

Progress with safety!



BAM Report
2024/25

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Editorial

Dear readers,

We tend to grow not in times of tranquillity, but in times that challenge us. Times that force us to change things. And we are in the midst of such a time right now, as a society, as an economy, as a community of scientists and researchers. The challenges are obvious and have been mentioned abundantly: Climate change, technological transformation and – most recently – global trade wars.

But those challenges also mark an opportunity. Because if change is inevitable, then it is our task to address those challenges boldly and responsibly, with an emphasis on safety. After all, what good are advances in technology if those advances fail to deliver tangible benefits in practice? If new materials disappoint, if digital systems lack robustness, or if new, promising technologies prove unreliable in everyday use? Progress built on unstable ground does not create trust – it undermines trust.

This is why our mission at BAM is so crucial: Building on science-based testing methods, reliable standards, active transfer of knowledge and technology as well as international networks, we drive – and ensure safety in – innovation.

As a senior federal research institute, our mission is to tackle the key transformational challenges of our time: Creating safe energy infrastructures, building a climate- and resource-friendly construction sector, establishing circular value chains, and developing sustainable high-performance materials. Our research aims to identify new hydrogen storage methods and to increase the lifespan of wind farms, to develop standards for new materials, to boost AI and data-driven methods that will help research in materials to go digital, and to support transfer from research to industrial practice – together with economic, science, and policy partners.

Our new BAM Report provides you with current insights into our work. I look forward to engaging with those among us who are keen to shape the coming decades and ensure we progress towards a safe future.

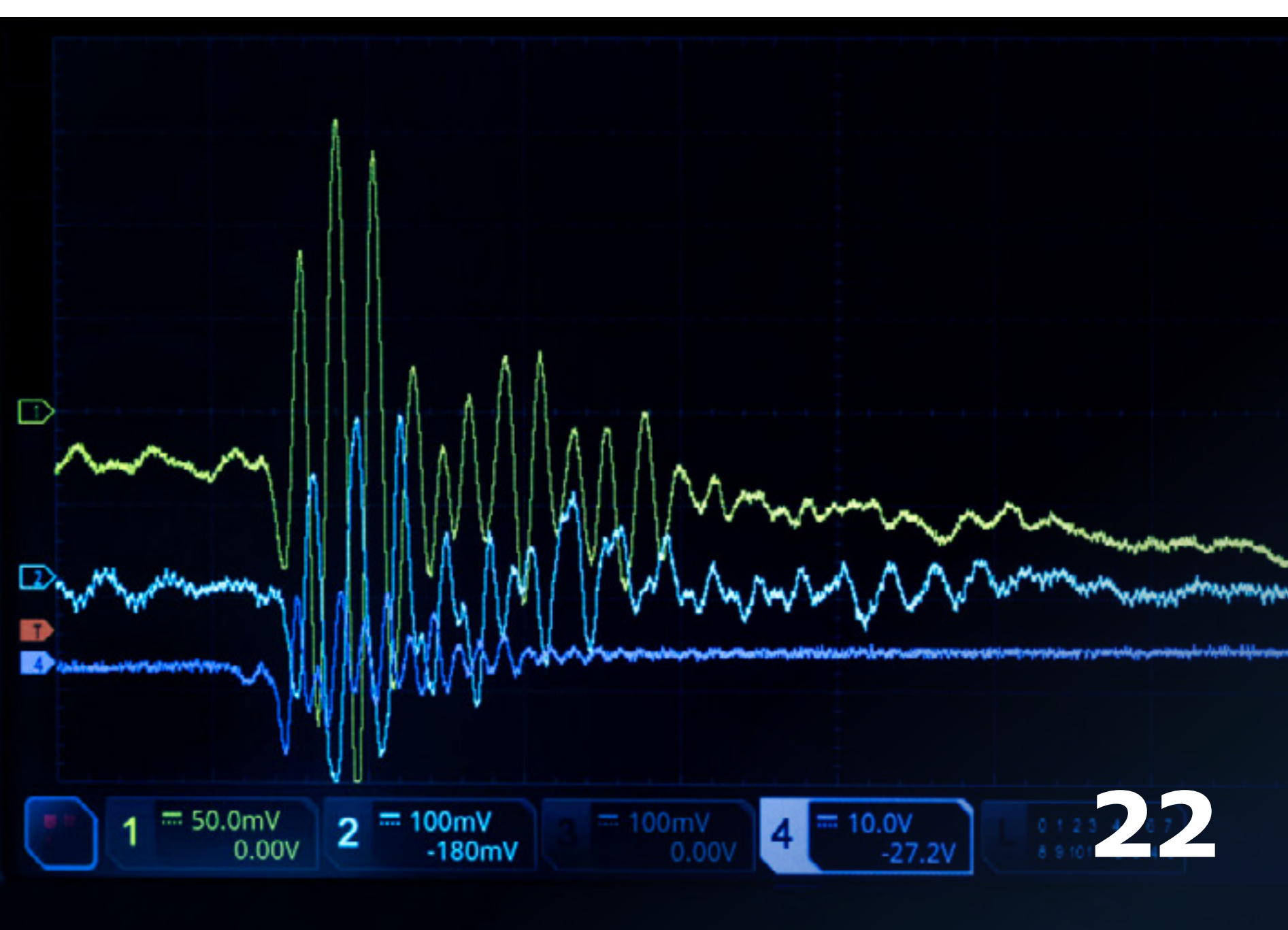


Sincerely,
Ulrich Panne
President
Bundesanstalt für Materialforschung und -prüfung (BAM)





12



22



27

Content

Editorial	2
Progress with safety!	4
BAM and its five focus areas	6
Energy	
Recycled titanium iron as hydrogen storage	8
Stable wind towers	12
Materials for high-performance batteries	16
Infrastructure	
The perfect wave for safe bridges	21
Smart hazardous substance analysis from the air	24
Better protection for forests against fires	27
Optimizing 3D printing with concrete	30
Environment	
Sustainable steel production with hydrogen	35
Materials	
Data treasures of additive manufacturing	40
New materials from the supercomputer	43
Chemistry and Process Engineering	
Simulation creates safety	48
Quality infrastructure digital	
Made in Germany goes digital	52
History of BAM	
Departmental research during the National Socialist era	55
BAM at a glance	58
Members of the BAM Board of Trustees	59
Publishing information	60



40



43



55



“Taking responsibility with the BAM climate protection strategy so that future generations can live well.”

Anja Wunsch,
Environmental and sustainability
management



“Developing sustainable solutions for the concrete of the future with AI-supported systems.”

Tim Klewel,
Department Non-destructive
Testing

Progress with safety!

In times of rapid change, it takes more than just smart ideas – it takes a reliable foundation for innovation. That’s exactly what we offer: For over 150 years, we have been combining scientific excellence with practical safety research. Our employees live this commitment every day – with their expertise, dedication, and clear goal of leading technology and chemistry safely into the future. Here, they reveal what “progress with safety!” means to them in concrete terms.

“Advancing a digital quality infrastructure – in line with our social mandate.”

Matthias Honnacker,
Head of Department Quality
Infrastructure



“Creating the foundation for a safe, resilient, and sustainable future through material innovations.”

Özlem Özcan,
Head of Division Material and
Surface Technology





“Fully exploiting the potential of sustainable clay building materials for solid construction.”

Johanna Baier,
Division Buildings and Structures



“Investigating corrosion damage to bridges – before it becomes a hazard.”

Gino Ebell,
Division Corrosion and Corrosion Protection

“Transferring knowledge in a way that integrates innovation and safety from the very beginning.”

Clara Seitz,
Head of BAM Akademie



„As a BAM spin-off, to bring our innovation to market in a responsible manner.”

Fatma Nur Akyel,
Team member of BAM spin-off WeldNova



Advancing hydrogen technologies through trust, science, and collaboration.”

Natasya Rizka,
Division Safety of Energy Carriers



“Monitoring wind turbines so that they supply electricity as efficiently and for as long as possible.”

Somsubhro Chaudhuri,
Division Thermographic Methods



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 focused on five focus areas: Energy, Infrastructure, Environment, Materials, and Chemistry and Process Engineering.

Energy | Infrastructure | Environment | Materials | Chemistry and Process Engineering

Energy

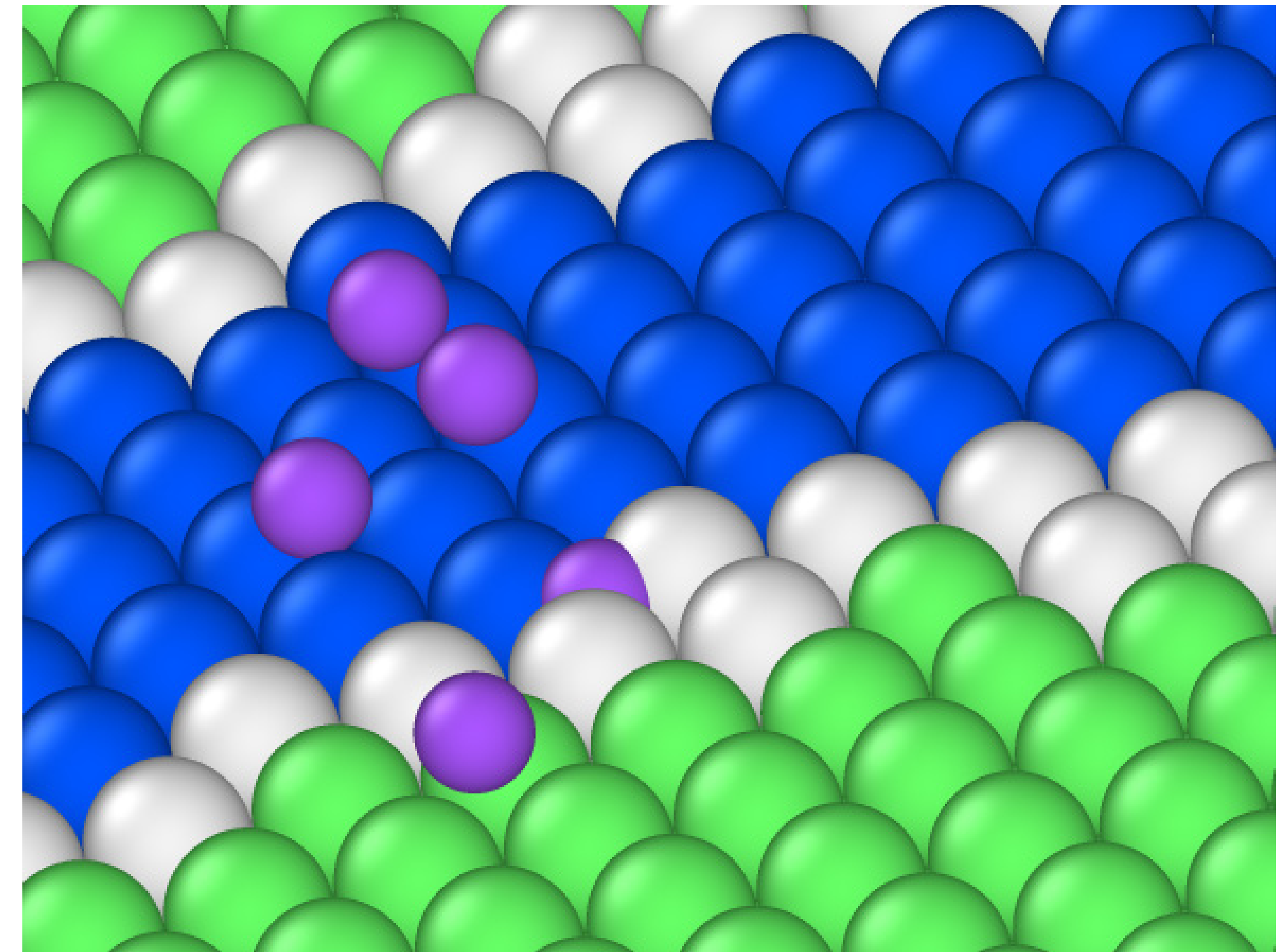
Recycled titanium iron as hydrogen storage



Metal alloys made of titanium and iron are particularly suitable for hydrogen storage, but are comparatively expensive. As part of the German federal government's basic hydrogen research, BAM is investigating whether recycled material can also be used safely.

