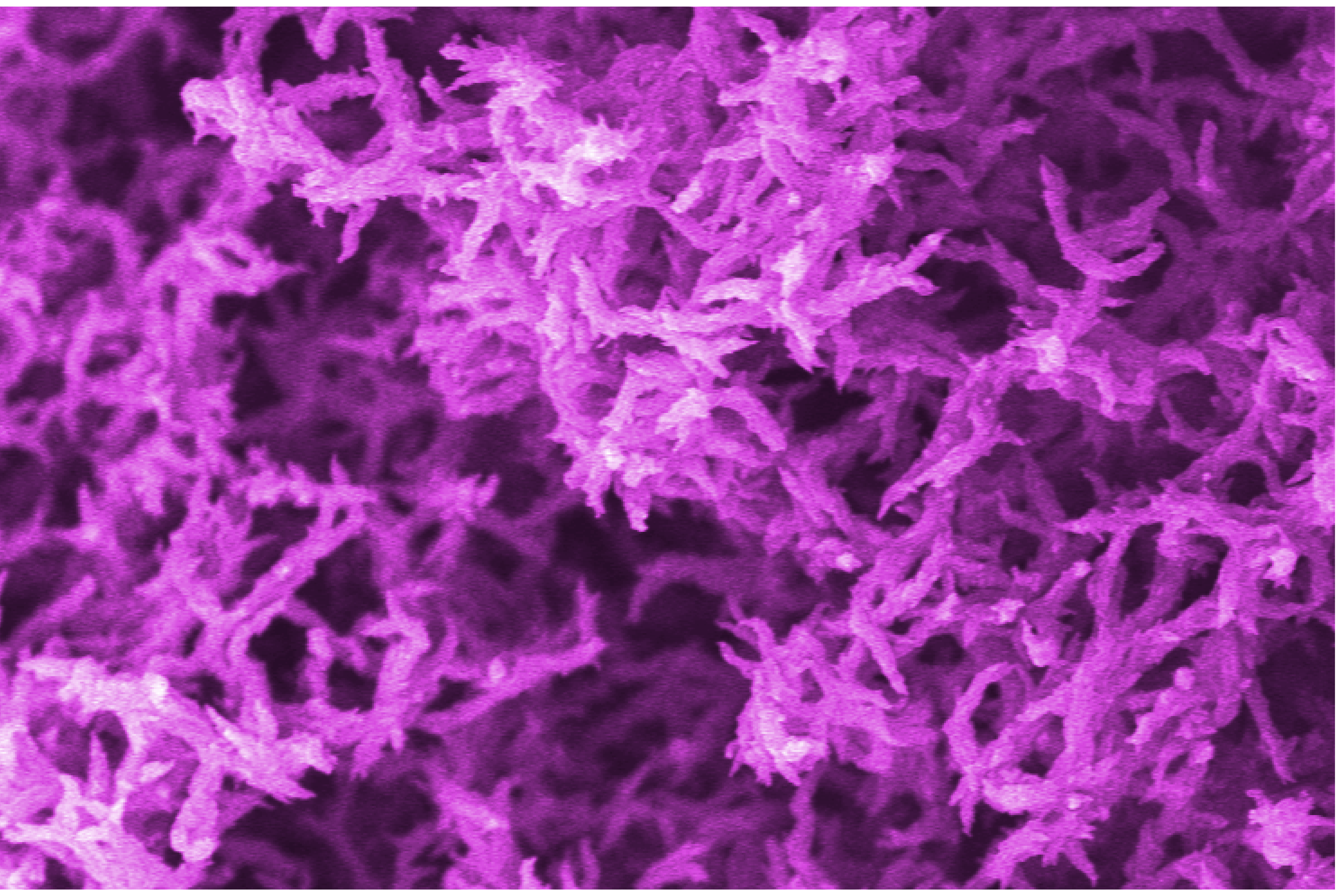
What is particularly important to achieve innovative leaps?

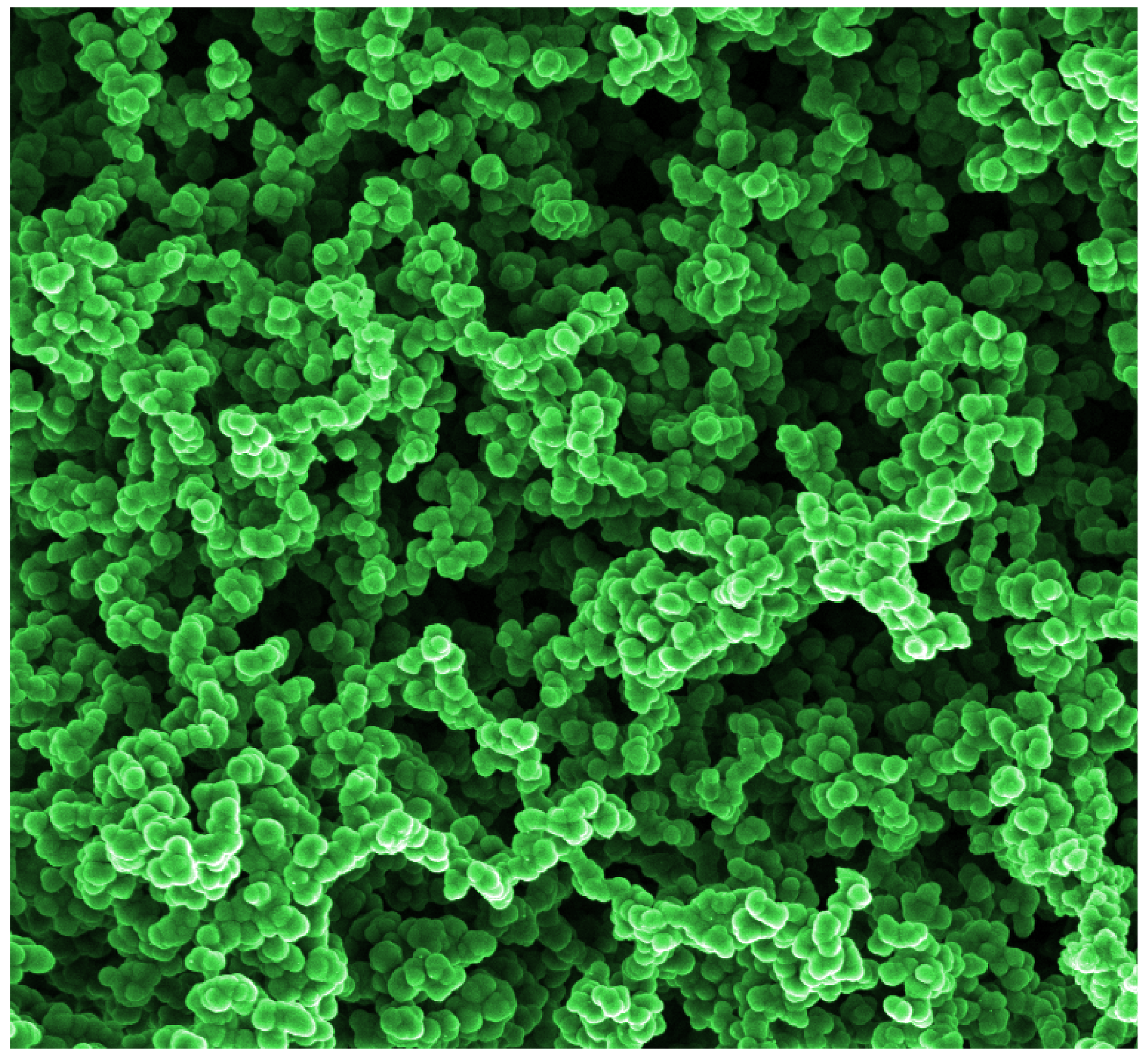
In order to be able to develop better-performing, safer and ideally also more sustainable batteries, it is important for start-ups and other companies to characterise the anode and cathode materials in detail and deeply understand their behaviour throughout the storage processes. Already established methods such as X-ray crystallography are increasingly reaching their limits here, as the components built into battery cells are becoming more and more complex and need to be understood down to the nanolevel.

What contribution can BAM make here?

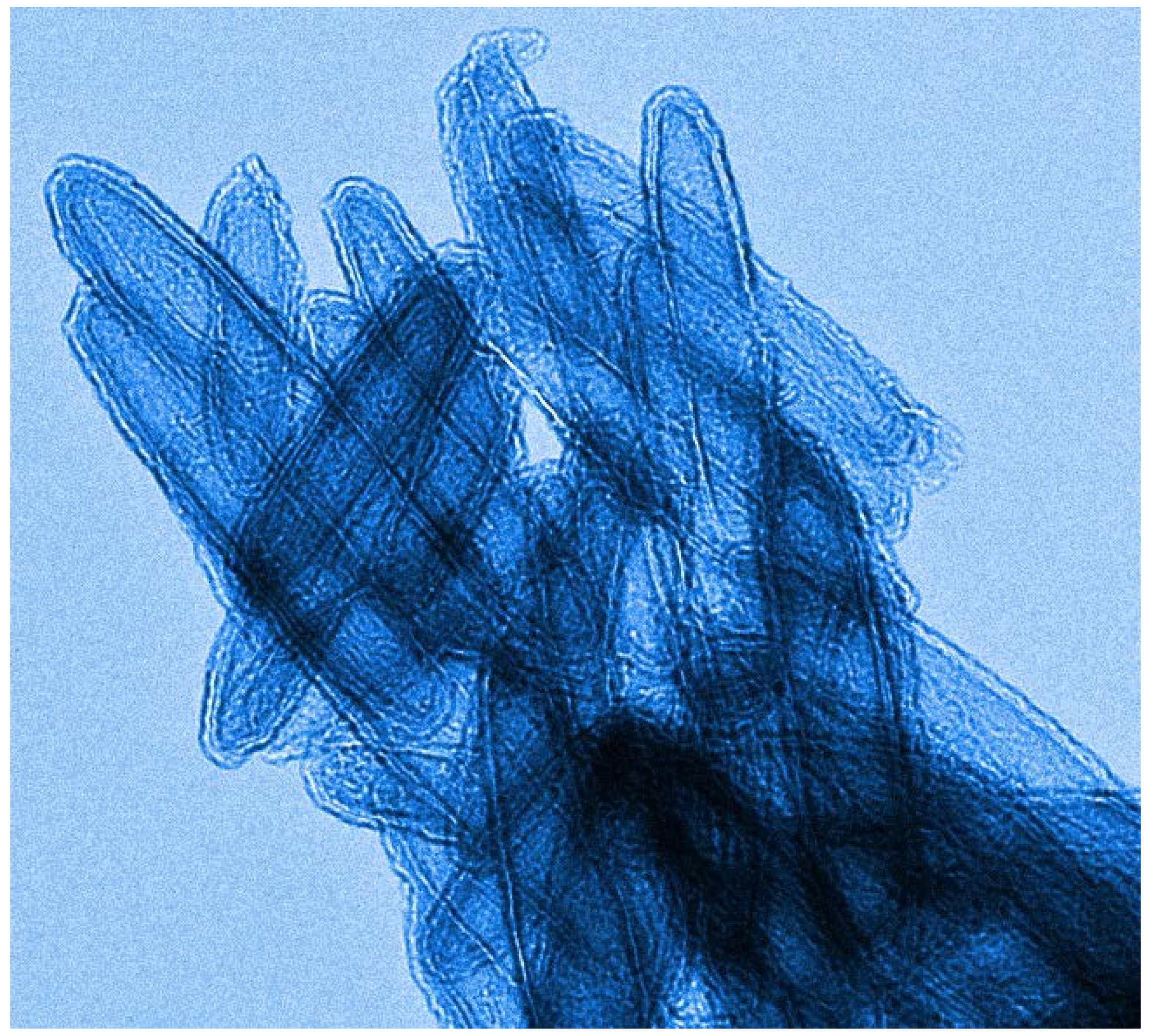
Recently, when it comes to characterising energy materials and battery components, nuclear magnetic resonance spectroscopy has come into focus. It allows a particularly in-depth investigation of both common lithium batteries and new battery concepts such as sodium-ion batteries. We are currently setting up a powerful nuclear magnetic resonance spectroscopy at BAM. In this way, we want

Tim-Patrick Fellinger is an expert for energy materials.





The shape and structure of synthetic carbons can be specifically designed to optimise individual battery components



to offer companies in the battery sector and the scientific community fast and uncomplicate access to this state-of-the-art measurement technology, including our expertise. Many companies in the field of battery cell production would not be able to afford to set up such an infrastructure themselves and operate it with specialised personnel due to the high costs involved.

Why are these measurements so important?