In the future, Germany and Europe will need to store hydrogen in large quantities to advance the green transformation. In addition to pressure storage, solid bodies such as certain metal alloys are also being considered. The hydrogen is absorbed like a sponge: The H₂ molecules split into individual atoms on contact with the surface of the metal, penetrate the lattice-like structure of the metal and are stored in the interstices.

Hydrogen atoms are stored in the lattice-like structures of the titanium-iron molecules.



Particularly safe storage of hydrogen

This not only allows for highly efficient hydrogen storage, but is also a particularly safe approach, because the hydrogen atoms bind to the metal and cannot immediately escape or ignite. Unlike with gas storage tanks, high pressure and extremely low temperatures are not required. When the hydrogen is needed, it can be released as a gas again, for example, by applying a small amount of heat.

Titanium-iron alloys are particularly suitable for this purpose, but they are significantly more expensive than liquefied gas tanks. Therefore, this method has not been considered for large-scale use so far. For this reason, materials informatics scientist Tilmann

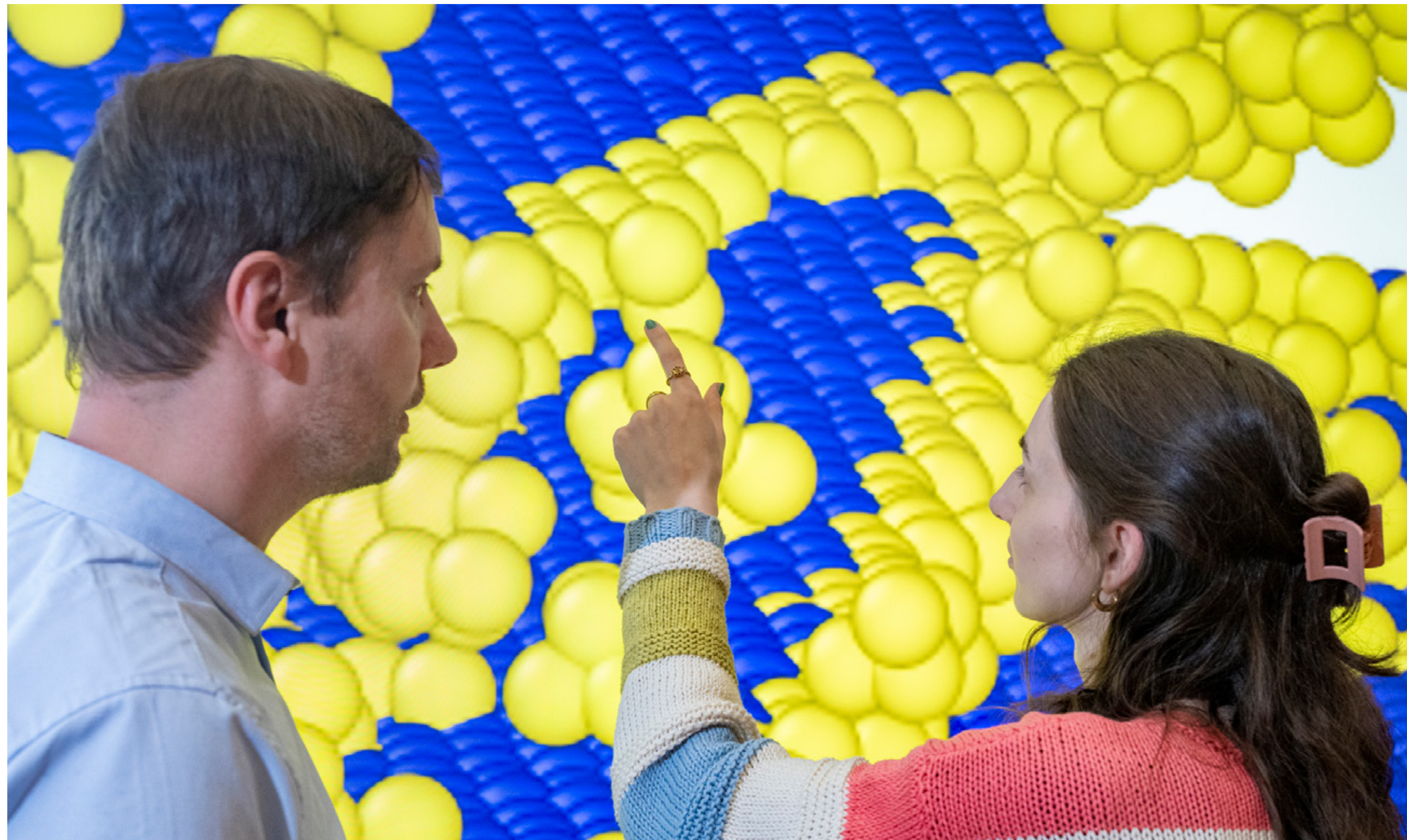
Hickel and his team are investigating whether recycled material from the circular economy can also be used for this type of hydrogen storage as part of the GreenH₂Metals joint project. “The most important factors are how efficiently the material can absorb hydrogen and how stable and safe it is over longer periods of time,” says Tilmann Hickel.

The team uses material informatics methods for this purpose, i. e. they do not conduct any physical experiments in the laboratory, but only calculations on the computer. They use simulations, develop workflows for these, and write code. The core task is to make predictions about material behavior –

and this is possible with great reliability in digitalized science, without any empirical assumptions and often faster than in the laboratory.

Billions of cube-shaped structures

“Titanium-iron alloys are crystalline, so they consist of billions and billions of cube-shaped structures arranged next to each other, creating a huge, seemingly impenetrable three-dimensional lattice,” explains Hickel’s colleague Ali Tehrani. “Every hydrogen atom that enters this lattice from the outside and has to find its place covers an unimaginable journey in relation to its own size.”



Incorporation of desired defects

Defects in the lattice, such as a vacancy caused by a missing iron atom, are particularly attractive for storage. “Six hydrogen atoms fit into a single one of these gaps. We are using our simulations to investigate how defects can be specifically incorporated and used in the recycled material,” says Tilmann Hickel. The aim is also to predict whether impurities in the recycling process affect the safety and long-term stability of titanium iron and its defects. A second team from **BAM’s hydrogen Competence Center**  is investigating variants

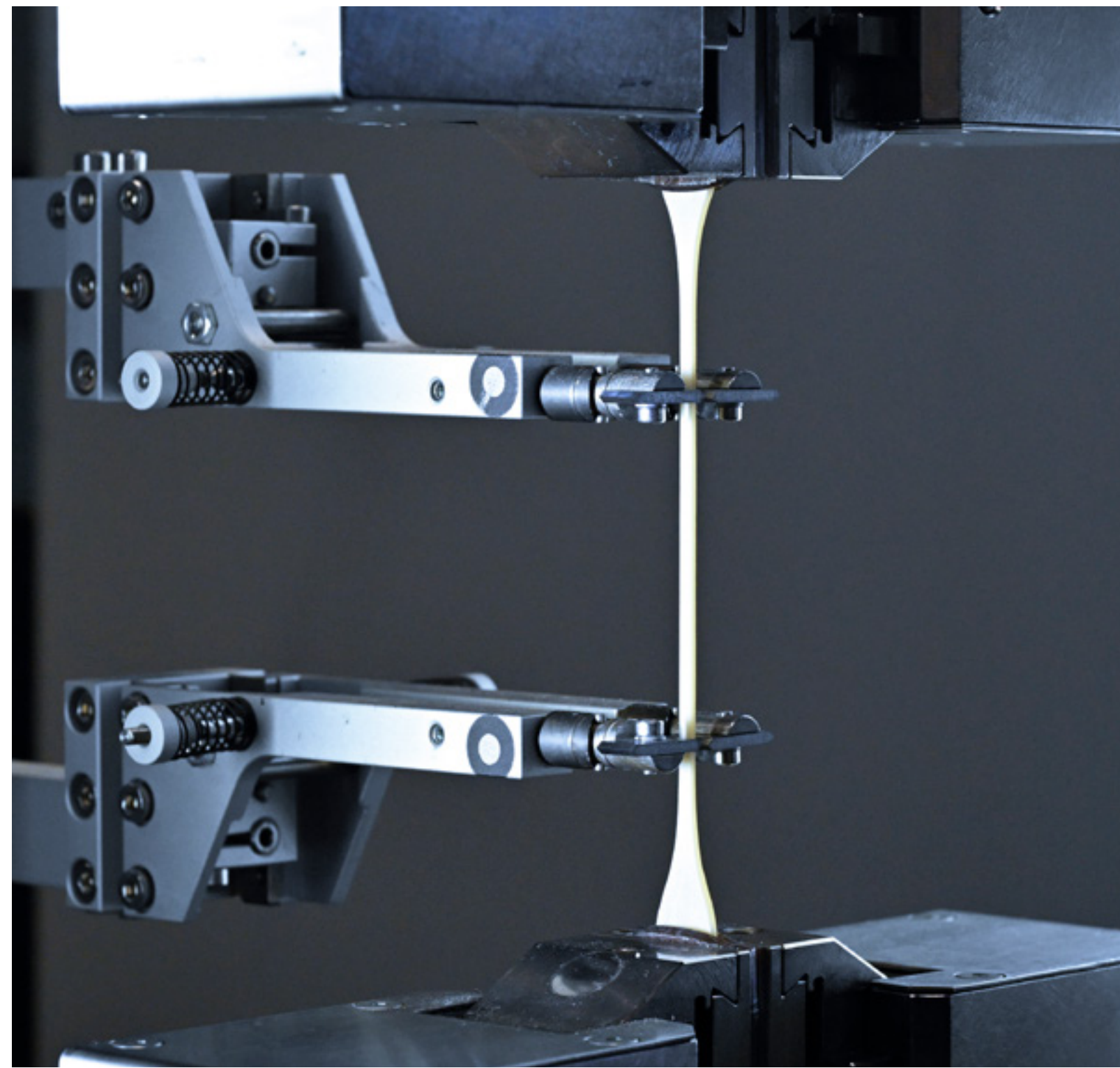
with particularly desirable properties for their safety. “These tests cannot yet be fully replaced by simulations. However, our computer pre-screening reduces the need for physical testing,” adds the materials computer scientist.

In addition to BAM, RWTH Aachen University, Ruhr University Bochum, and the Max Planck Institute for Sustainable Materials are involved in the joint project coordinated by the Helmholtz Center Hereon. GreenH2Metals is funded by the Federal Ministry of Education and Research (BMBF) with around 2.6 million euros. —

Defective areas (l.) are particularly suitable for storage. Investigations are also being carried out to determine whether impurities in the recycled metal (r.) compromise safety.

Fiber optic sensors protect hydrogen storage facilities

In the future, underground caverns will also be used to store green hydrogen. The advantage: In natural cavities up to 1,400 meters deep, thick layers of salt rock enclose the compressed gas and shield it from external influences. However, these salt domes are not static geological formations: They are in motion. This can lead to leaks, subsidence on the earth's surface or, in extreme cases, earthquakes in the vicinity of the caverns. Cavern storage facilities must therefore be monitored continuously. Until now, this has only been done on specific dates using individual ultrasonic sensors – a method that is both inaccurate and time-consuming. BAM is developing a new monitoring system in a joint project. It is based on fiber optic acoustic sensor technology. Light signals are transmitted through fiber optic cables. Changes in these signals indicate fine vibrations and strains that can be localized with an accuracy of up to one meter. Seismic waves and settlement effects can thus be detected earlier and more accurately than before. The new technology allows the permanent and complete monitoring of entire cavern fields for the first time. “We want to develop the technology to market maturity so that it can be quickly put into practice and support the establishment of a safe hydrogen infrastructure in Germany,” says project manager Konstantin Hicke from BAM. The joint project is funded by the Federal Ministry for Economic Affairs and Energy (BMWE) as part of the Central Innovation Program for SMEs.



Stress test for elastomers: Measurement of elongation under tension

Safe polymers for hydrogen

Materials made from polymers are indispensable for the hydrogen economy: They are needed for reliable seals, pipes, valves, and membranes. But which polymers are actually suitable for this purpose? Elastomers, for example, are materials that are characterized by high elasticity, flexibility, tightness, and durability. However, initial investigations have shown that they are susceptible to what is known as rapid gas decompression. This occurs when there is a sudden drop in pressure, for example when refueling from a high-pressure storage tank. This can cause cracks in elastomer seals. To prevent this, the industry has modified synthetic elastomers. In the international joint project “Polymer4Hydrogen,” Géraldine Theiler from BAM investigated several of these new materials for their resistance to high pressure and changing loads. The material samples were then subjected to extensive testing. “The best performance was achieved by a rubber reinforced with carbon black particles,” says Géraldine Theiler. The aim is to use this as a basis for developing a high-performance elastomer that can meet all the challenges of a future hydrogen economy.

Database for European gas network

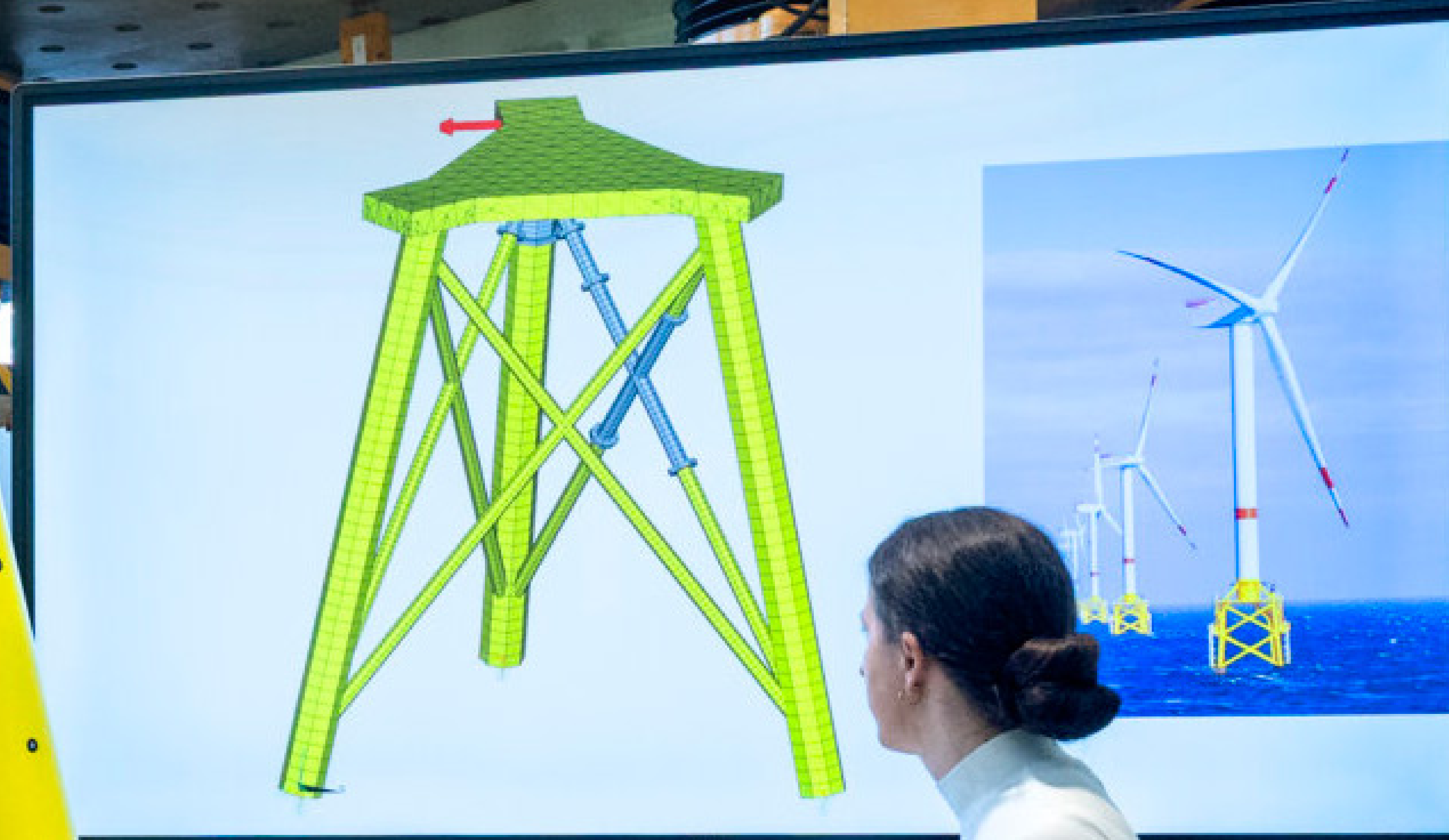
The injection of hydrogen into existing gas networks poses both technical and regulatory challenges. These relate in particular to the material integrity of pipelines and the harmonization of legal requirements. The [Shimmer project](#), funded by the European Union, aims to improve the understanding of the hydrogen injection into the existing gas infrastructure and thus support the market ramp-up towards safe hydrogen technologies as a whole. BAM is coordinating the development of a comprehensive database for the project, in which

information on typical components in existing European gas networks was collected and systematically processed. Based on this data, decision-making on testing, qualifying, and using materials and components for hydrogen operation will be developed. The database will be freely accessible on the [project website from June 2025](#). In addition to BAM, eleven other European partners are involved in the project, including government institutions and gas network operators. SHIMMER is funded under the Clean Hydrogen Partnership program.

Energy

Stable wind towers

Data on the supporting structures is fed into the digital decision-making tool.



Continue using or replace? A digital tool helps wind farm operators decide whether to continue operating older wind turbines or replace them.

The rapid expansion of wind energy plays a central role on the path to climate neutrality. Germany plans to massively expand its onshore and offshore capacities in the coming years. To achieve the set targets, many new plants will be needed. At the same time, it is important to develop smart concepts for the reuse of wind farm sites whose planned end of use is approaching.

Complex decision-making

Every year, hundreds of older wind turbines reach the end of their intended service life of 20 to 25 years. In 2024, 555 turbines were decommissioned onshore alone, while 635 new units were connected to the grid. However, engineering studies show that many older turbines are safe and stable enough to be used for a few more years. This realization raises the question of whether – and under what conditions – continued operation can make economic and ecological sense. As wind energy use increases, this question will arise more and more often in the future.

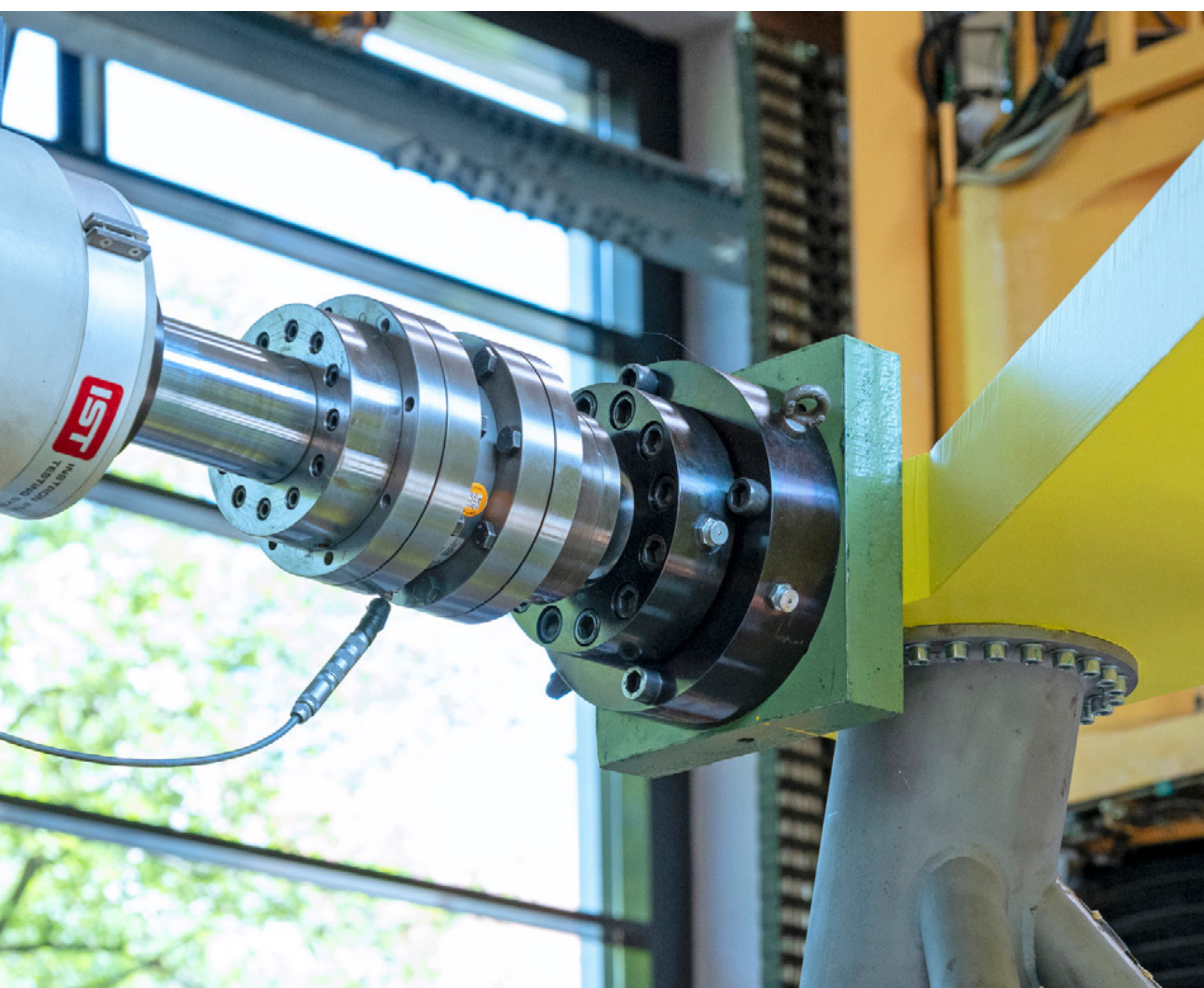
For those who operate wind farms, this involves a lot of considerations: Is it worth continuing to operate? Are the supporting structures still strong

Offshore, the supporting structures are exposed to particular stresses.



enough? Is it worth upgrading the turbines or is it more economical to dismantle them completely and invest in a new plant? This decision is particularly complex offshore, where ever larger wind turbines with optimized rotor blades generate up to 20 megawatts and thus three to four times the output of older structures. The costs for dismantling, transport and installation of new plants are considerable and the availability of resources and skilled workers is limited. These factors make decision-making for wind farms a challenging task that must take into account technical, ecological and economic aspects.