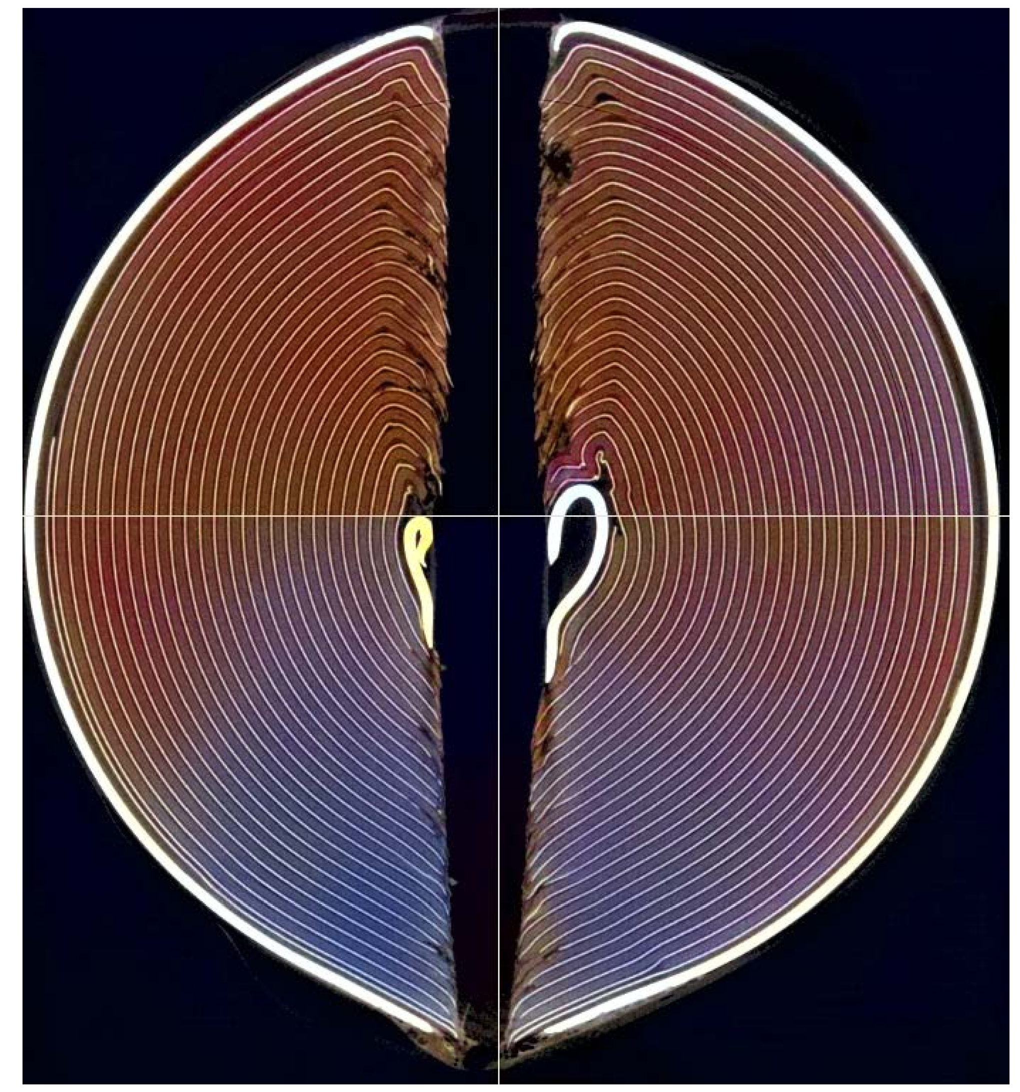
An outstanding infrastructure for the analytics of battery materials is indispensable for jointly driving innovation. It can encourage companies and start-ups to test new and sustainable battery materials quickly and easily, even beyond the common lithium-ion technology. This favours innovation thrusts in battery research in Germany as a whole. Our nuclear magnetic resonance spectroscopy will also be readily available through networking with the existing competence clusters in the battery field.

How do you and your team use nuclear magnetic resonance spectroscopy for your own research?

Together with our research partners, we will investigate sodium-ion batteries, for example, which are considered a sustainable alternative to lithium batteries. Currently, we are particularly interested in so-called hard carbons, a very promising and not fully explored carbon-based energy storage material. We want to increase the storage capacity of these materials so that they can one day replace fossil graphite.

BATTERIES SHOCK-COOLED

Nils Böttcher from BAM's Battery Test Centre is researching how critically defective lithium-ion batteries can be transported more safely in the future. For this purpose, battery cells are cooled down to -80 °C. and damaged. Initial investigations show that this method can delay dangerous thermal runaway, which can cause fires with extremely high temperatures and toxic gases. The thermal runaway of lithium battery cells, triggered by overcharging or an accident, for instance, is one of the greatest sources of danger for emergency services on site and also poses problems for the manufacturers of lithium-ion batteries. In Germany, BAM defines the safety regulations for the transport of such critically defective batteries. At the same time, it conducts extensive research on the state of safety of batteries at its battery test centre and develops new technical solutions. Nils Böttcher is currently investigating whether thermal runaway can be completely stopped by shock cooling.



Damage (simulated here) can trigger the thermal runaway of a battery cell.

MORE LITHIUM THROUGH RECYCLING

Lithium is indispensable for the energy transition. The global demand for this important light metal will continue to rise sharply in the coming years. Many battery manufacturers are therefore already setting up recycling chains. However, for a quarter of all lithium-ion batteries, no practicable recycling method exists yet; especially for lithium-iron-phosphate (LFP) batteries, a type of lithium battery which is used in portable electronic devices, e-cars and large-scale storage. "In previous processes, LFPs tend to be seen as useless by recyclers because they complicate operations. So they sort out this battery type and 'downcycle' it – the lithium it contains is thus lost to the circular economy", says Anita Schmidt from BAM's Battery Test Centre. However, the EU Battery Regulation, which is planned to come into force in 2023, will make recycling mandatory for LFPs as well. BAM deals with thermochemical processes for the recovery of critical raw materials and therefore wants to make them work also for LFPs. In this process, the materials in LFPs are separated at high temperatures. The recovered lithium can then be used again as a raw material for future batteries.

EARLY WARNING SYSTEM PREDICTS BATTERY FIRE

Battery fires can quickly become a danger for the occupants of electric cars. Therefore, legal regulations in the EU and China stipulate that an optical or acoustic warning signal must be emitted at least five minutes before the so-called thermal runaway. This is controlled by the battery management system for example. The solution mainly used so far is the utilisation of sensors that react, for example, to suspicious changes in temperature or pressure inside the battery. The disadvantage: For the sensors to trigger an alarm, serious damage to the cell must already have occurred. The thermal runaway of the battery and thus its destruction are usually unavoidable at this point. In cooperation with a manufacturer of battery management systems, BAM is researching an early warning system that indicates critical changes early on so that the cell can be switched off and fire or total loss of the battery can be avoided. This increases safety and saves costs and valuable resources. The basis of the new early warning system is a measuring method that continuously records and analyses the frequency-dependent electrical resistance in the cell. Ideally, it should be possible to integrate it into all types of batteries.

Energy | **Infrastructure** | Environment | Materials | Analytical Sciences

INFRASTRUCTURE

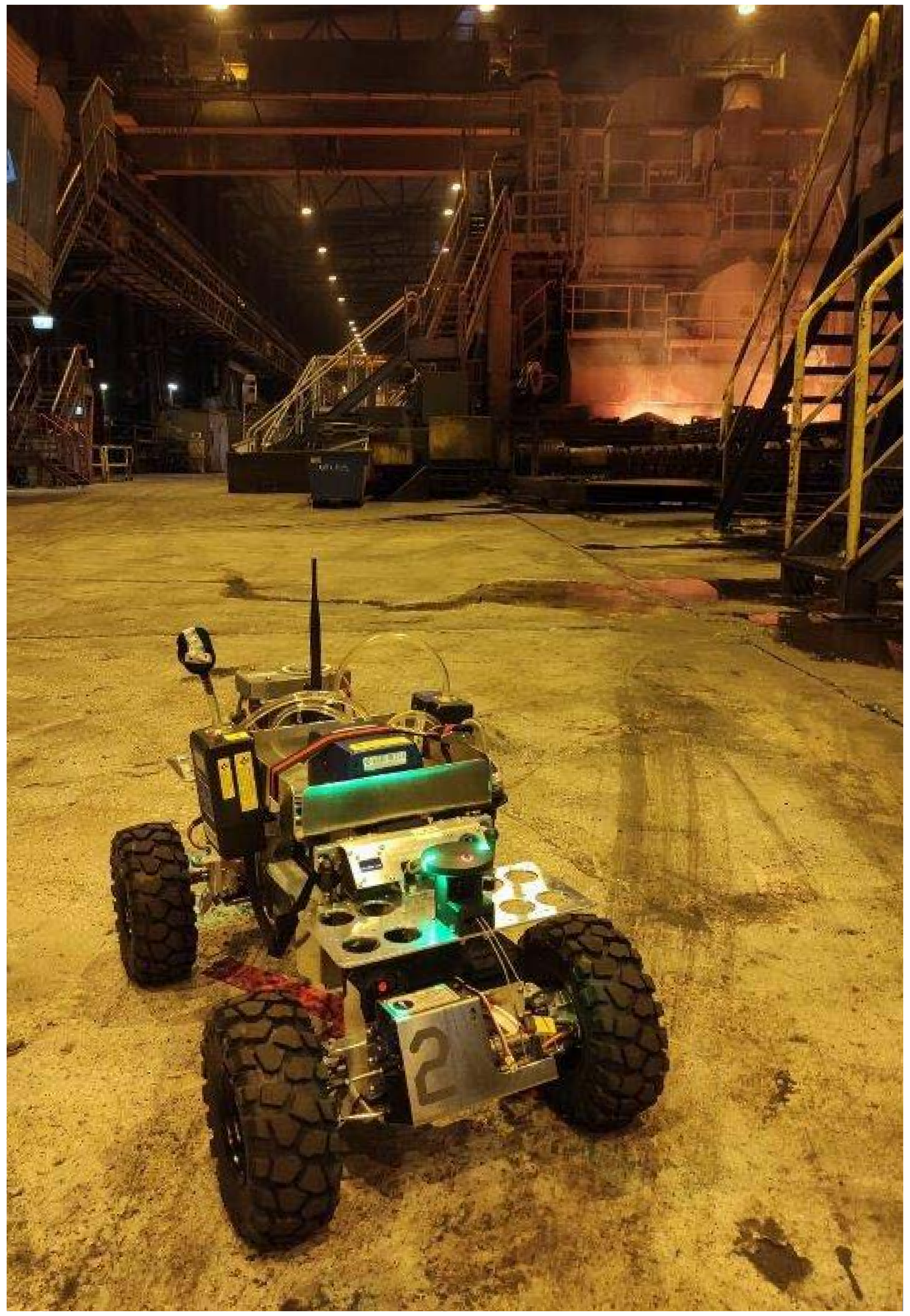
Smart sensor networks

Toxic gases and fine dusts can be released in industrial plants. A smart sensor network developed by BAM helps to determine the pollutants contained in the air more precisely and protect people.

Fine dust, or nitrogen oxides, are tiny air pollutants that are invisible to the eye. They are mainly released by industry, fossil energy production and traffic, and they can endanger health. To determine the concrete risks and implement suitable protective measures, measurement campaigns are usually carried out on single days. However, these measurement campaigns provide just a snapshot of the air pollution and capture the substances only partially, as most of the sensors measure at specific locations. In addition, the proportion of air pollutants is influenced by many different parameters and can vary from day to day.

Innovative environmental monitoring

The RASEM project (Robot-Assisted Environmental Monitoring for Air Quality Assessment) uses a completely new approach to environmental monitoring: A system of stationary sensors and mobile robots inside and outside industrial plants permanently collects extensive data. Continuous, long-term monitoring of the environment also considers the influence of temperature fluctuations or deviations during the manufacturing process. These factors can influence the measurement signal. “By combining stationary sensors, drones and ground robots, we can measure the spatial and temporal distribution of dusts and gases much more accurately than before,” explains Patrick Neumann, an expert in sensor technology at BAM. “Ground robots cover predefined areas of the production site, while at the same time drones register pollutants in the ambient air. With stationary sensors, optimal placement is important in order to accurately determine the pollutant concentration.”



A mobile ground robot was also used in a steel plant in Finland.

Better predictions through AI

The team uses AI-base algorithms to create three-dimensional distribution maps of air pollutants from the measurement data. Compared to conventional numerical solutions, which must be individually adapted and crucially depend on having exact knowledge of the environment at any given time, the new models should be as easily and quickly adaptable as possible to new scenarios or different industries. “We use machine learning methods or neural networks for this,” says Neumann. “Our models ‘learn’ how air parameters usually behave, and with this knowledge we can create distribution maps more accurately and quickly.”

The team was able to gather initial results in a steel plant in Finland. There, Neumann and his colleagues installed 16 sensor modules for dust, gas, temperature and humidity. They collected and analysed measurement data for more than a year. This showed that a sensor network can compensate well for the failure of individual sensors. “By using AI methods, we can not only make sensor networks more efficient, but also create data security and thus improve protection for people and the environment,” says Neumann. In the future, the team wants to test further use cases for its sensor system.

By combining robots, drones, stationary sensors and AI, three-dimensional maps of pollutant distribution can be created

INFRASTRUCTURE

Sustainable flame retardants

A team at BAM wants to improve the ecological balance of flame retardants. To do so, it uses the flame retardant properties of nature.

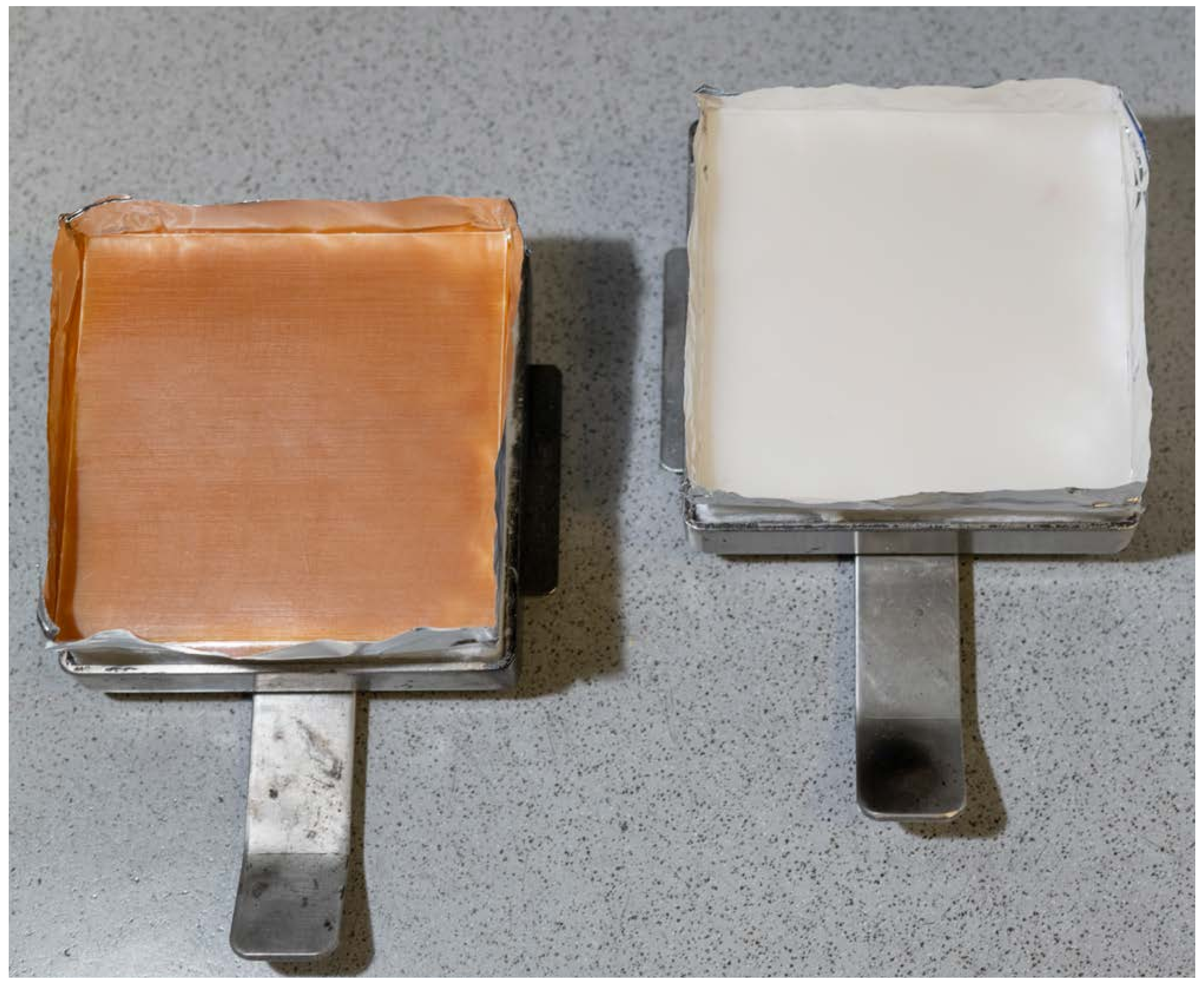
Plastics are ubiquitous in everyday life – from insulating materials in buildings to car bodies and electronic devices. Because these materials are highly flammable, flame retardants and flame retardan coatings are used to prevent or delay fires. However, these often have a suboptimal life cycle assessment. Researchers at BAM are therefore working on a new generation of flame retardants made from natural waste and renewable raw materials that is environmentally friendly and sustainable.