“So far, wind farm operators have been left alone with this decision,” explains Ronald Schneider from the [Wind@BAM Competence Center](#) . “Every dismantled plant simultaneously blocks scarce resources at manufacturers and installation companies, as well as onboard ships that transport offshore wind turbines. These capacities are needed in Germany for an accelerated expansion of wind energy.” To overcome these challenges, BAM is developing a digital decision-making tool together with Jörss-Blunck-Orde-mann GmbH and RWE Renewables GmbH that takes all relevant aspects into account.



Modular digital decision-making tool

The aim of the project is to provide operators with a simple modular system that enables them to make the best decision in just a few steps. “There is a great need for such a tool in the industry,” says Schneider. The tool will be linked to a digital twin of the plant, into which all current data on the state of maintenance can be fed via sensors and monitoring systems. If the tool reveals weak points, the Wind@BAM Competence Center offers specific solutions for strengthening the support structures and advice, for example, on how welds that hold the support structures together can be retroactively reinforced at a reasonable cost.

The digital decision-making tool is being tested for its practicality at an offshore wind farm in the North Sea. This practical test is crucial to ensure that the tool works reliably under real-life conditions and actually offers operators valuable support. The joint project is funded by the Federal Ministry for Economic Affairs and Energy in the 7th Energy Research Program with approx. 780,000 euros. —



Particular focus: The weld seams of the supporting structures.



Award for BAM start-up WeldNova

WeldNova GmbH, a BAM spin-off, was awarded the prestigious “Berlin Brandenburg Innovation Award” in 2024. The award is presented annually by the Berlin Senate Department for Economics, Energy, and Public Enterprises and the Brandenburg Ministry of Economic Affairs, Labor, and Energy. The BAM start-up was honored for its innovative welding technology. The jury particularly praised the economic and ecological advantages of the process. The WeldMagnet, a special electromagnet for laser hybrid welding, significantly speeds up the production of wind towers and other steel structures. The magnet’s unique feature is its ability to prevent the melt from dripping off

thick sheets of metal – a challenge that has previously limited the widespread use of laser hybrid welding. With conventional welding technology, the 30-millimeter-thick sheets of a tower require around 95 hours of welding. With the WeldMagnet and laser hybrid welding, this time can be reduced to eleven hours. This corresponds to a cost saving of 90 percent and a reduction in CO₂ emissions by a factor of 16. WeldNova receives support from the EXIST funding program of the German Federal Ministry for Economic Affairs and Energy (BMWE). At the same time, the team has access to BAM’s excellent research infrastructure during the start-up phase.



The WeldNova team at the award ceremony in November 2024.



Thermography allows weak points to be identified at an early stage.

Innovative testing methods for longer-lasting rotor blades

Rotor blades on wind turbines are truly gigantic: They can reach lengths of up to 130 meters and weigh up to 60 tons. During operation, they are exposed to enormous forces. These forces put stress on the materials, which can lead to cracks, fatigue, or breakage. Repairing or replacing a blade not only incurs high costs, but also results in expensive downtime. Rotor blades are mainly made of fiber-reinforced plastics, balsa wood, and PVC foam. Before being launched on the market, each new model must pass a so-called full-blade test for certification. At the same time, the industry is designing and testing innovative designs for ever more efficient turbines. These tests are costly and time-consuming. However, current standard tests do not always reveal the weak points of a new rotor blade design. The **ReliaBlade2**

project , coordinated by the Fraunhofer Institute for Wind Energy Systems (IWES) and funded by the German Federal Ministry for Economic Affairs and Energy, brings together science and industry to improve full-scale tests using modern, non-destructive testing methods. BAM is contributing its expertise in thermography, which plays a key role in gaining insights from the stress tests: Thermal imaging cameras are used to detect stresses and internal damage at an early stage. “We not only want to identify weak points at an early stage, but also increase the knowledge gained from full-scale tests,” says Michael Stamm, an expert in measurement methods at the **Competence center Wind@BAM** . “Ultimately, both industry and the environment will benefit from more robust and efficient wind turbines.”

Energy

Materials for high-performance batteries

Additives: Crucial for increasing the stability of solid electrolytes.



A newly developed solid electrolyte could mark a breakthrough for solid-state batteries: The material promises high electrochemical stability, improved safety and a longer lifespan – and thus provides a powerful alternative to lithium-ion technologies.

Conventional lithium-ion batteries have reached their limits: Their anodes, usually made of graphite, can only store a limited amount of ions. Anodes made of pure lithium or the more sustainable and affordable sodium offer an alternative – they could increase energy density by up to 40 percent. However, a solid electrolyte is needed to operate them safely instead of a liquid one. A key problem here is that contact losses and voids can occur at the interface between the solid anode and solid electrolyte, rendering the battery unusable. One possible solution is to use a partially liquid anode.

Liquid alkali metal anode as a game changer

“In a previous study, we were able to show that a liquid alkali-metal anode is a hundred times more powerful than conventional graphite anodes,” explains Gustav Graeber, battery material expert and guest scientist at BAM. “This is partly because the ion transport works much better with a liquid anode. So far, however, this technology can only be used at 250°C. Our goal is to transfer their advantages to room temperature.” To achieve this, the

research team is experimenting with potassium additives that lower the melting point of the anode made of sodium metal. The challenge here is that many common solid electrolytes are not stable enough against potassium, because the ions of the alkali metal can penetrate the lattice structures of the electrolyte and destroy it from the inside.

The solution could be a special solid electrolyte based on sodium superionic conductors (NASICON). This is a whole class of crystalline high-performance materials that have increasingly become the focus of battery research in recent years. These materials offer high ionic conductivity at room temperature and are also chemically stable against potassium, especially when they are mixed with hafnium, a so-called transition metal. However, hafnium, which is one of the critical raw materials, is rare and expensive. In the NASICON project, Graeber and his interdisciplinary team of BAM experts are therefore looking for alternative additives, such as magnesium, that are just as powerful but more sustainable and widely available. The most promising candidates are being tested directly in sodium batteries.



NASICON is a high-performance material with a crystalline structure.

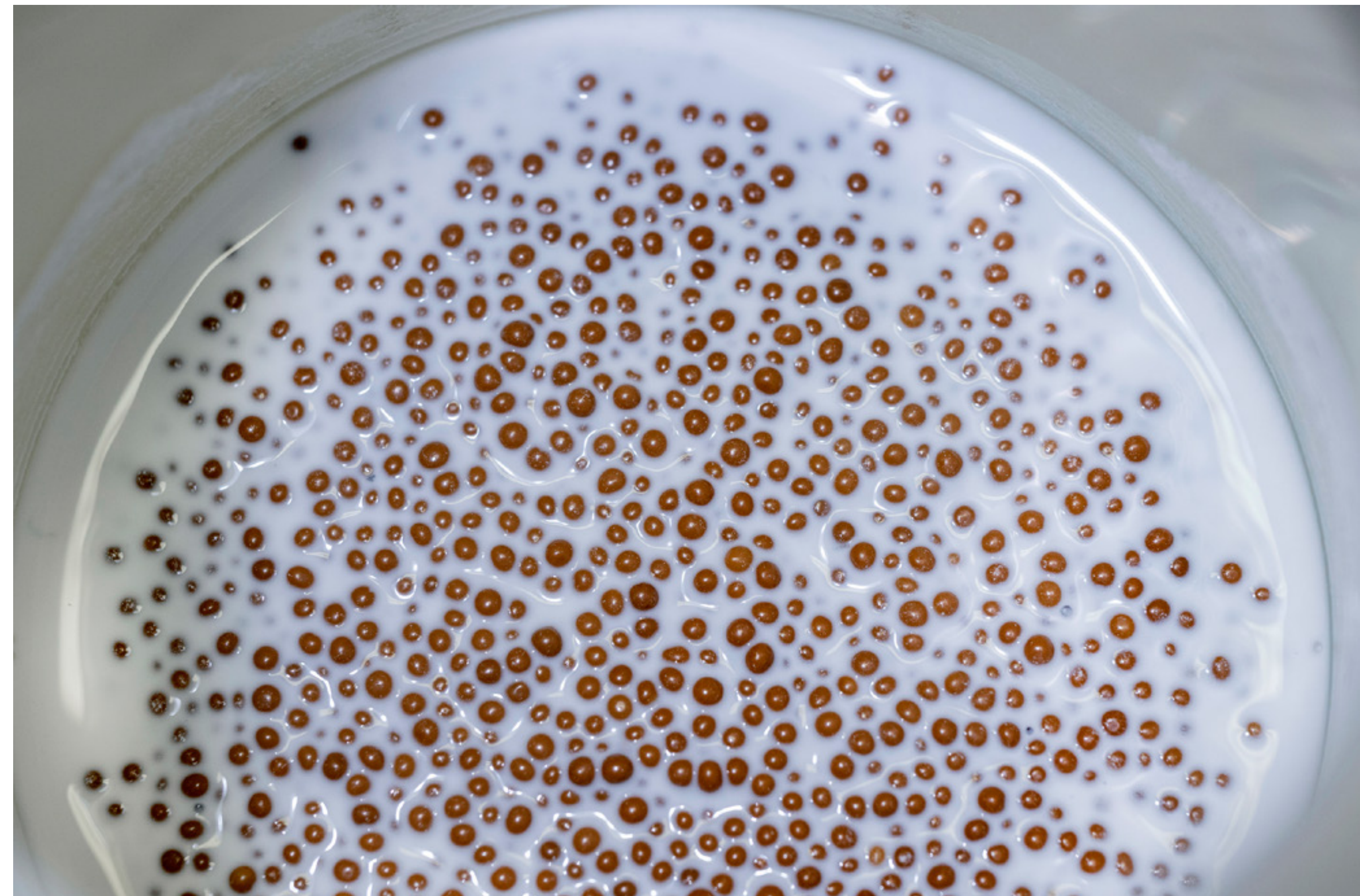
“ **Sodium solid-state batteries could drastically reduce charging times and significantly improve the performance of mobile and stationary energy storage devices – an important contribution to decarbonization.** ”

Drastically reduced charging times

“Our research project is a decisive step towards high-performance batteries that are more sustainable, affordable, and efficient,” says BAM scientist Andrea Cornelio, a member of the team. “Sodium solid-state batteries could drastically reduce charging times and significantly improve the performance of mobile and stationary energy storage devices – an important contribution to decarbonization.”

Another focus of the project will be on research into the long-term stability of the batteries. Systematic tests and simulations can help to ensure that innovative solid-state batteries function reliably even under extreme conditions.

The project benefits from close cooperation within BAM and with various industrial partners and other research institutions. “This collaboration is invaluable to us,” emphasizes Graeber. “It enables us to integrate the latest findings and technologies and work together on solutions that could revolutionize the market.” –

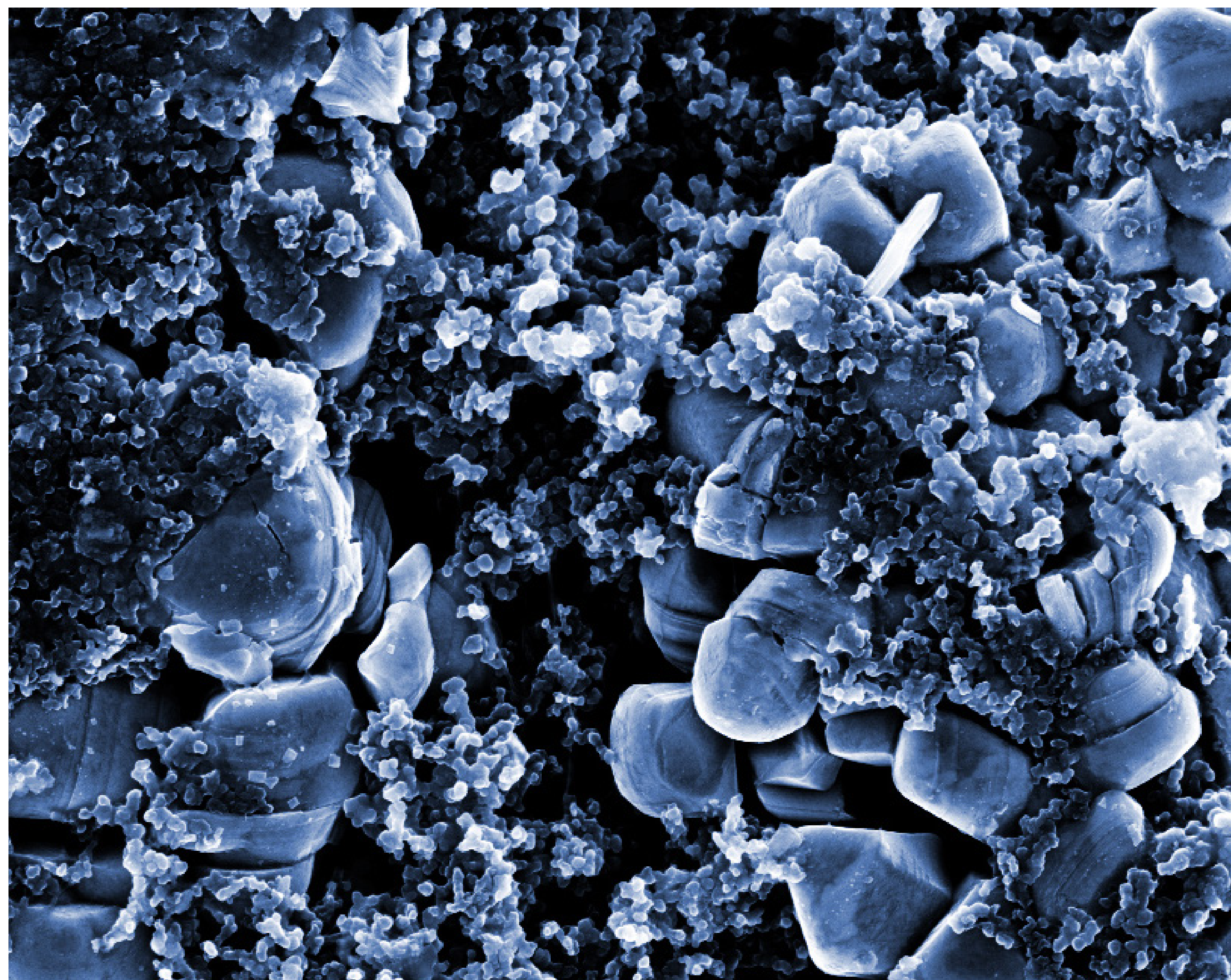


Gustav Graeber (l.) and Andrea Cornelio (r.) select the most promising materials and test them later in sodium cells.

Safe nanomaterials in lithium-ion batteries

Nanomaterials have great potential for improving the performance of lithium-ion batteries: They can increase the energy density of electrodes, shorten charging times, and extend the overall service life of batteries. However, nanomaterials in batteries also pose significant challenges: They can be released during battery manufacture, use, and disposal and may be harmful to health and the environment. There are also implications that they can increase the risk of thermal runaway – a vigorous chemical decomposition reaction involving flames or even an explosion of the battery. In the [Nano-SaNE project](#), BAM is addressing these challenges in collaboration with Sapienza University of

Rome and the French INERIS institute and developing comprehensive safety assessments for nanomaterials in LIBs. The project investigates their synthesis and characterization, their integration into battery cells, and their behavior under extreme conditions such as overheating or overcharging. A particular focus is on analyzing the particles and gases released during thermal runaway and their potential effects on humans and the environment. The aim of the project is to increase the safety of nanomaterials in lithium-ion batteries and promote their use in various areas, from electric mobility to stationary energy storage.



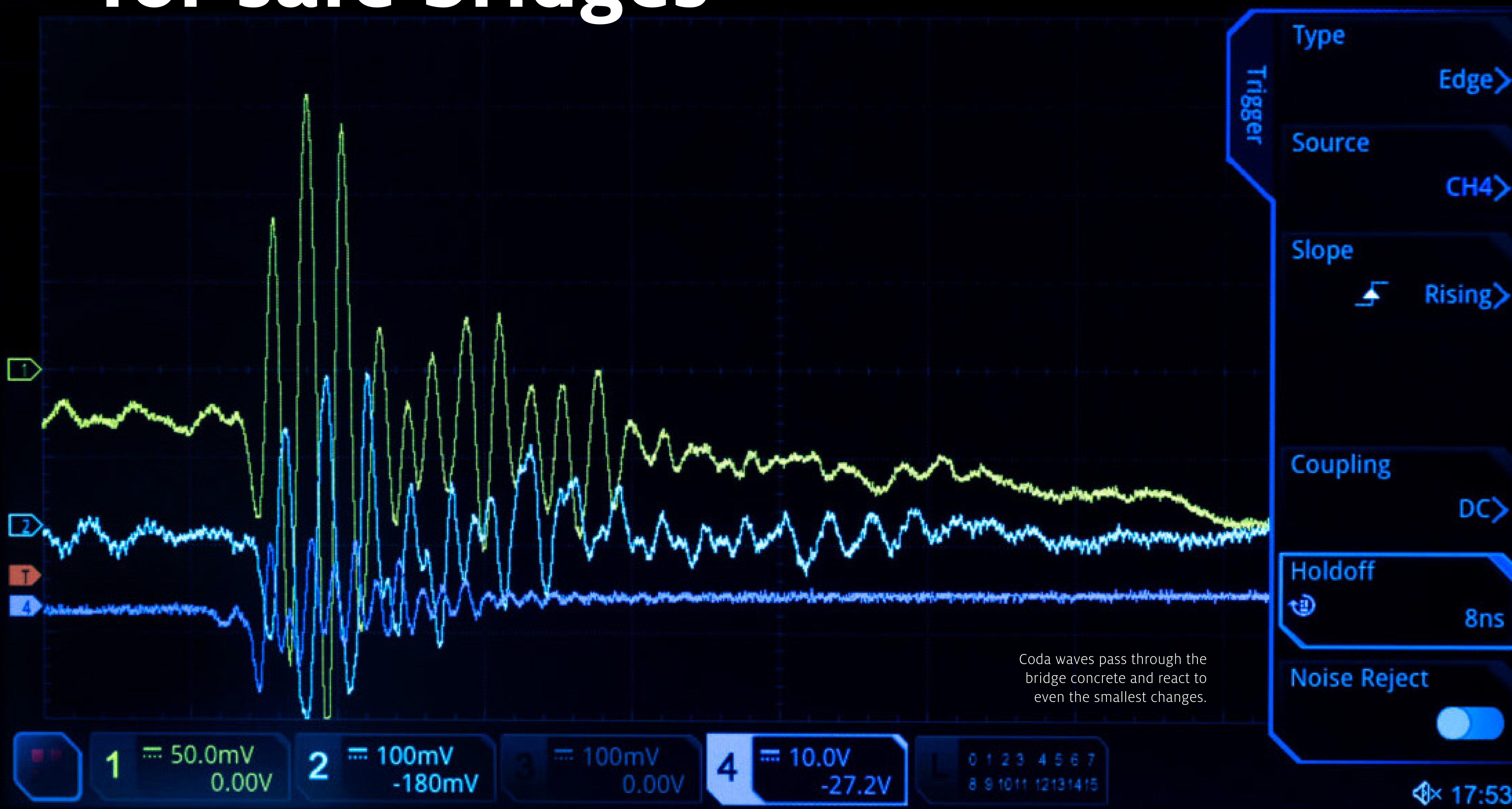
The positive electrode of a lithium-ion cell. The smaller carbon nanoparticles are designed to improve conductivity.

BAM, HZB, and HU Berlin set up Berlin Battery Lab

In May 2025, BAM, the Helmholtz Zentrum Berlin (HZB), and Humboldt-Universität zu Berlin (HU Berlin) signed a Memorandum of Understanding (MoU) to establish the Berlin Battery Lab (BBL). Berlin has established itself as an important location for research in sodium-ion batteries and lithium-sulfur batteries. The city offers concentrated expertise in these areas, supported by numerous research projects and high-profile research groups. The BBL will combine the strengths of the three partner institutions: BAM has internationally recognized expertise in battery safety and electrochemical energy materials. HU Berlin is a leader in Germany in academic research on sodium-ion batteries. HZB is particularly active in research on lithium-sulfur batteries. The BBL aims to accelerate the transfer of material developments into marketable products. It is open to industry partners from all over Germany and Europe and serves to promote the development and production of locally manufactured sustainable batteries.

Energy | **Infrastructure** | Environment | Materials | Chemistry and Process Engineering

The perfect wave for safe bridges



Coda waves pass through the bridge concrete and react to even the smallest changes.

Thousands of bridges in Germany are in need of modernization. To ensure that they can be operated safely in the meantime, the BAM start-up ConScope has developed a method that uses Coda waves to detect damage at an early stage.

Coda waves are a type of ultrasonic wave that are particularly sensitive. They are scattered in concrete and thus travel longer distances. As they pass through the material, they react to small changes. The use of coda waves is an approach adapted from seismology, where they are used, among other things, to better understand earthquakes and their causes. The method based on this is called coda wave interferometry (CWI).

Detecting even the smallest changes

The ConScope founders Niklas Epple, Julia Hau, Sven Waschkuhn, and Daniel Fontoura Barroso use Coda waves and specifically CWI to monitor bridges and detect damage at a particularly early stage. To do this, sensors – known as ultrasonic transducers – are embedded directly in the concrete of a bridge. They permanently send and receive ultrasonic signals, which are digitally evaluated. The reference measurement is the starting point for damage detection: It records the initial condition of the structure. All further measurements are compared with this. Codawaves are so sensitive that even the smallest deviations from the initial value, i.e. changes in the material, can



be registered. The method thus makes it possible to detect potential damage to the structure at an early stage.

Safe operation in the long term

Since bridges, as part of Germany's outdated transport infrastructure, sometimes have to wait a long time for modernization, monitoring methods such as these are needed to make the operation of bridges and other structures safe for all road users. "With



The sensors – ultrasonic transducers – (l.) are embedded in the concrete of the bridge (r.) to send and receive signals.

our method, we want to ensure the safety of aging structures, on the one hand,” explains Niklas Epple. “On the other hand, we want to support the longest possible operation of structures. Our tests have shown that the embedded sensors can reliably provide data over years.”

The method is suitable for all concrete bridges – there are 39,000 of them in the German autobahn network alone. The initial focus is on monitoring bridges that are to be replaced in the next decade but are still to be operated safely until then. The monitoring data is intended to support infrastructure operators in maintenance management.

An inexpensive solution

Installation and operation of the system have already been successfully tested at the Gänstorbrücke in Ulm and at the Scheidplatz underground station in Munich. The Gänstorbrücke was particularly suitable for a test run of the technology: It was only supposed to be in operation for a few more years and was already equipped with a commercial monitoring system. The ConScope team embedded 24 sensors in the bridge’s concrete, which then generated data for almost five years and monitored changes in the material. Not only did the measurements with CWI confirm the results of the existing monitoring system, the technology also proved suitable for long-term operation under real-world conditions.