Enormous potential

One way to make flame retardants more ecological is to use less plastic and replace it with fillers or additives based on natural fibres, as these usually do not burn as fast. "Biogenic flame retardants, for example from industrial waste or renewable sources, have enormous potential," says Alexander Battig, flame retardant expert at BAM, adding: "If we can make flame retardant materials efficient and sustainable at the same time, we will make an important contribution to the circular economy and to a climate-neutral economy." However, the processing of biogenic additives in flame retardants still poses a challenge so far, as they should not influence the material properties of the plastic. "Additives often change the properties of plastics, for example their density. Thus, some flame retardants require excessive filling quantities," says Battig. "We are investigating how the components interact with each other during a fire and how we can optimise filling quantities." The goal is to maximise flame retardancy while improving material properties.

Alex Battig develops sustainable flame retardants, for example, from leather scraps.

Flame protection made of leather fibres (l.) develops a charred surface when it burns (r.), which acts like a heat shield



Biogenic flame retardants, for example from industrial waste or renewable sources, have enormous potential.

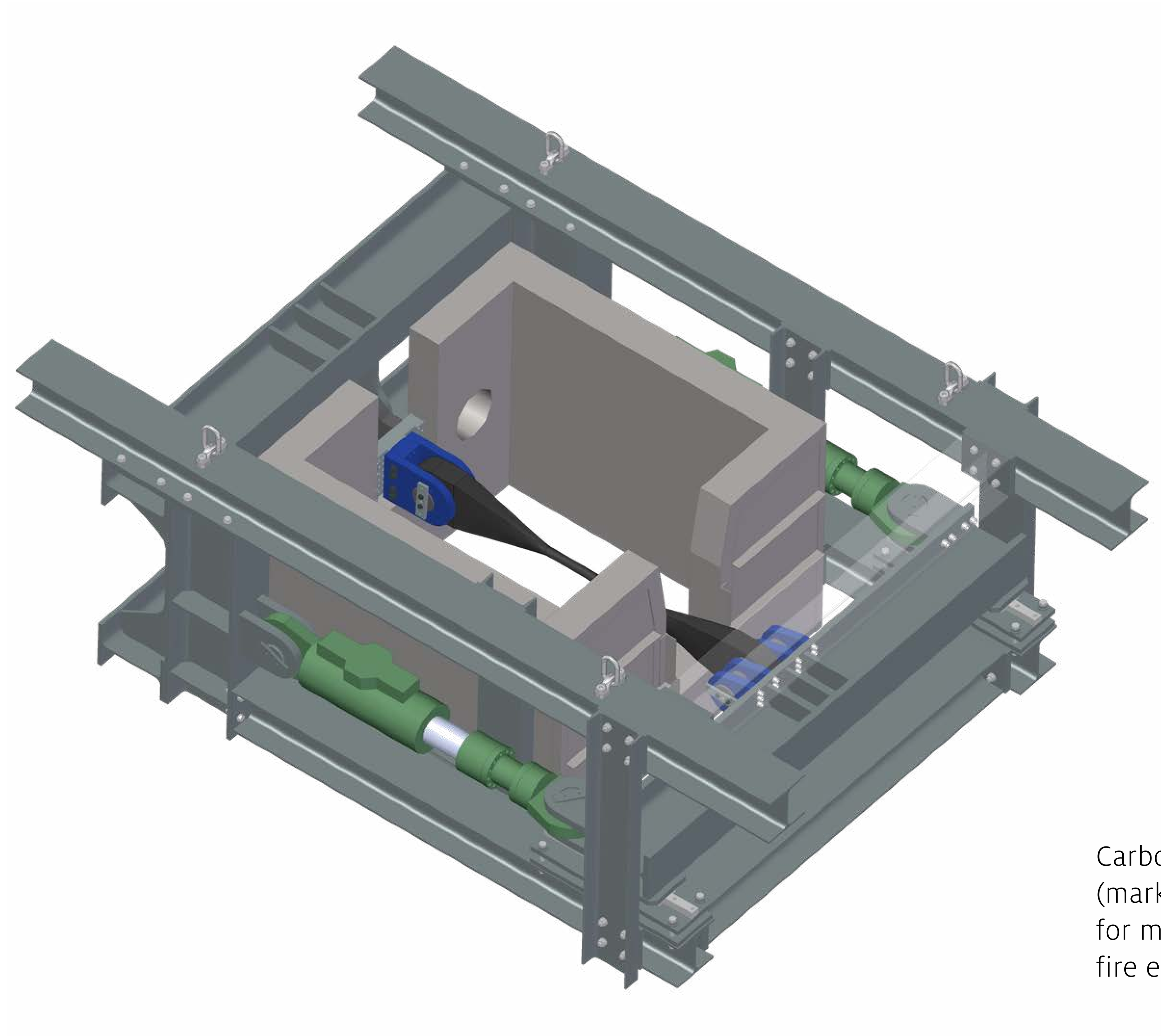
Diverse biomaterials with individual advantages

The BAM researchers are exprimenting with industrial waste such as leather residues and eggshells, as well as with renewable raw materials such as algae. “Each of these additives offers individual advantages for flame protection,” explains Battig. In the case of flame-retardant materials with leather fibres, for example, a charred layer developed in the fire acts as a heat shield and protects the plastic surface from heat radiation and further fire spread. The proteins contained in the leather waste – the collagens – have a positive effect and further strengthen flame protection. In a research project that has just started, algae are also being investigated as an additive for flame retardants, or more precisely, marine algae as well as phosphorus-enriched algae from sewage treatment plants are being analysed with regard to their suitability for flame retardancy. Since they contain a lot of phosphorus, the algae are supposed to act as a kind of sponge and thus build up a flame retardant barrier.

“Our investigations show that upcycling, such as the recycling of waste products or the use of sustainable resources, significantly improves the eco-balance of flame retardants and at the same time achieves a high fire protection effect,” says Alexander Battig, summing up. In the future, other natural raw materials could be used, such as cork or shells, which have the potential to serve as ecological flame retardant materials.

FIREPROOF TENSION MEMBERS FOR LIGHT-WEIGHT CONSTRUCTION

Arch bridges for railway traffic are usually built with steel tension members. Carbon tension members may be an alternative. They are not only lighter, but also reduce the amount of concrete and steel required to construct the bridge – thus saving CO_2 at the same time. However, to use carbon tension members, all safety requirements must be fulfilled. In the joint project NeZuCa, BAM, Technische Universität Berlin, the Karlsruhe Institute of Technology, the University of Stuttgart, the engineering company Schlaich Bergermann Partner and Deutsche Bahn cooperated to investigate the fatigue behaviour and fire resistance of carbon tension members. At BAM, a special testing device was used to simultaneously apply a tension load and create fire exposure. Thus, it was possible to assess the load-bearing capacity of carbon tension members in case of fire and identify recommendations for improving fire resistance. In the future, the findings can contribute to establishing the use of carbon tension members for railway bridges as well as for building constructions.



Carbon tension members (marked blue) are tested for mechanical load and fire exposure

NEW TEST STANDARD FOR INTUMESCENT COATINGS

Reactive fire protection systems create a thermal protective char that delays the heating of the steel

To improve the fire resistance of steel structures used for high-rise buildings, warehouses or industrial buildings, intumescent coatings, which known as reactive fire protection systems, are commonly used. In the case of fire, these thin coatings, which consist of several components, create a thermal protective char which delays the heating of the steel. As a result, the load-bearing capacity of the steel construction is maintained for a longer time to allow firefighting and evacuation of the building. However, there is no standardised testing and assessment procedure for intumescent coatings applied to steel tension members. In the FIRESTEMIC project, BAM scientists, together with two companies that produce such coatings, have developed a proposal for a new European test standard to test and assess intumescent coatings on steel tension members. For this purpose, the team carried out extensive real-scale fire tests under mechanical tensile load. The results provided information on how fire tests need to be carried out to proof the performance of these products. The findings are currently to be incorporated into national and European standardisation on fire protection. Thus, they can contribute to establishing a uniform safety level for the application of intumescent coatings applied to steel tension members.

Intelligent bridge monitoring

Load test on a Main bridge with an 85-tonne electric locomotive

Bridges in Germany are inspected using analogue methods. With the help of digital monitoring and latest testing methods, premature closures and demolitions could often be avoided.

Bridges in Germany are still largely inspected "manually" for their safety. The structure is inspected on site, and the findings and their evaluation are entered manually into databases and logbooks. On this basis, experts then decide on necessary actions, such as repairs or closures.

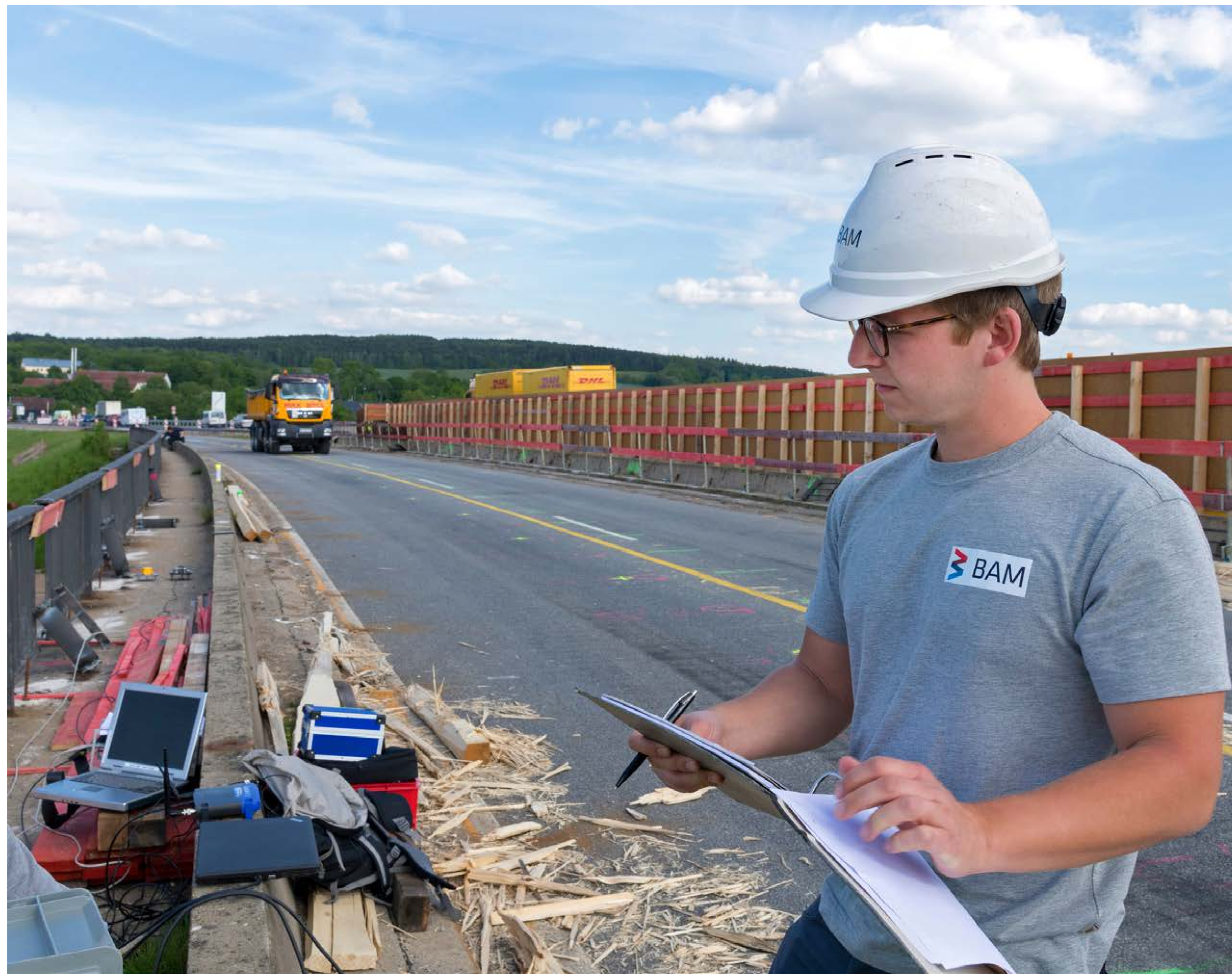
Detecting damage processes at an early stage

"In future, assessing the condition of bridges and other engineering structures will be digitised and improved using more efficient concepts," says Ronald Schneider, an expert in structural integrity management at BAM. "Ideally, monitoring should also allow for predictive maintenance, so that inspections and maintenance actions can be optimally planned. If damage processes are detected at an early stage, the risk of bridge closures can be reduced."