The process is now being prepared for market launch with the support of EXIST – Start-Ups from Science, a funding program of the Federal Ministry for Economic Affairs and Energy. The aim is to offer an inexpensive and easy-to-install monitoring system for infrastructure operators. Proto-

types consisting of a measuring device, sensors, and automated evaluation have already been developed by the DFG research group CoDA. They are currently being tested on buildings in collaboration with Autobahn GmbH and Stadtwerke München. –

The ConScope team wants to bring its innovation to market quickly.



Infrastructure

Smart hazardous substance analysis from the air

Testing on the process at the BAM test site.

When accidents occur during the transport of hazardous goods or in industrial plants, every minute counts. It is crucial to identify chemical pollutants safely. BAM is developing a novel method that relies on drones, chemosensors, and AI.

Accidents involving hazardous goods in transport or in industrial plants can result in the release of chemical substances – sometimes with considerable risks for people and the environment. It is often unclear at first what substances are involved: They can be toxic, corrosive, flammable, or explosive. Samples usually have to be analyzed on site or in the laboratory, which is a time-consuming process. Furthermore, the appropriate protective equipment is not always immediately available.

A research team at BAM is therefore working on an innovative solution: Automated, contactless hazardous substance detection using drones, chemosensors, and artificial intelligence. This allows hazardous substances to be identified and mapped quickly, accurately, and from a safe distance.

Confetti made of chemosensors

At the heart of the Passive Smart Dust project are tiny cellulose particles coated with chemical indicators – known as chemosensors. These are scattered like confetti by a drone over a potentially contaminated area. As soon as senso discs come

into contact with certain liquids or gases – such as gasoline, acids, bases, or toxic gases – they change their color or fluorescence.

The drone then flies over the area again and uses a high-resolution camera to detect the changed sensors. Specially developed software automatically evaluates the images and creates a precise hazard map of the affected area within a few minutes.

Special filters are used for this purpose, which search specifically for certain color values and visual characteristics to narrow down potentially contaminated areas. In addition, AI-supported image recognition enables precise classification of the image data and fast and reliable localization of the danger zones.

Successful field test with acids and bases

The first field tests have already delivered promising results. “Our sensors have reliably detected acids and bases,” says Patrick Neumann, head of the project. “This was the best choice for us to test our model system because it delivers clear and



A drone detects the specially coated chemosensors on the ground.

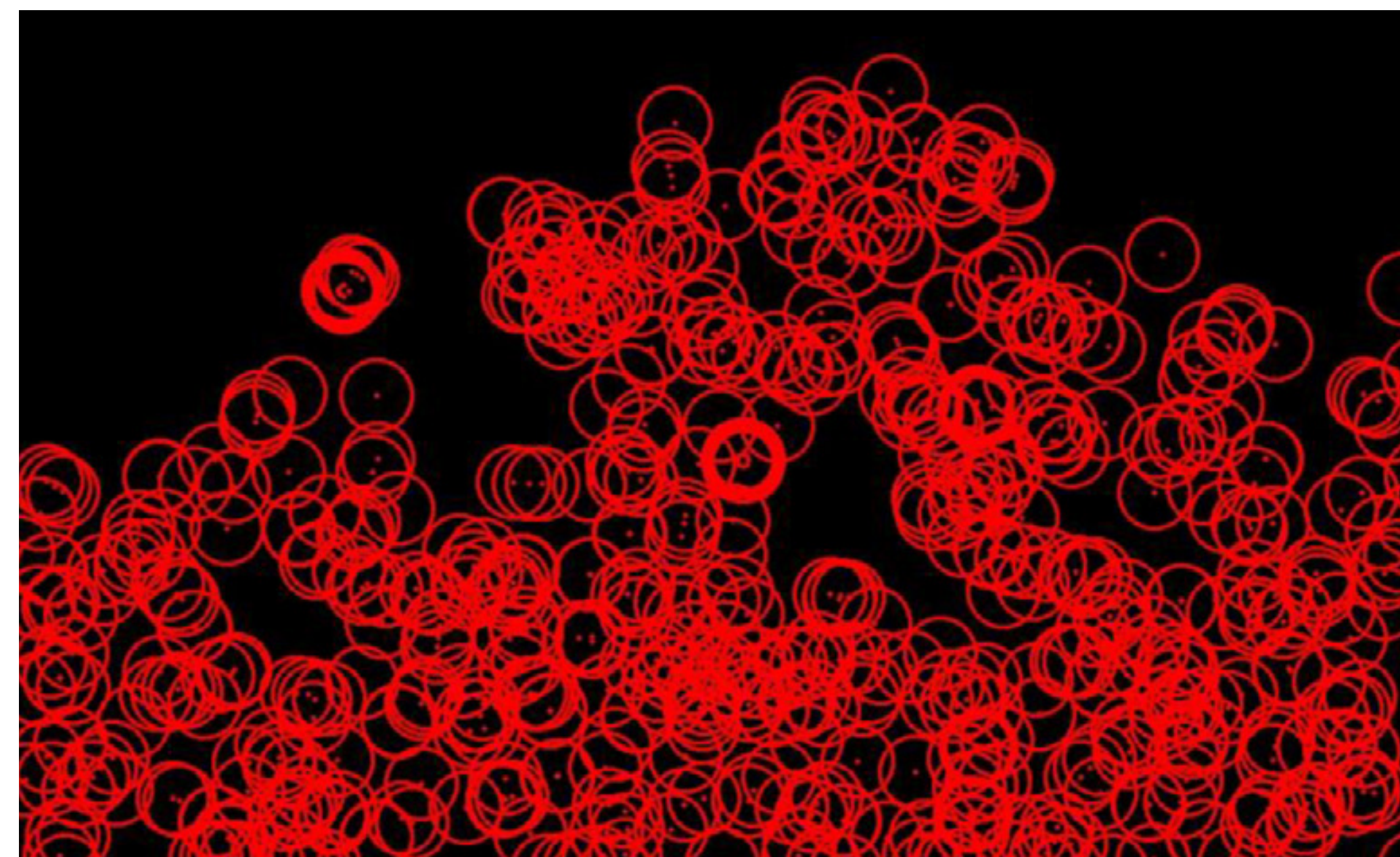
consistent results.” The team is now working on combining the system with additional sensors to detect an even broader and more complex range of hazardous substances, such as fuels like diesel or premium gasoline.

To this end, the scientists will conduct further tests and adapt the sensors to different environmental conditions. The surface of the reactive particles can be precisely tailored in the laboratory to specific hazardous substances: From short-term, biodegradable sensors for accidents to long-lasting variants for long-term monitoring of industrial plants.

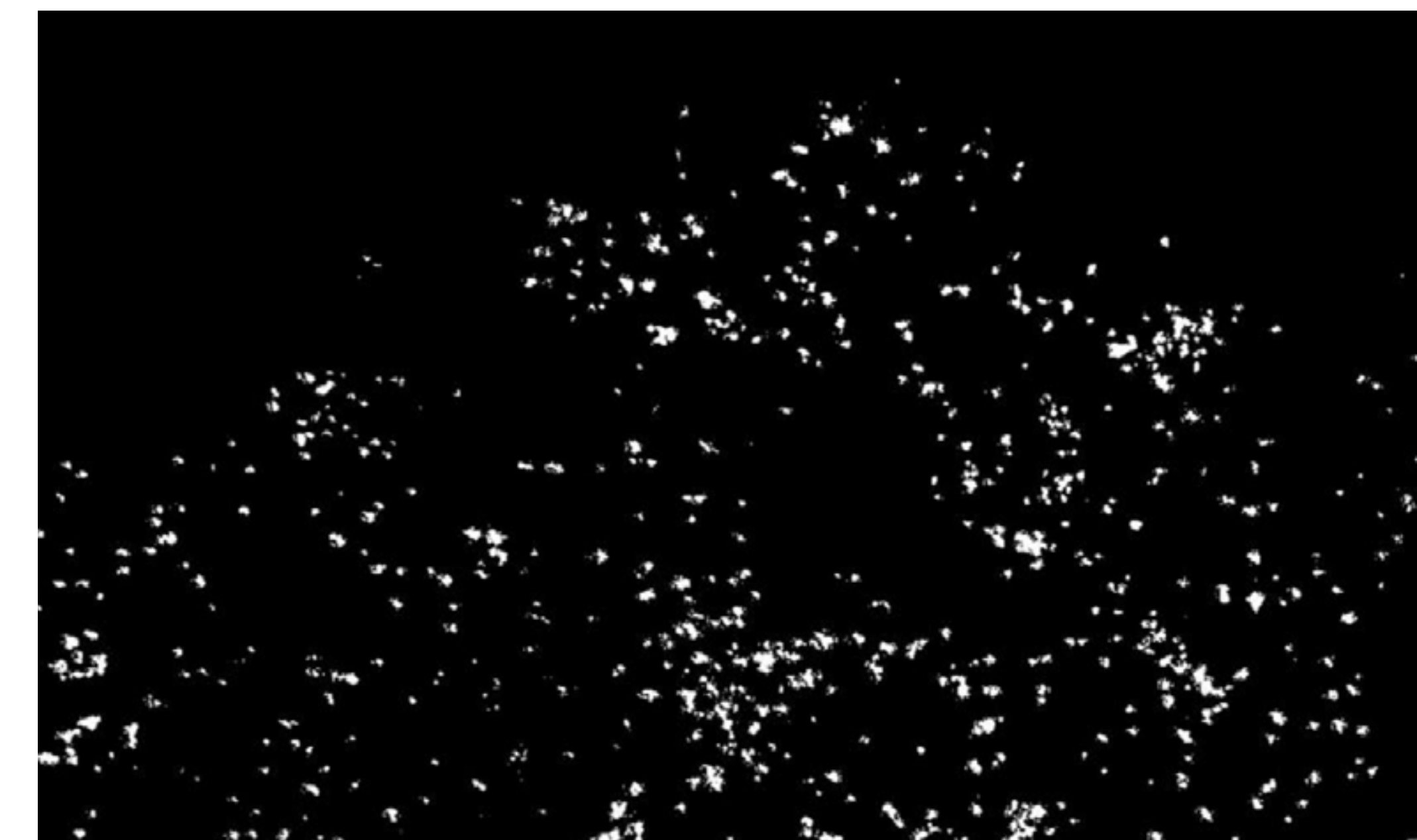
Major progress in hazardous substance detection

The innovation could be used in disaster areas, industrial plants, or for monitoring critical infrastructure in the future. “Our technology opens up new avenues in environmental monitoring and critical infrastructure protection,” explains Neumann’s colleague Tino Nerger. “The ability to detect and map chemical threats over large areas in an automated manner represents a huge advance in hazardous substance detection.” —

“ Our technology opens up new avenues in environmental monitoring and critical infrastructure protection. ”



Software uses AI to analyze the images and create a map of the contaminated area.



Infrastructure

Better protection for forests against fires

Determining moisture levels in forest soil.



Climate change is not only causing temperatures to rise – forest fires are also becoming more frequent, less predictable, and increasingly dangerous to people, the environment, and infrastructure. This has changed fire hazards and places new demands on research.

In 2023, over 1,000 forest fires were recorded in Germany. Around 1,240 hectares of forest went up in flames – equivalent to more than 1,700 soccer fields. Regions such as Brandenburg and Saxony-Anhalt are particularly affected, where drought, sandy soils, and monocultures further increase the risk of forest fires.