Schneider and his team have developed a fully digital solution for this purpose in the AISTEC research project in cooperation with partners from science and industry. It enables the automatic monitoring of bridges based on continuous sensor data. The monitoring system even allows a look into the future: It makes it possible to predict future defects by linking the sensor data with predictive models of relevant damage processes. BAM's sensor-based monitoring system was successfully tested on an almost 800-metre-long railway bridge in Bavaria.

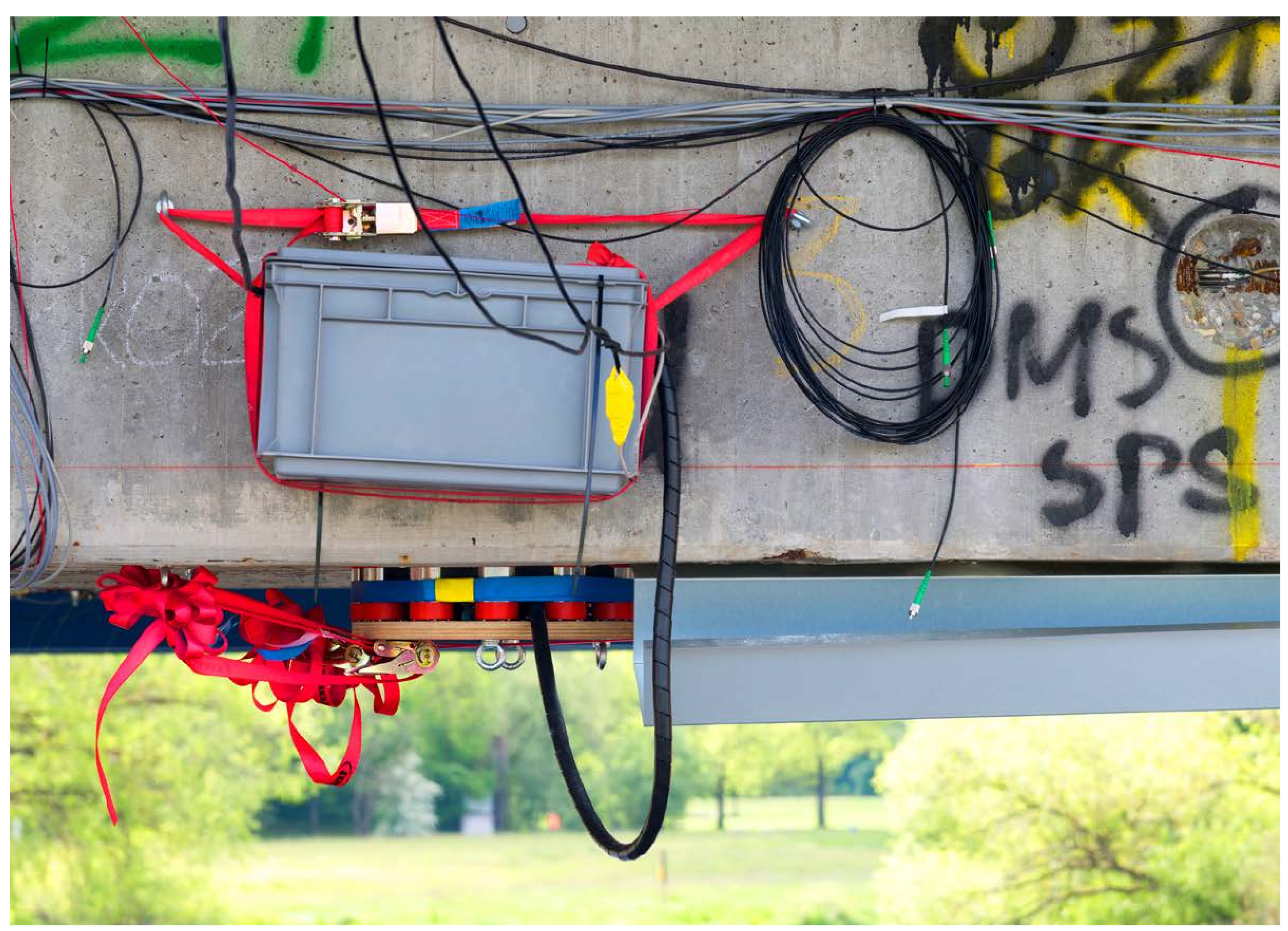
Extending service life

Use restrictions can also be avoided by using the latest testing methods, as the safety of structures can be better assessed with the additional knowledge. Their load-bearing capacity is checked through structural analyses to assess whether a bridge can continue to withstand the ever-increasing volume of traffic. "In the vast majority of cases, the calculations are not based on measurement data describing the actual characteristics and condition of the structure, but on documents from the time of construction, or on assumptions if the old plans are missing or incomplete," says Stefan Küttenbaum, expert for structural investigations at BAM. "For some time now, modern non-destructive testing methods have actually allowed a much more detailed assessment of bridges. So far, however, these methods are not part of the official guidelines for performing structural re-assessments. We want to change that."



Stefan Küttenbaum and the team test the latest structural assessment methods.

If damage processes are detected at an early stage, the risk of bridge closures can be reduced.



With current measurement data from sensors, it is possible to assess more accurately whether a structure is still able to withstand the loads

The research project ZfPStatik has set itself the goal of integrating the most modern structural testing methods into the calculations and regulations together with partners from industry and science. To this end, the BAM team analyses the strengths and weaknesses of various non-destructive testing methods and evaluates their quality. The project aims to transfer methods and processes into practice that can be used to implement non-destructive testing on site economically and reliably and that have the potential to avoid premature demolitions in many cases and increase resource efficiency.

Energy | Infrastructure | **Environment** | Materials | Analytical Sciences

ENVIRONMENT

Carbon fibres recycled

By recycling damaged carbon fibres under the scanning electron microscope

The demand for carbon fibres for lightweighting is increasing worldwide. However, there is no circular economy infrastructure in place yet for this high-performance material.

It is essential for aerospace, it is used in the rotor blades of wind turbines, in automotive construction and for numerous applications in consumer products. Carbon fibre-reinforced polymers (CFRP) have become a broadly applied lightweight material. CFRP plays a crucial role in the transformation to climate neutrality: It helps to save mass, material and thus resources, energy and CO_2 at the same time. In the future, the material will also be needed for robust and lightweight hydrogen tanks, for example.

Circular economy is missing

Worldwide consumption of the high-performance material is already at around 130,000 metric tonnes per year and rising. Despite the growing demand, there is still no circular economy infrastructure in place for CFRP, although it is possible to release used carbon fibres from the surrounding polymer matrix, e.g. by means of pyrolysis, i.e. the thermal splitting of chemical compounds, and to process them into a high-quality starting material. Nevertheless, the demand for recycled carbon fibres is low. Their market share is less than five per cent. "There are concerns in industry about the performance of components based on recycled carbon fibres," explains Florian Loose, a chemist at BAM. "Many CFRP processing companies prefer to use virgin fibres because little is known about the impact of recycling carbon fibres on the performance of the final component. In addition, there are no established quality assurance standards for recycled carbon fibres that could dispel biases.

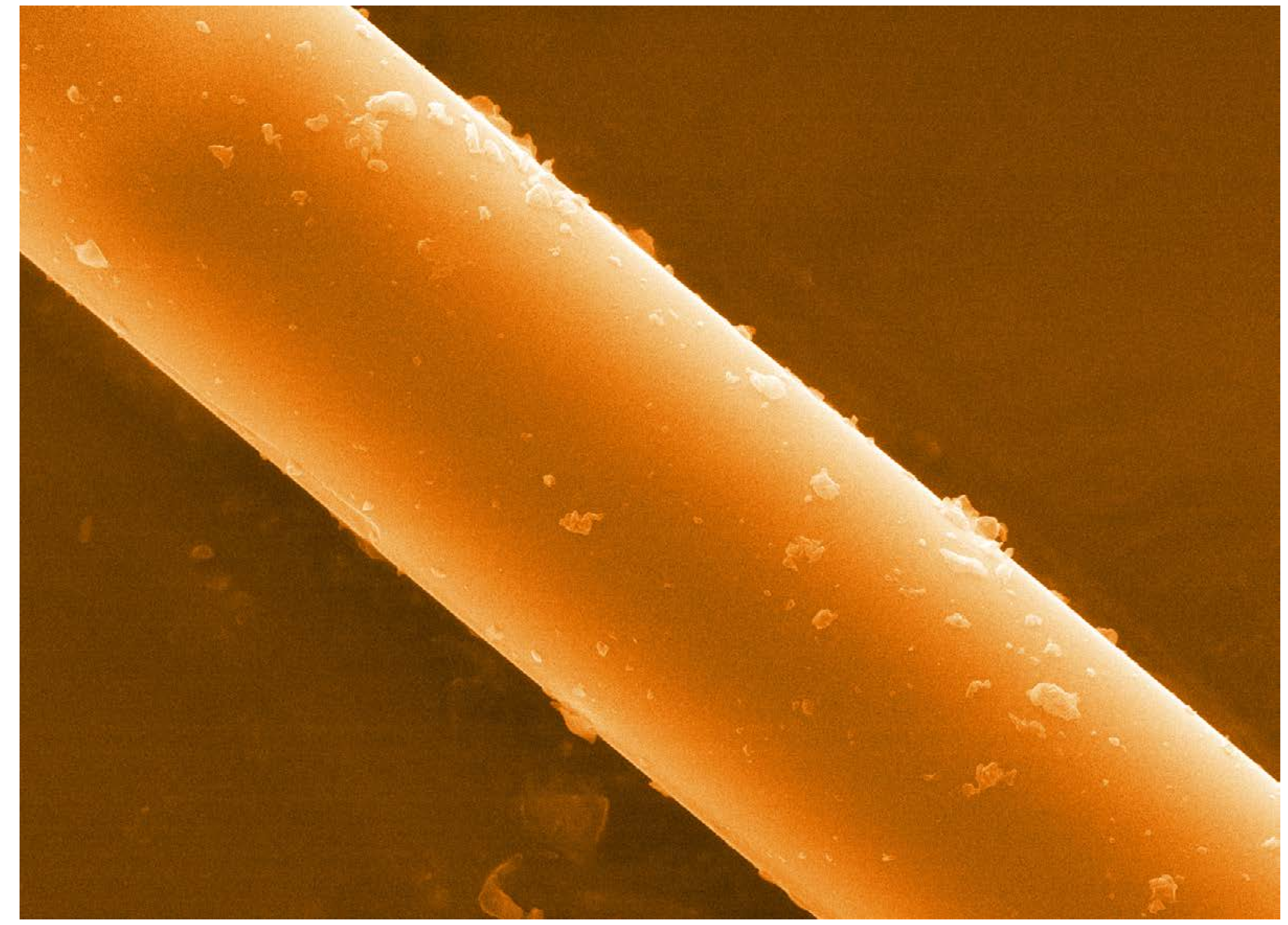
Florian Loose wants to establish quality standards for the recycling of carbon fibres.

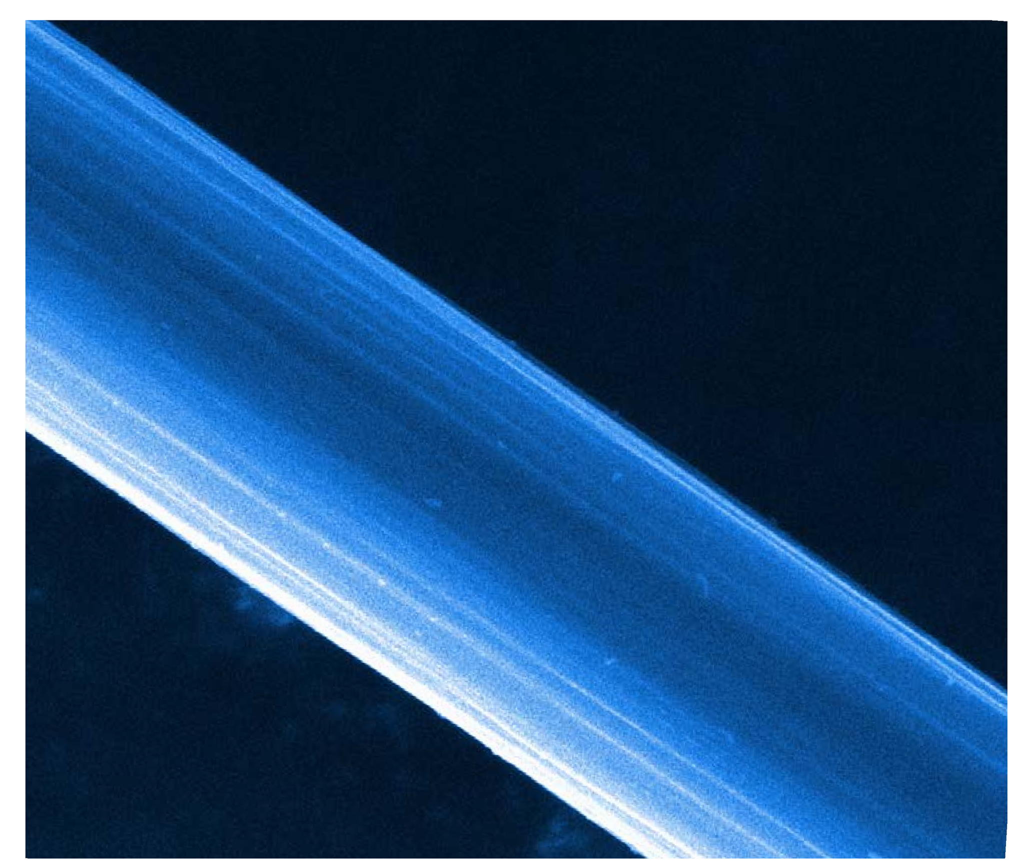
Consequently, the material is currently either subjected to less sustainable downcycling, e.g. processed into park benches, or disposed of." Florian Loose and his colleagues want to change this. They are investigating the recycling process more closely and want to develop reliable standards for recycled carbon fibres.

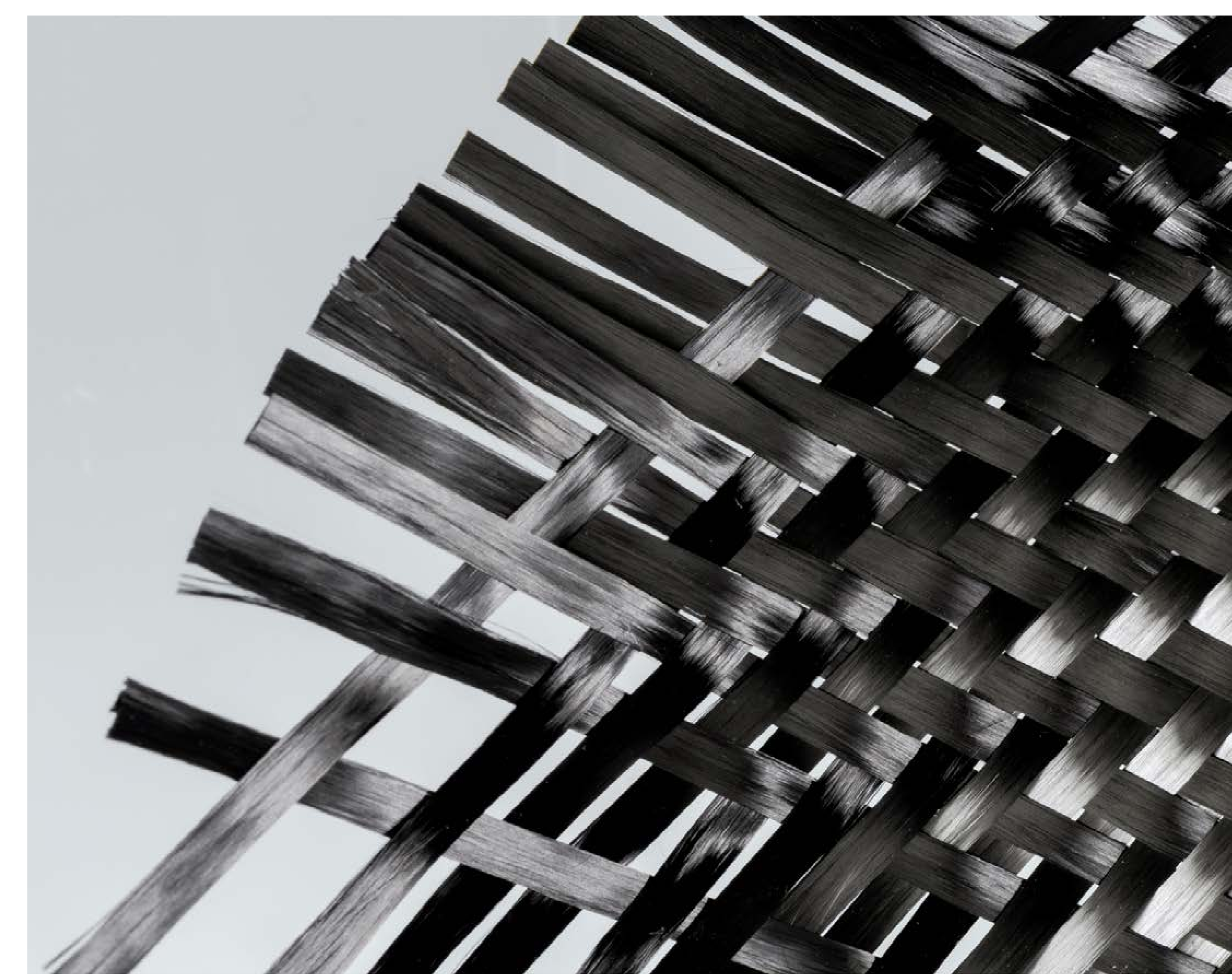
Direct performance comparison

In close dialogue with science and industry, the team collects the parameters and material properties that are important for application. These parameters are followed over the entire life cycle of a CFRP test specimen: From manufacturing and use to the recovery of the fibres by means of pyrolysis and their reuse in a structurally identical workpiece. In particular, mechanical roperties, e.g. inter-fibre fracture strength and fatigue strength, are determined in this direct performance comparison. These are relevant for the use of the recycled material because they determine the load-bearing capacity of the product and have rarely been investigated systematically so far.

The researchers also want to take a closer look at the recycling process itself to understand its impact on the component properties. "Finally, we want to develop quality standards for recycled carbon fibres and their application to increase their acceptance on the market and to establish a circular economy for CFRP – with a reliably high level of safety," says Florian Loose.







Almost like new: CFRP from recycled CF (below, left) and material from virgin CF (above) perform similarly.

39 years is the average lifespan of a building in Europe. Then it is demolished - although it could often still be used. This produces huge amounts of construction waste, almost a third of all waste in Europe. Sabine Kruschwitz, BAM expert for the recycling of building materials and co-coordinator of the large-scale European project "Reincarnate", wants to change this. 16 organisations from eight different countries have joined forces in the project. The goal: to embed the idea of the circular economy in the European construction industry so that 80 percent less construction waste is produced in the long term. At the same time, the CO_2 footprint of the construction sector could be reduced by 70 percent through the reprocessing and subsequent recycling of materials that have already been used once. To achieve this, the recycling potential of building components and materials is to be assessed and fed to digital models and linked to the architects' planning software. In this way, the information can already be taken into account during the design stage. Non-destructive testing methods, which can be used to investigate the condition of buildings, and data-driven modelling approaches for the recycling of building materials – both core competencies of BAM – are also important in extendingbuilding life cycles.

Construction waste could be reduced by 80 percent through circular economy strategies

Steel slags can save many millions of tonnes of CO_2 in the cement industry

SAVING CO_2 WITH STEEL SLAGS

Blast furnace slag, which is a by-product of steel production, has so far been used as a valuable and at the same time sustainable raw material in the cement industry: As so-called granulated blast furnace slag, it replaces clinker and thus helps to save around 4.5 million tonnes of CO_2 every year in Germany alone. The upcoming transition of the steel industry to low-CO_2, hydrogen-based productio brings both a change and a challenge: Granulated blast furnace slag is no longer produced in the new process. Instead, a different type of steel slag is produced that cannot be as easily recycled as before. Together with Salzgitter Mannesmann Forschung GmbH, the Institut für Baustoff-Forschung e. V., Friedrich Rohstoffe GmbH, Holcim Deutschland GmbH and LOI Thermprocess GmbH, BAM is researching how the properties of the new slag can be changed so that it continues to meet the requirements of the cement industry. "The chemical composition of the slag must be specifically modified by additives and a controlled cooling process to give it the desired properties," says project manager Christian Adam. "In this way, we ensure that the new steel slag, which will be available in large quantities in the future, is used in a high-quality manner, and that the volume of CO_2 savings achieved is maintained."

INTERNATIONAL NETWORK

Microbially influenced corrosion (MIC) can damage important infrastructures and energy supply facilities such as bridges, port facilities, motorways, electricity pylons, wind turbines or gas pipelines. This can lead to high economic and particularly serious environmental damage. To counteract this, BAM biologist Andrea Koerdt has set up an international research network that explores strategies to combat MIC and is supported by Cooperation in Science and Technology (COST), a European funding organisation.

In August 2022, the first international conference of the new Euro-MIC network took place at BAM with participants from all over the world, from China to the US and South America. The focus of the numerous lectures and workshops: Improving the exchange of knowledge between industry and academia as well as the latest research approaches to combat MIC. “Only with the help of a networked and interdisciplinary approach can we solve the global challenges posed by MIC,” says Andrea Koerdt.

August 2022: The first conference of the new Euro-MIC network at BAM

USING BIOCIDES SAFELY AND SUSTAINABLY

Corrosion of oil and gas pipelines and other important energy and water supply infrastructures causes damage worth several trillion euros worldwide every year. One of the culprits are microorganisms, or more precisely, sulphate-reducing bacteria. In their metabolism, they produce hydrogen sulphide, which can cause leaks in steel pipelines. To prevent this, companies combat these harmful single-celled organisms with biocides. However, microorganisms can develop resistance against biocides – especially with repeated use. Until now, this survival strategy has never been investigated in detail for sulphate-reducing bacteria. BAM is therefore dedicating a separate research project to deciphering biocide resistance in sulphate-reducing bacteria. “The aim is to understand molecular mechanisms in order to be able to use biocides more effectively and more sustainably,” says BAM biologist Lydia-Yasmin Sobisch.

Energy | Infrastructure | Environment | **Materials** | Analytical Sciences

MATERIALS

Powerful nano-semiconductors

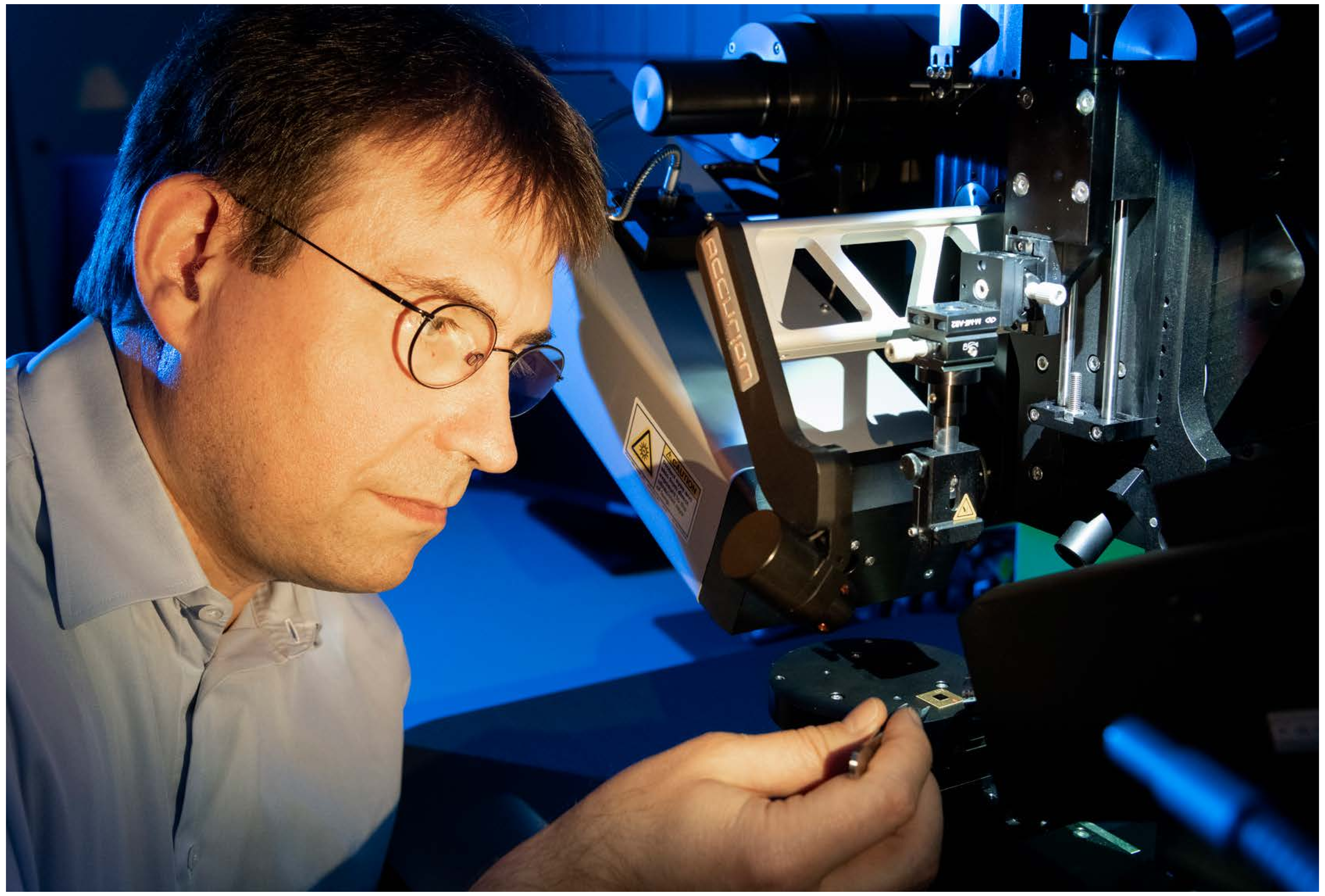
Powerful and reliable semiconductors are needed for the use of wind energy and e-mobility. BAM is developing test methods for the latest generation of chips.

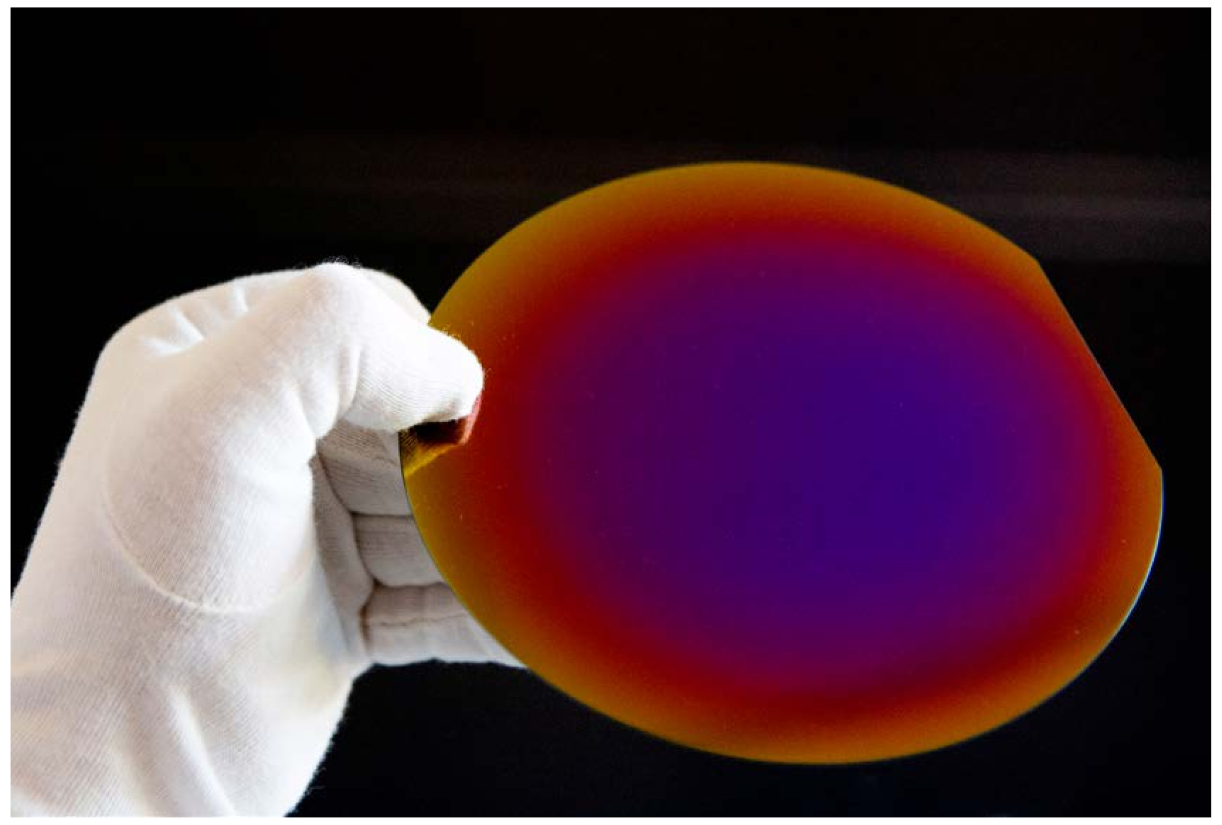
Wide bandgap (WBG) semiconductors allow devices to operate at higher voltages and temperatures than before and at the same time have very low energy losses. However, with the increasing miniaturisation of chips, which today already contain billions of densely arranged circuits, the susceptibility to errors is also increasing. This leads not only to increased production costs, but also to safety risks: Defective components can become a danger to people and the environment.