New protection strategies

In these regions, BAM has teamed up with Otto-von-Guericke University Magdeburg for the **EU research project TREEADS**  to investigate the role of soil, vegetation, and smoke gases in the development and spread of fires – and how this can be used to derive concrete protection strategies. TREEADS is a European joint project in which 48 partners from science, industry, and administration are pooling their expertise. The project was funded as part of the EU research program Horizon Europe.

BAM has contributed its special expertise in chemistry, material behavior, and fire protection to the project. “We are working to gain a better understanding of how fires spread so that we can fight

them in a more targeted and proactive manner,” explains Anja Hofmann-Böllinghaus, fire expert and project manager at BAM.

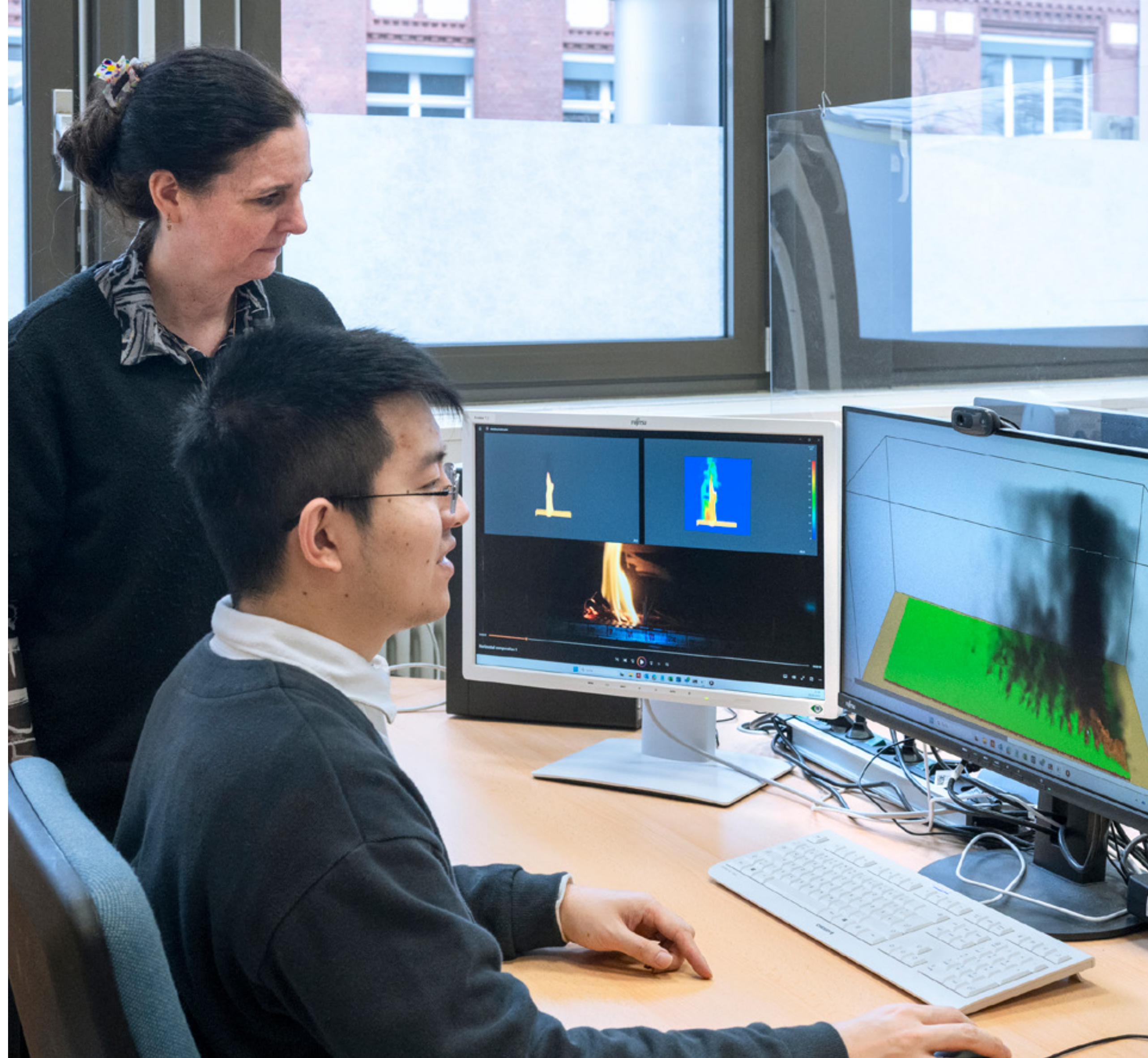
The investigations ranged from chemical analyses in the laboratory to controlled outdoor fire tests. Among other things, the proportion of organic substances in the soil, moisture conditions, and fire propagation in different types of vegetation were recorded.

This data forms the basis for computer-aided simulation models that can be used to predict the spread of fires under real conditions – such as different wind conditions, specific topography, and specific vegetation – with greater precision.

Machine learning is also used in this process: It analyzes large amounts of data and identifies patterns that are typical for the development and spread of fires. These findings are then fed into computer-assisted models, which can be used to make increasingly accurate predictions – for example, about how a fire might develop under certain conditions.



The proportion of organic substances in forest soil is determined.



Computer-assisted simulation models enable the spread of fires to be predicted more accurately.



Preventive countermeasures

This makes it possible to identify forest fire risks at an earlier stage and take preventive countermeasures, such as selectively thinning particularly vulnerable vegetation or providing suitable extinguishing agents.

In addition to the flammability of forest soil, the **fire science experts at BAM**  have also investigated the toxic components of smoke gases and identified six particularly critical components that occur in concentrations harmful to health during vegetation fires. “Even brief exposure to these substances can cause damage to health,” warns Hofmann-Böllinghaus.

Findings such as these help to better assess health risks for emergency services and residents. They will also be incorporated into safety guidelines and taken into account when new protective equipment is used.

Extinguishing with foam

Another goal of TREEADS is to develop innovative extinguishing technologies for difficult operating conditions. To this end, BAM tested an environmentally friendly compressed air extinguishing foam that penetrates deep into the ground and reliably smothers hidden embers. This is a promising addition to conventional methods, especially

in regions with limited water supplies, such as Brandenburg.

The findings from TREEADS show that effective forest fire protection does not begin with the fire itself, but with understanding it. Only those who understand the causes of fires can contain or prevent them. Scientifically sound, practical – and life-saving in an emergency. –

Infrastructure

Optimizing 3D printing with concrete



Concrete component in front of a 3D printer.

Concrete 3D printing has great potential for the future, but is influenced by many parameters. BAM researchers are developing simulation models to optimize the process. Their goal is to make the technology widely applicable.

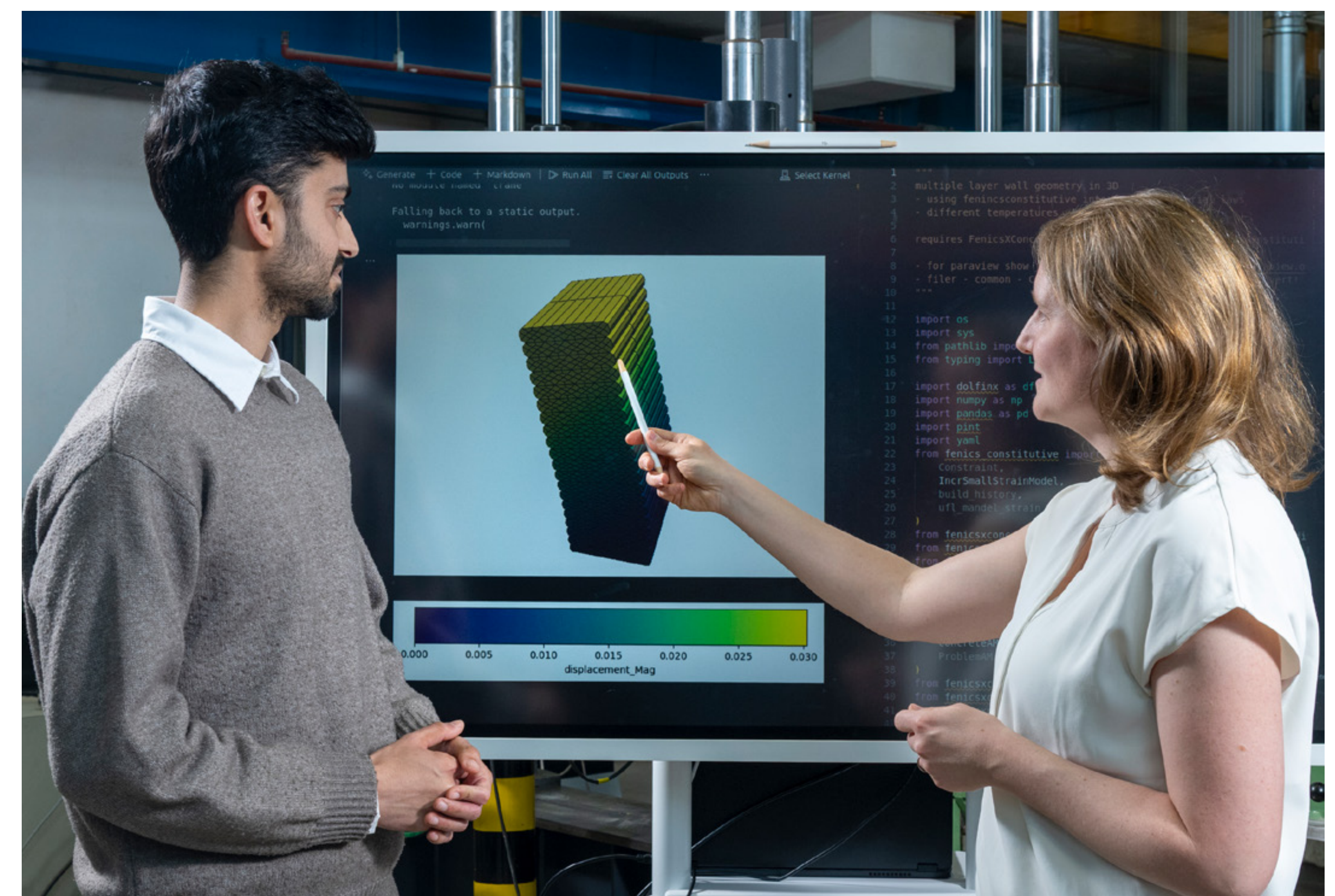
During the production of concrete components in a 3D printer, various parameters influence their properties, stability, and quality. Normally, a lot of time and material would have to be spent on tests to optimize these parameters. Simulation models can be used to optimize these parameters more efficiently. This is what BAM researchers are working on. This not only saves material for test runs. Among other things, the computer can also be used to determine the optimum pressure conditions to reduce resource consumption during production. A digital prediction can be made as to when a component will fail, collapse, or buckle during 3D printing. In the simulation, the printing parameters can be virtually adjusted until a stable and optimally designed concrete component is created.

Higher, faster, stronger?

“Assuming I want to print a one-meter-high wall, we can use the model to determine the optimal printing parameters for the job – for example, the printing speed or the hardening properties of the material. Provided that you know the real material and process parameters, it is also possible to simulate how the hardening of the material affects its stability during printing,” explains civil engineer Annika

Robens-Radermacher.” 3D printing mortar hardens much faster. This is necessary to ensure that the new layer of concrete can be supported by the layers below. Depending on how quickly this happens, the printing speed can influence how high you can print or whether an element remains stable during printing.”

Simulation models can be used to optimize the 3D printing of concrete components.