Detecting anomalies on the nanoscale

“Reliably detecting defects, in addition to increasing yield, is a key focus for the industry in order to fully exploit the performance advantages of these semiconductors,” says Andreas Hertwig from BAM, which operates one of the leading research laboratories in Europe in this field. Hertwig and his team are investigating compound semiconductors for nanoscale anomalies using various spectroscopic and optical methods. In the PowerElec project, they are developing measurement methods and standards to reliably determine the quality of semiconductors. The goal is to detect possible defects already during production. “To do this, we combine different imaging methods. This allows us to measure the electronic and optical properties of the materials,” says Andreas Hertwig. A light beam determines the thickness of the individual layers for this purpose. Material deviations are detected within seconds using complex algorithms and the compressed sensing method. “The process is similar to the compression of image files,” explains Hertwig. “The amount of data is already reduced during measurement and assembled to create a

Defects at the nanoscale can be detected using a spectrometer





Anomalies in materials are detected within seconds by combining several imaging methods

comprehensive picture using algorithms." The electrical conductivity of the chips is also crucial, because the higher this turns out to be, the more powerful and energy-efficient a device or component works. "Measuring it accurately and efficiently is currently one of the major challenges in the electronics industry," explains Hertwig. "We are developing suitable methods for this in a second project – ELENA." They will enable faster and more energy-efficient digital technology in the future.

Faster evaluation of components

A total of 20 European partners from science and industry are involved in both research projects. They are funded by the European Metrology Programme for Innovation and Research (EMPIR). Initial results show that combined imaging methods make it easier to detect defects. "It is particularly promising that we can also determine the abundance and size of defects," says Andreas Hertwig. "In the future, this will enable fast measurements providing direct statements on the quality of components." The analysis methods will be developed to maturity in cooperation with semiconductor manufacturers.

MATERIALS

Living Lab 3D Printing

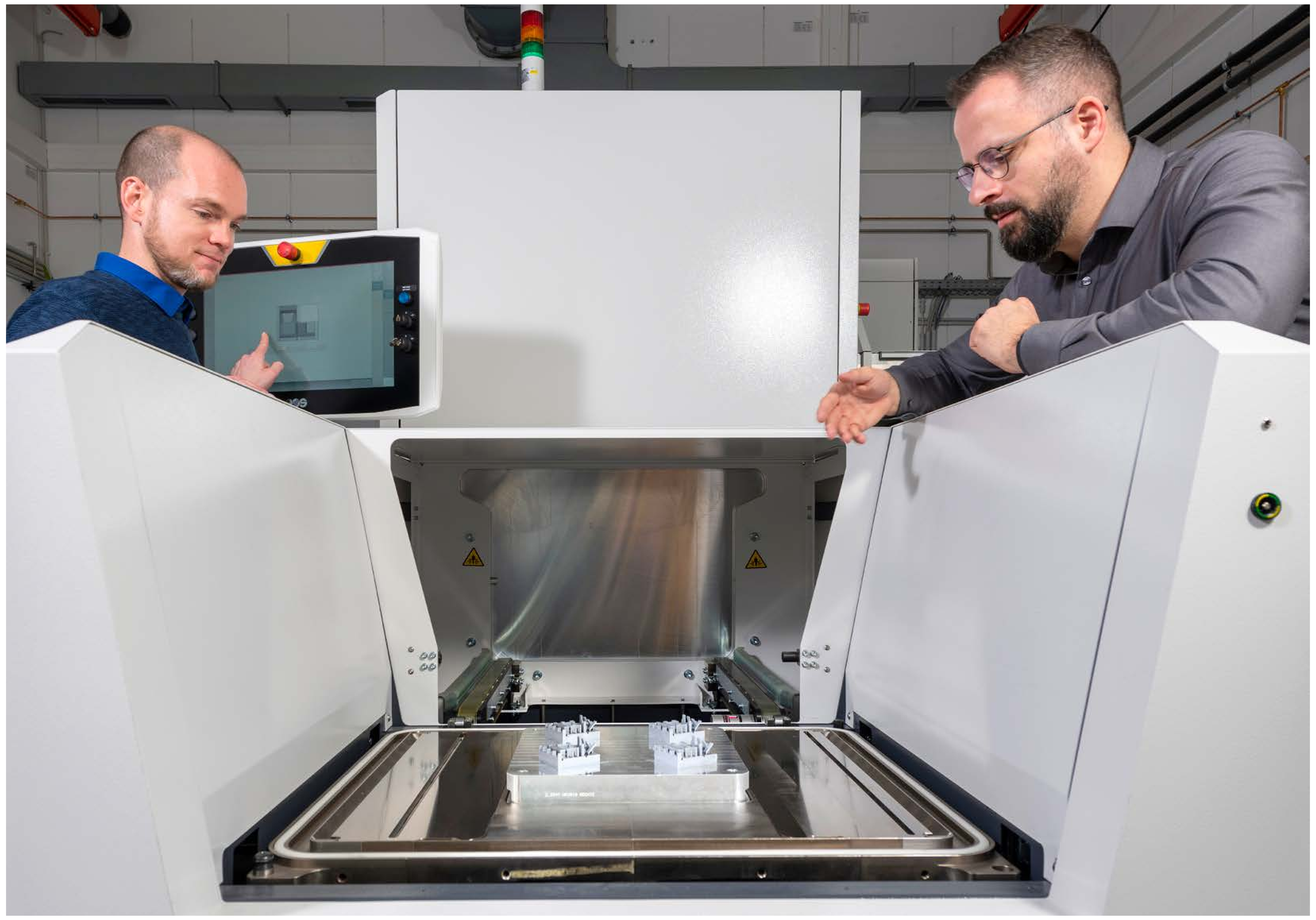
3D printing of metals is becoming the new key technology. In BAM's living lab, the entire production process is digitised to ensure consistent component quality.

In powder bed-based additive manufacturing of metals, a powder is applied layer by layer on a platform and fused by means of a laser beam. The layering makes it possible to realise highly complex, stable and lightweight geometries with cavities and honeycomb structures, e.g. lightweight components for aircraft.

However, as their complexity increases, so does their susceptibility to defects. "Quality assurance reaches its limits here," explains Kai Hilgenberg, head of the Additive Manufacturing Competence Centre at BAM. "In order to rule out defects, companies have to carry out very time-consuming and cost-intensive tests. For series production, additive manufacturing of metals has therefore not been economical in many cases so far."

Continuously networked production process

In the competence centre'snew living lab, BAM is developing solutions for quality-assured additive manufacturing of metallic components in a pilot project that is part of the Quality Infrastructure Digital (QI-Digital) initiative. Here, BAM scientists are conducting research together with German QI partner institutions and interested companies that meets the requirements of the market. "We want to digitise the entire manufacturing process – from th starting material to the manufacturing process to the finished component and the downstream non-destructive tests," summarises the coordinator of the pilot project, Martin Epperlein. "Our data are the basis for the development of reliable safe-



In BAM's real laboratory, the entire manufacturing process is digitised.

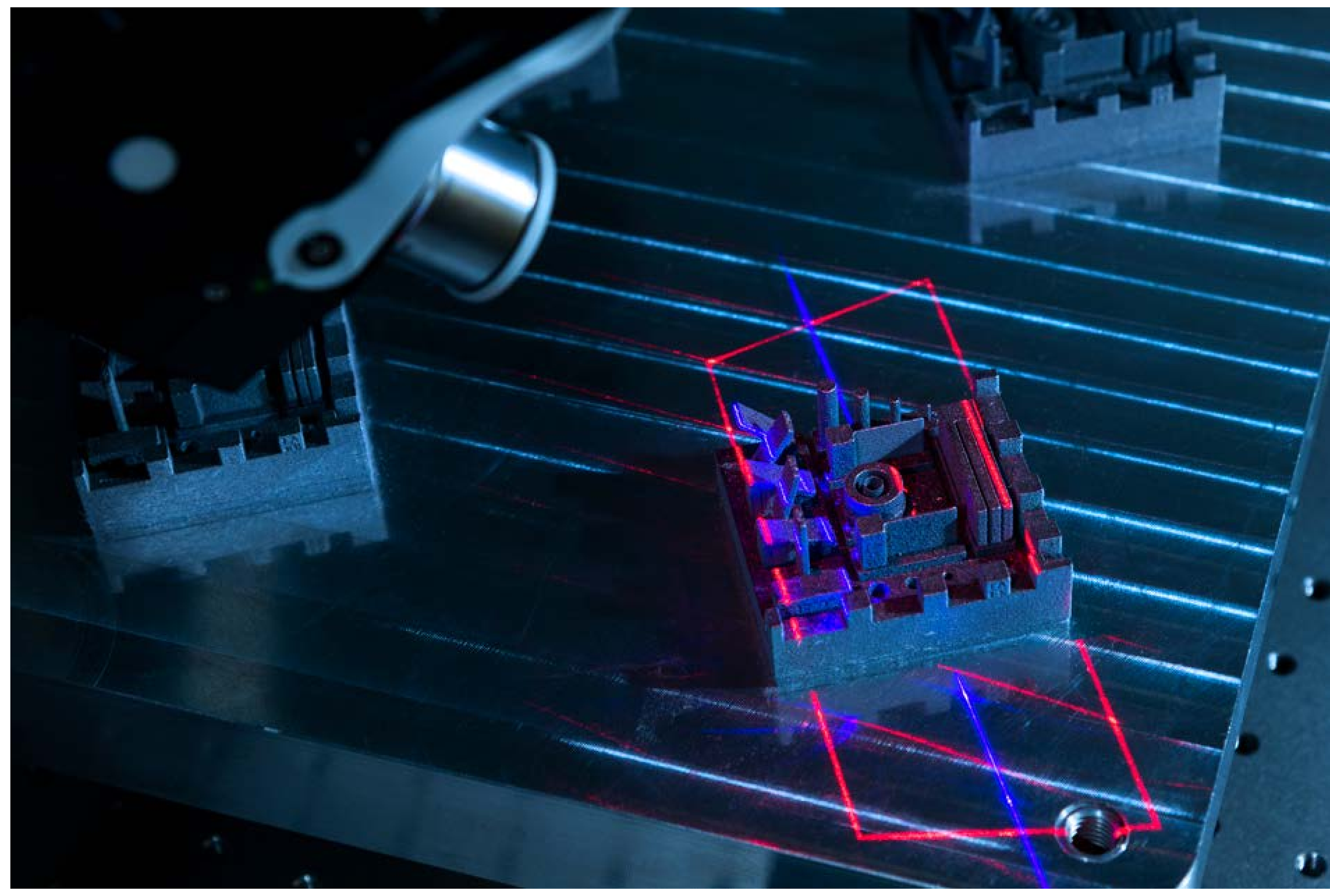
ty standards." To this end, the team has invested in state-of-the-art equipment: A multi-laser system paired with cameras for process monitoring enables the targeted evaluation of quality-relevant data, even during the printing process. During production, these special cameras automatically detect defects, such as cavities, unmelted powder or cracks, which are then compared again using computed tomography (CT) scans after printing. The finished component is also measured by a 3D scanner, which evaluates whether it complies with the predefined tolerances.

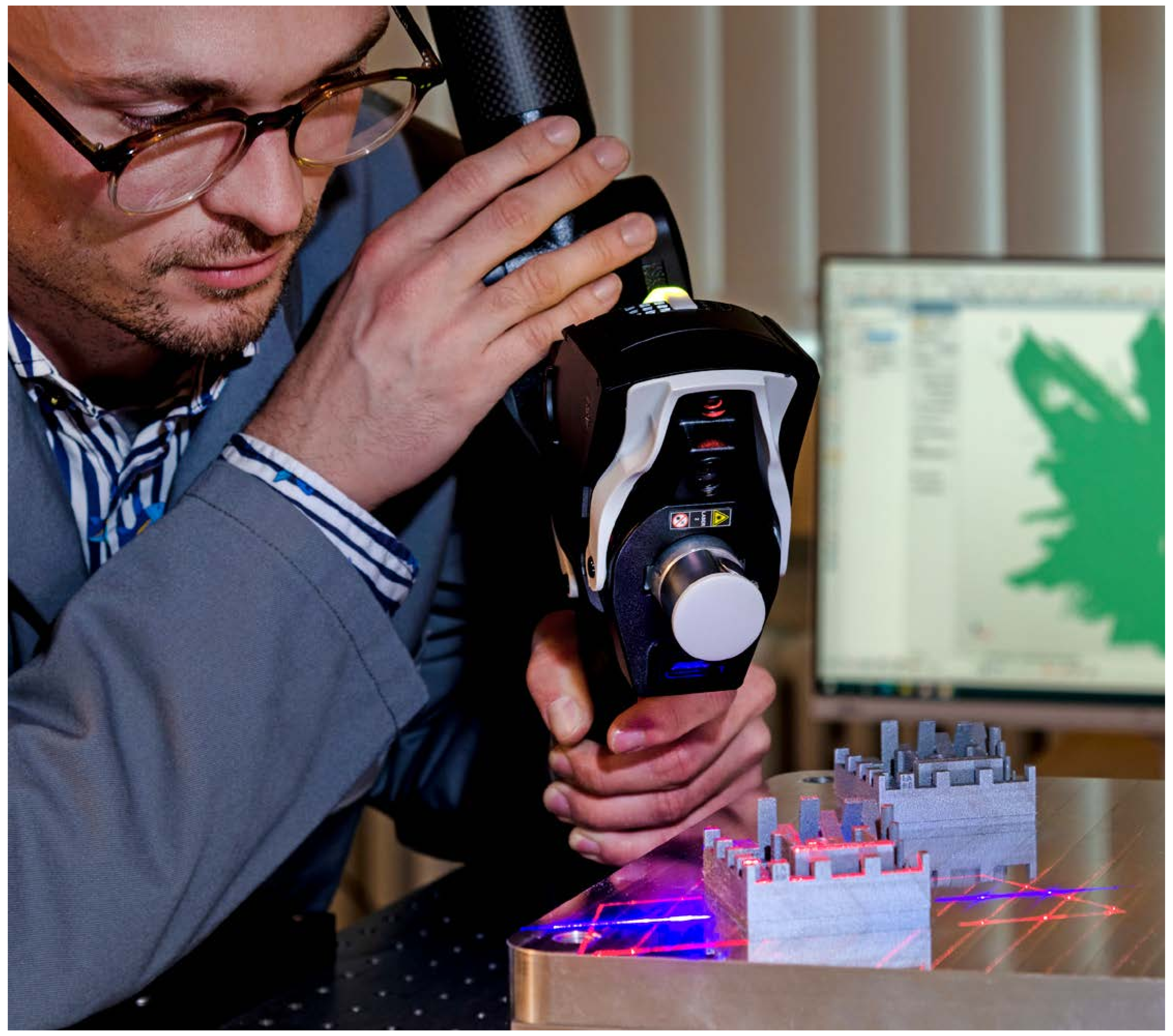
Standards and certificates from the cloud

From the multitude of data that accumulate during the entire printing process, the team uses artificial intelligence to determine the information that is relevant to quality. In cooperation with the QI Digital partners, prototypes of digital norms, known as smart standards, are created. The networking of all the systems in the living lab also enables a digital inspection of the production process via the QI Cloud. The result is certified in the form of a digital certificate.

"With our work, we want to make it easier for small and medium-sized companies to get involved in the additive manufacturing of metals," explains Epperlein. "In this way, we are helping to exploit the full innovation potential of this future technology for industrial production."

We want to exploit the full innovation potential of 3D printing for industrial production.

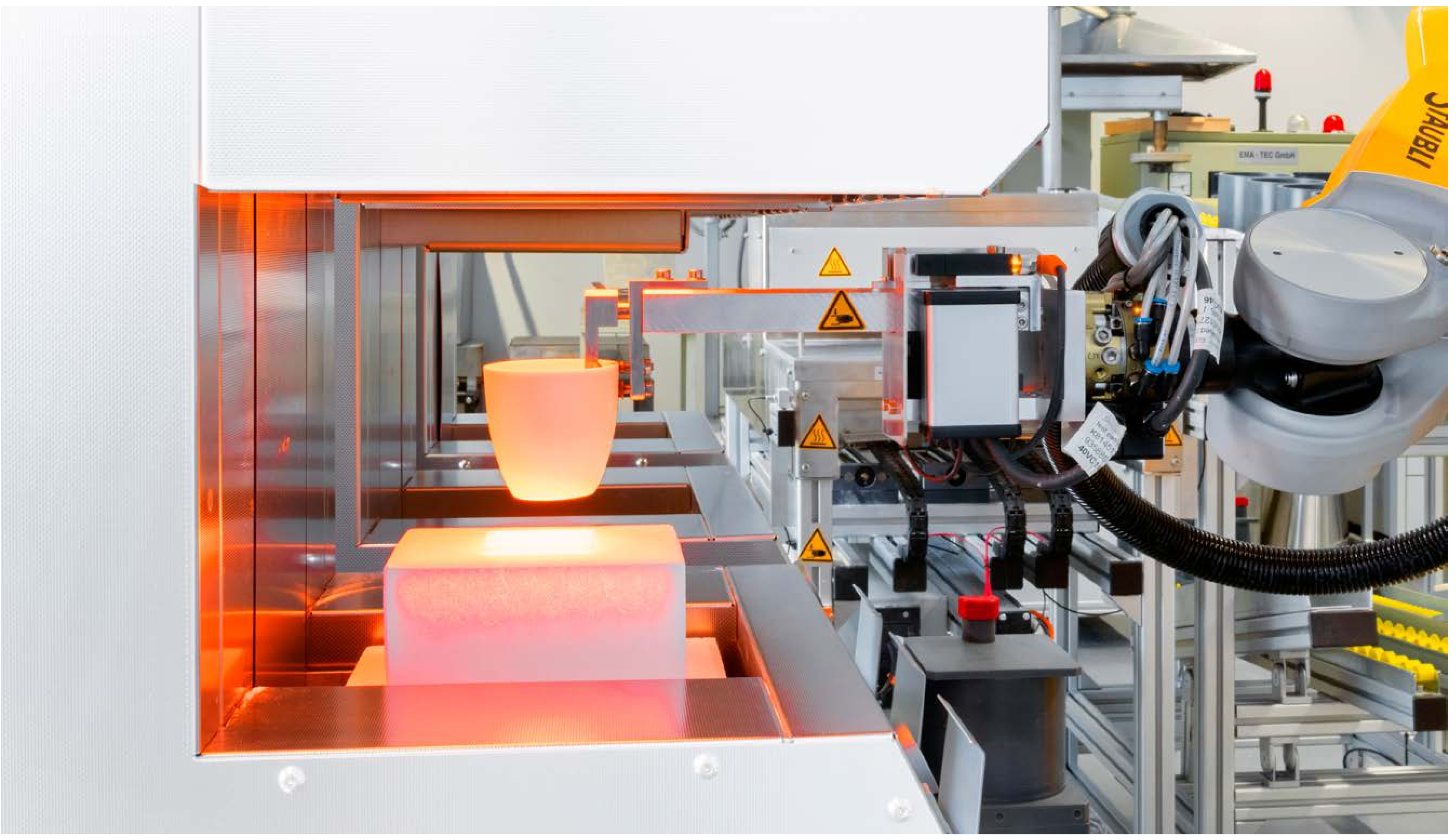




A special camera automatically detects defects in the component during the 3D printing process

DIGITAL WORKFLOW FOR GLASS

The material glass is characterised by a variable chemical composition, diverse formability and a broad spectrum of specific properties that can be specifically adjusted. These properties make glass a key component for modern high technologies. However, glass development is usually very cost-, energy- and time-intensive. Ralf Müller, head of the Glass Department at BAM, and his team want to change this: As part of the joint project GlasDigital, they are working together with the Friedrich Schiller University in Jena, the Fraunhofer Institute for Silicate Research ISC in Würzburg and the Technical University of Clausthal to develop new digital tools for data-driven glass development in Germany. To this end, the prototype of a robotic glass melting plant will be equipped with sensors for process monitoring, machine learning as well as adaptive algorithms for melt monitoring and connected to the MaterialDigital platform, a digital space for material data that is open to research and industry. "Overall, we want to significantly accelerate the development of high-performance glasses through a data-driven workflow," says Ralf Müller.



Prototype of a robotic glass melting machine at BAM

Prof. Dr Birgit Skrotzki is the new president of the DGM.

ELECTED

Prof. Dr Birgit Skrotzki is the new president of the Deutsche Gesellschaft für Materialkunde (DGM) as of 1 January 2023. The DGM looks back on a history of more than 100 years and, with more than 2200 members, is one of the largest professional societies in the field of materials science and materials engineering in Europe. Birgit Skrotzki, who heads the division of Metallic High Temperature Materials at BAM, shares her presidency with Prof. Dr. Heilmaier from the Karlsruhe Institute of Technology. The topics of sustainability and digitalisation as well as the transformation to climate neutrality will be at the centre of her term of office: "Materials science is an important key to solving societal tasks of the future: for example, to develop new, improved battery materials for electric cars, to make wind turbines more durable and efficient with lightweight materials or to realise a future hydrogen economy. In addition, the promotion of young researchers and the empowerment of women in materials sciences are of particular concern to me," says the new DGM President.

Energy | Infrastructure | Environment | Materials | Analytical Sciences

ANALYTICAL SCIENCES

Chemistry toolbox

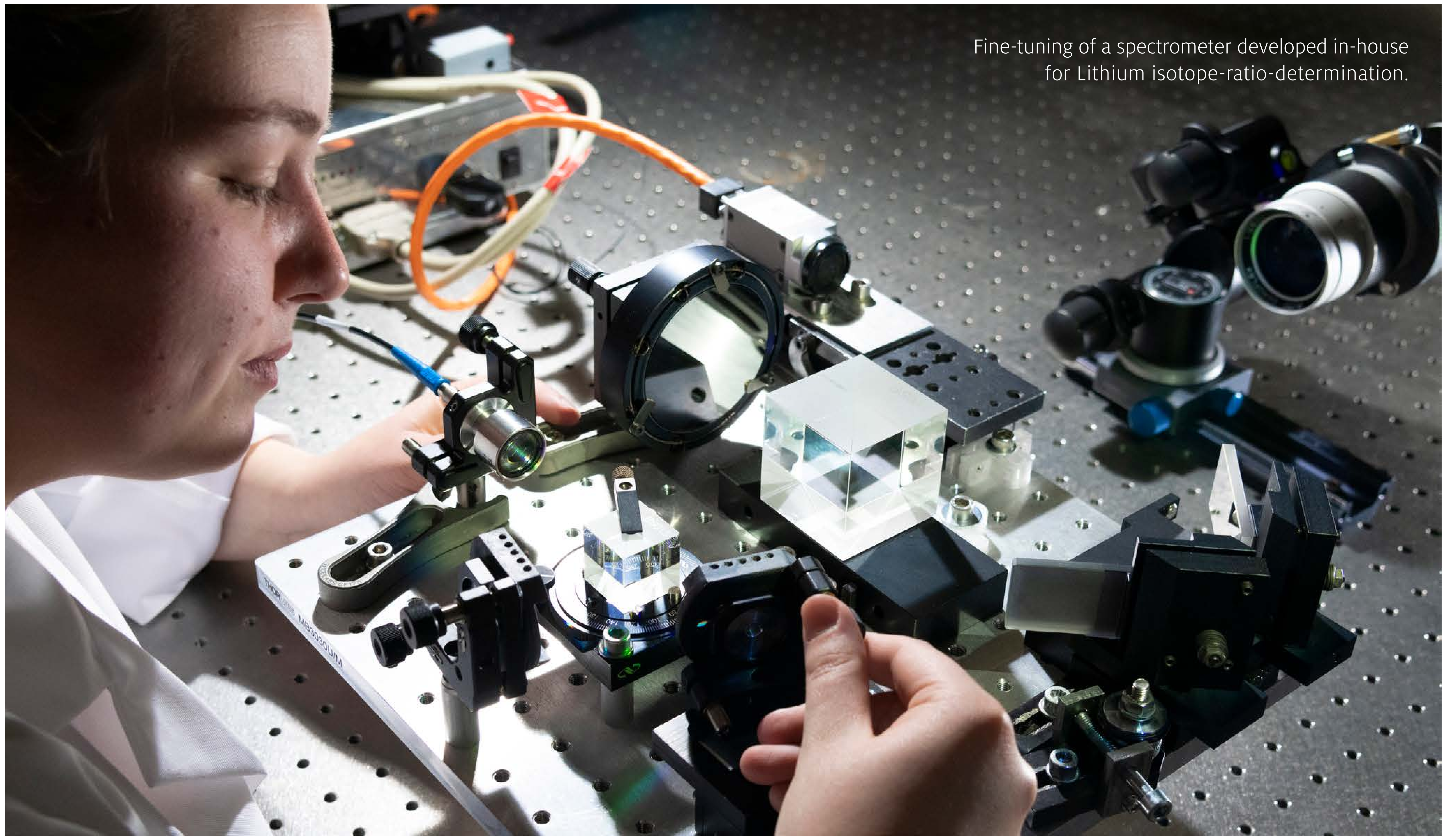
Cutting-edge chemistry tackles new challenges every day. In the new division Instrumental Analytics, an interdisciplinary team develops customised solutions.

The demands on modern chemistry are becoming increasingly complex and specialised. In modern day research, new tasks arise almost on a daily basis. At the same time, the time to respond to these developments is getting ever shorter. Pressing questions of the day require quick solutions that are as mature as possible for application in the field.

How, for example, can we determine the origin of the lithium used in batteries – as the new EU battery passport will require in future? How can fossil carbon be replaced by green hydrogen in steel production without compromising the quality of the steel produced? And how can we determine the origin of aged microplastics that have changed beyond recognition in rivers and lakes and are hidden under layers of biofilm?

A team with dual talents

“For all these questions, there are no dedicated analytical instruments that someone could order from a relevant company,” explains Jens Riedel, physical chemist at BAM. “Therefore, the associated analyses are costly and a lot of improvisation is involved. More often than not, a suitable apparatus even has to be devised and assembled from scratch.” BAM has created the new division “Instrumental Analysis” under Jens Riedel’s leadership precisely for such special cases. It is a kind of innovation hub and experimental laboratory, a creative



Fine-tuning of a spectrometer developed in-house for Lithium isotope-ratio-determination.

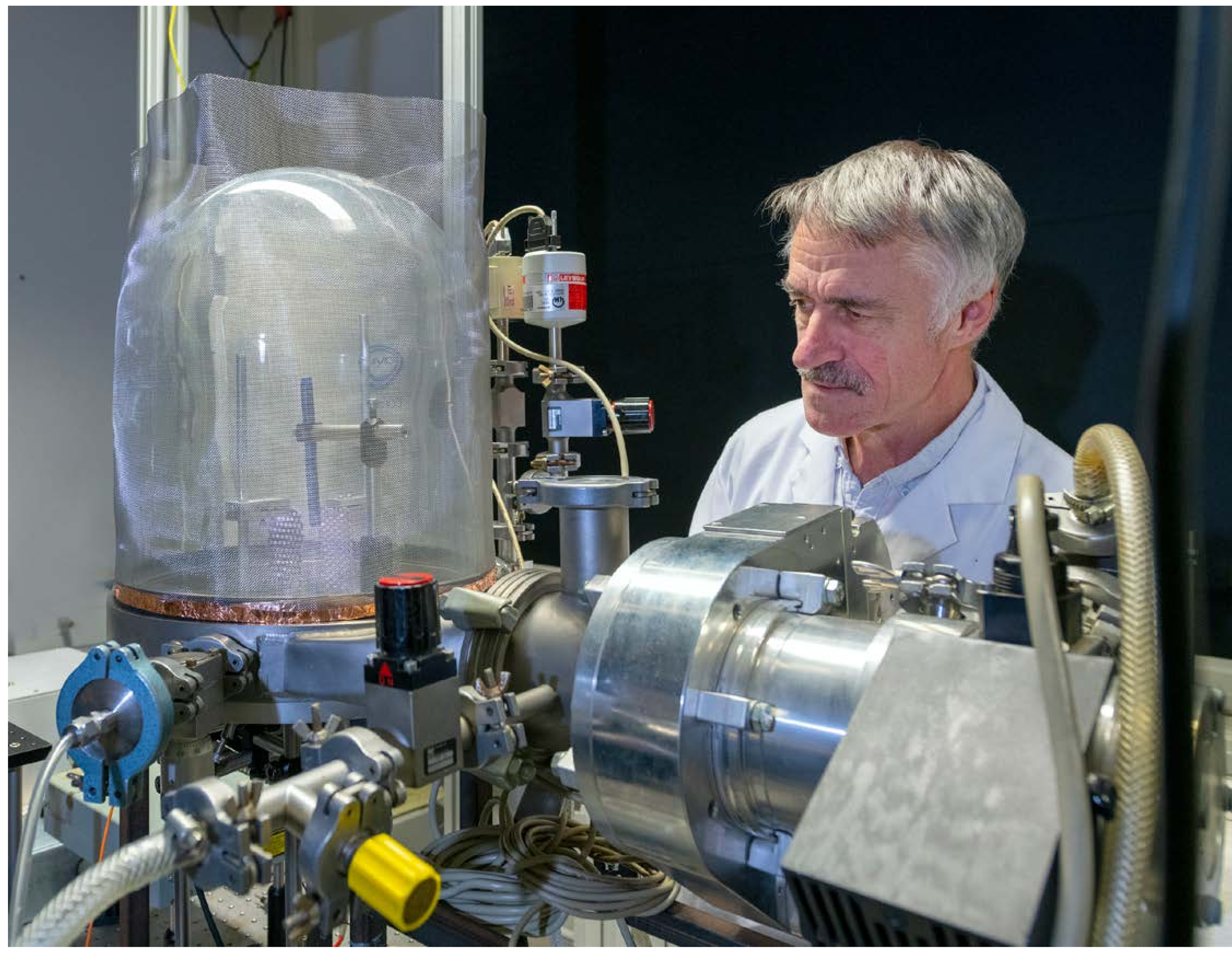
chemistry toolbox. Jens Riedel has put together an interdisciplinary team with many "dual talents", as he calls them. A mineralogist who also programmes software works alongside an analytical chemist with a talent for inorganic syntheses. Another chemist is well versed in mechatronics and precision engineering. Together, the team develops customised solutions for highly specialised requirements and implements them up to a prototype or demonstrator.

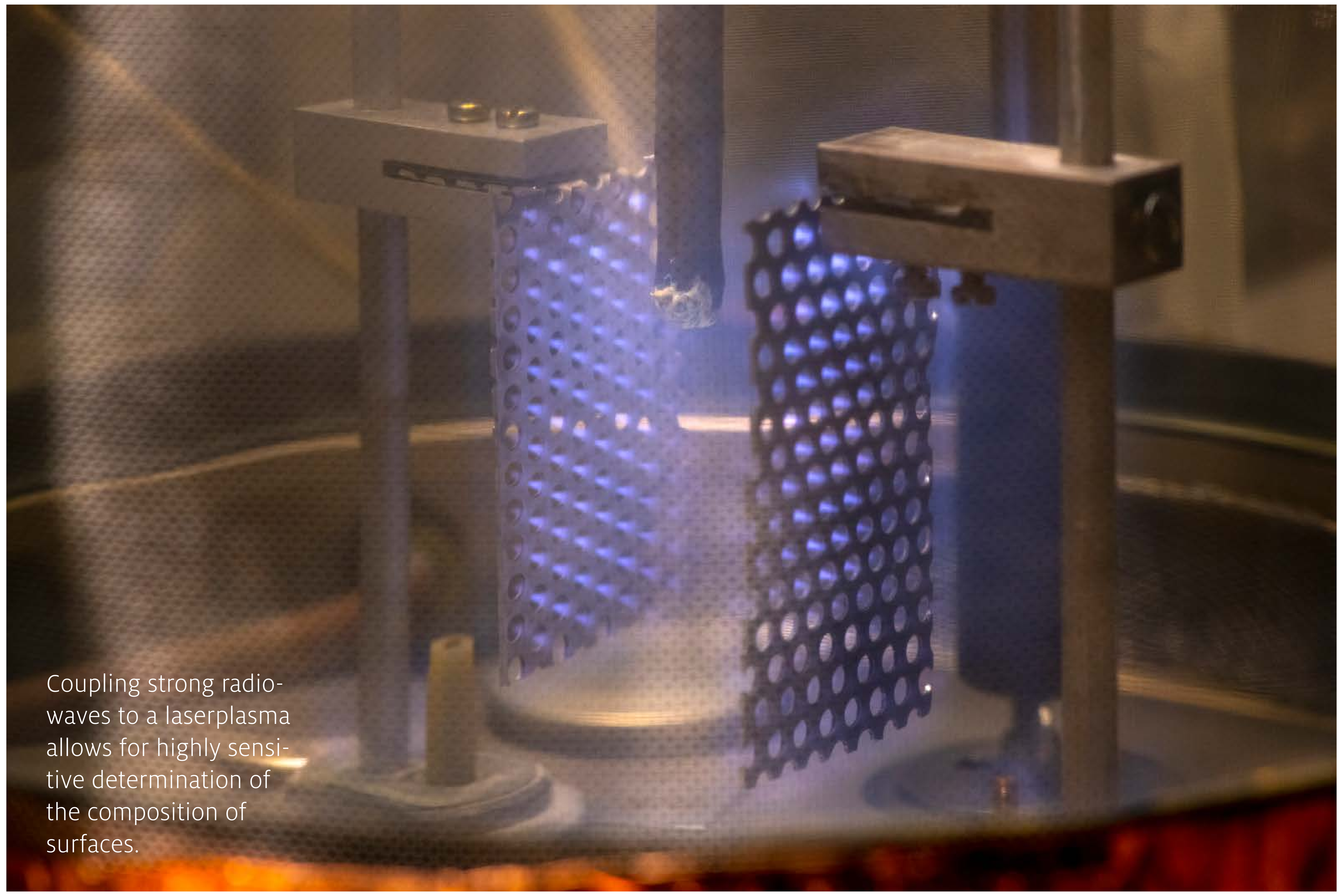
Accelerating science

In order to be able to determine the origin of lithium, the team has developed a particularly high-resolution optical spectrometer of the kind normally used in astronomy. The instrument was designed in such a way that it can specifically detect the elements that are crucial for determining the origin. In a similar way, samples in the steel industry can be precisely characterised and recipes adapted to the climate-neutral energy carrier hydrogen.

And for the determination of microplastics, Riedel and his colleagues have designed a novel instrument based on Raman spectroscopy. It can be used to measure the characteristic scattering of light by molecules. The team has succeeded in suppressing a disturbing fluorescence that emanates from the biofilms surrounding the microplastic particles. The new method is not only very cost-effective, the device is also so lightweight that it can be used in mobile applications. The method is also much faster than previous methods, so that very large numbers of samples can be analysed in a short time.

"Accelerating science is a very crucial factor for us," explains Jens Riedel. "We want to move things forward quickly to help solve very specific questions for the future."



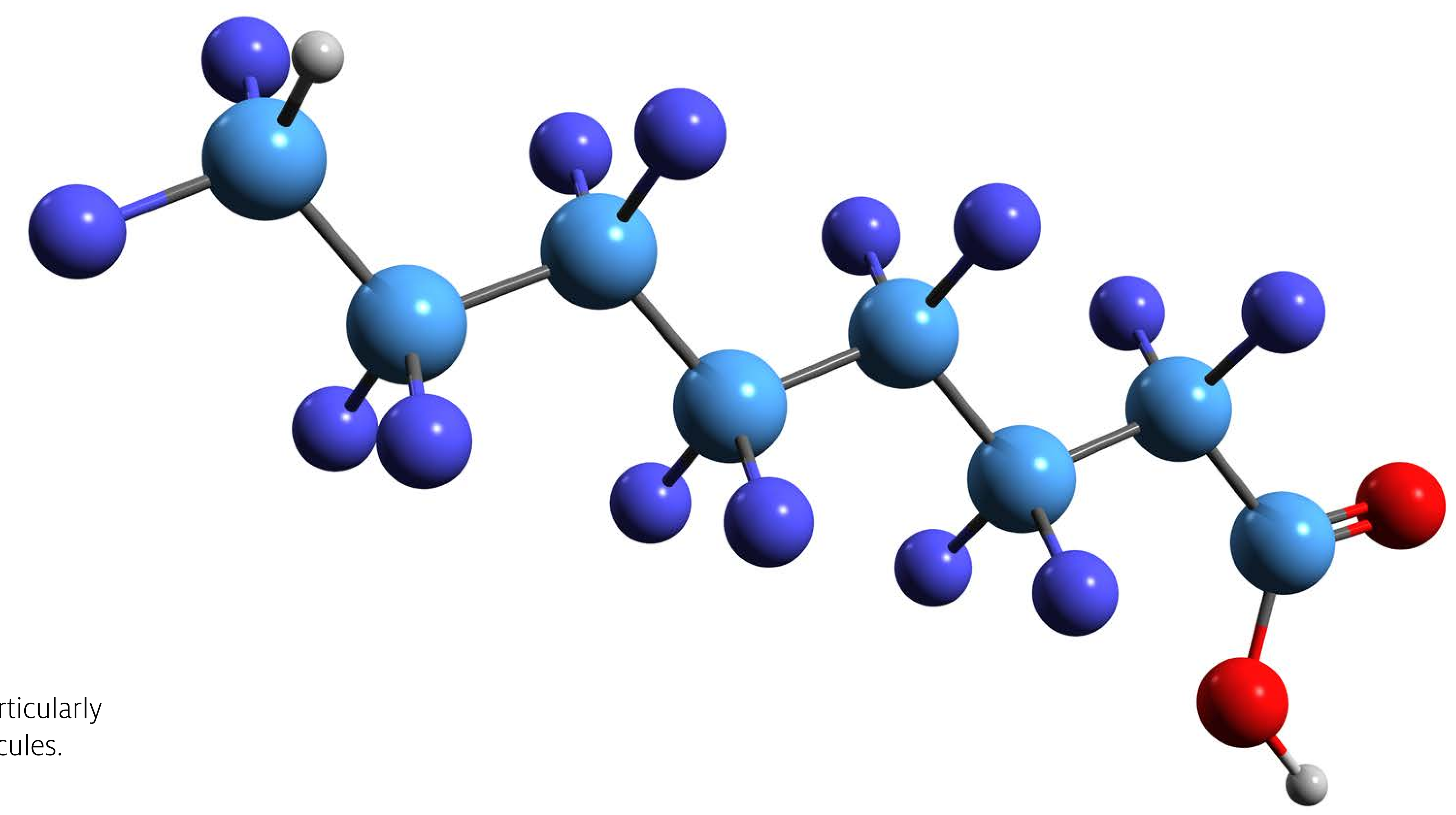


Coupling strong radiowaves to a laserplasma allows for highly sensitive determination of the composition of surfaces.

HIGHLY ACCURATE ENERGY GASES

In the energy sector, maximum accuracy is crucial to ensure the safe operation of plants and components, but above all to give consumers certainty in prices and billing. BAM, which has been producing reference materials for over 100 years, is now accredited by the Deutsche Akkreditierungsstelle GmbH as a producer of energy gases such as natural gas mixes containing hydrogen. "Our self-produced reference gases serve as national gas composition standards," explains Heinrich Kipphardt, an expert at BAM's Gas Analysis team. "They are used as a measurement and comparative standard in measurements or in tests." For example, measuring instruments can be precisely calibrated and checked, or material data can be obtained for scientific and technical applications. Highly accurate calibration gases are needed in research and development, especially in the transformation to a hydrogen economy.

With the aid of a weighing robot, BAM produces highly accurate calibration gases.



PFAS are particularly stable molecules.

REDUCING FLUORINATED POLLUTANTS

Fluorinated organic compounds (PFAS) are found in many everyday products: They are present in about a quarter of all pharmaceuticals, outdoor clothing, packaging, cosmetics, cleaning agents and fire-fighting foams. Around 4,800 of these substances are known to date. They enter the environment via waste streams and sewage – and travel from there through the food chain and drinking water into the human organism. PFAS are not only particularly stable, many of the compounds are also considered toxic or even carcinogenic. In several projects, BAM, in cooperation with the Federal Environment Agency, is researching the routes alongwhich PFAS enter the environment, how they can be monitored, detected and ultimately disposed of. "Our aim is to develop analytical methods on the basis of which we can derive recommendations to reduce the occurrence of these pollutants in the environment," says chemist Björn Meermann, who heads the projects at BAM.

BAM AT A GLANCE

1,622 Staff

52 Nationalities

56 Trainees

153 PhD students

20 Professorships and junior professorships

485 Refereed publications

36 Patents

74 Certified reference materials

165.8 million € Basic funding

20.8 million € Third-party funding

4 Research facilities in Berlin/Brandenburg

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