Simulating uncertainties

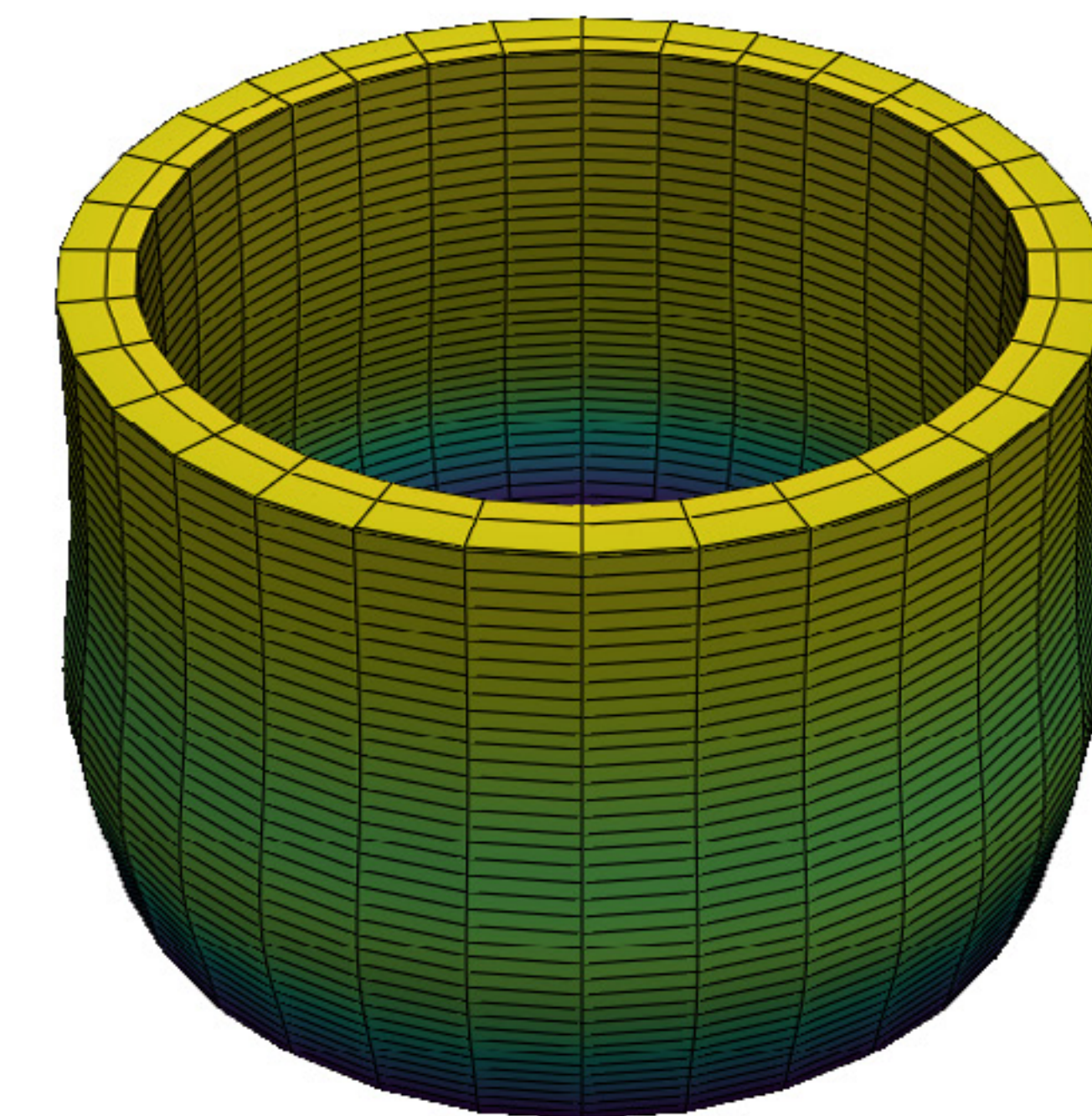
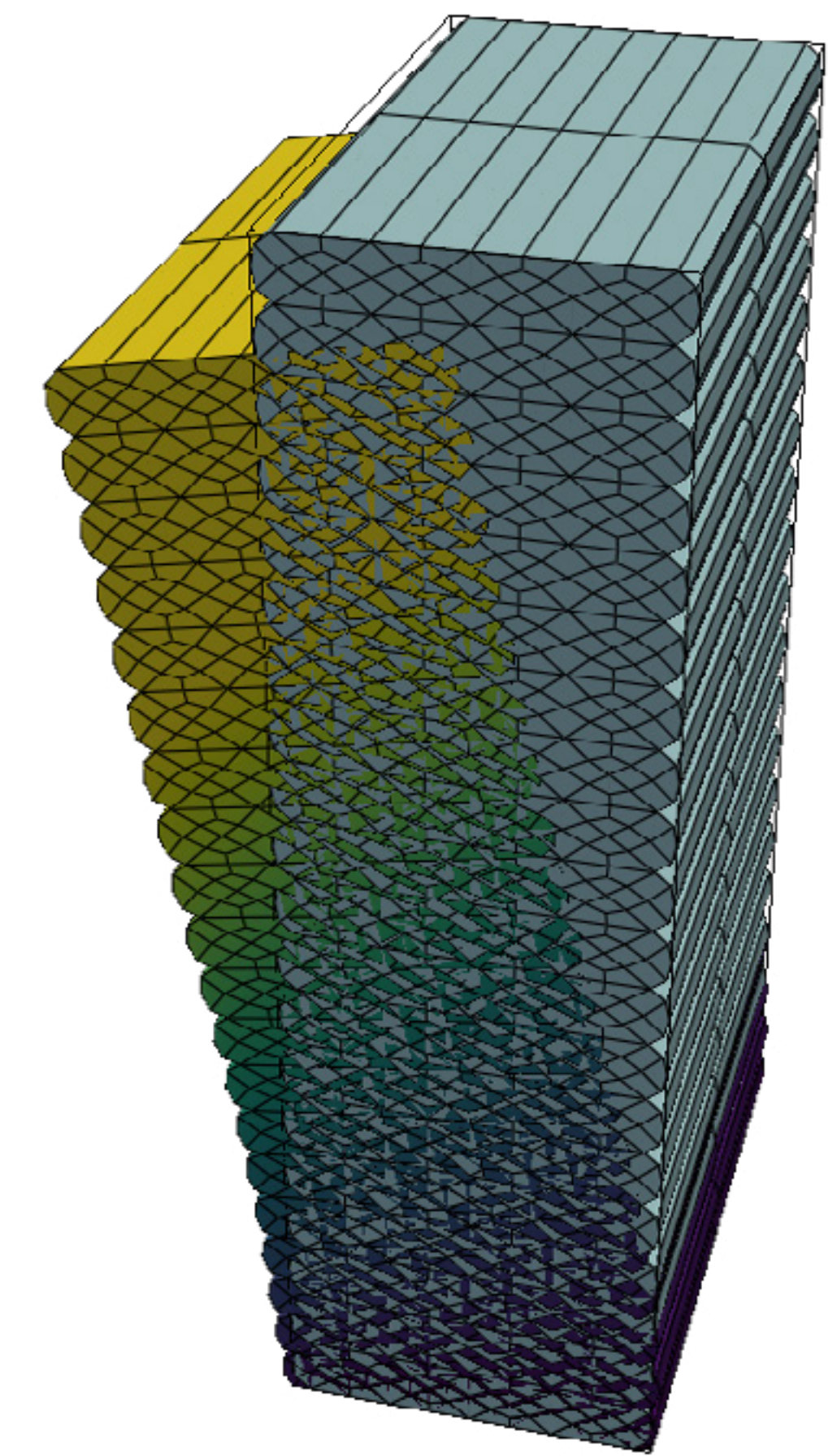
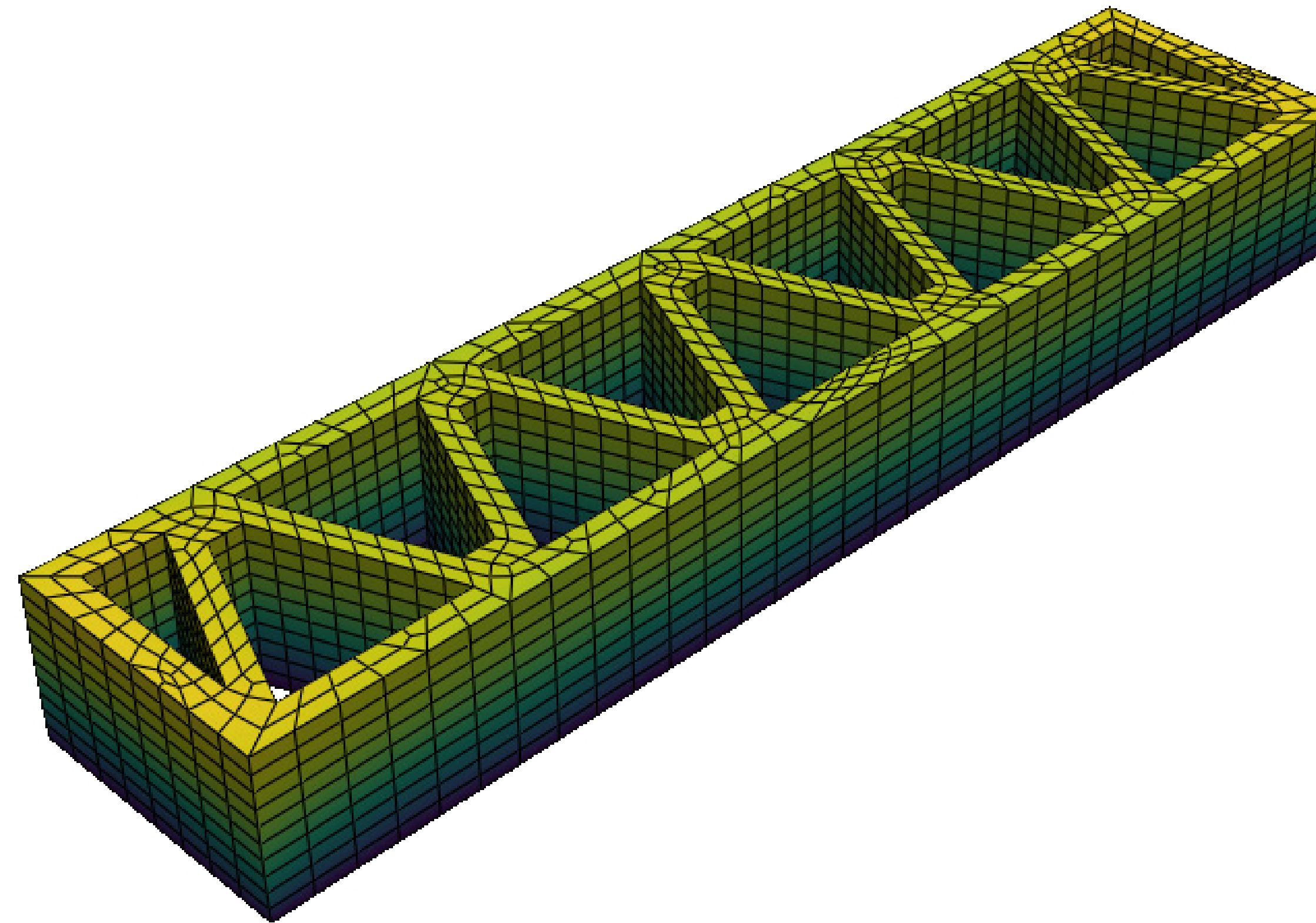
One challenge for the researchers is simulating varying influencing variables. Uncertainties arise during printing due to the multitude of factors influencing the process or due to necessary model assumptions. Material properties, for example, can fluctuate considerably depending on the batch or due to changes in environmental conditions. So how can the simulation models be so realistic that they also take these types of uncertainties into account?

To do this, individual parameters are not only assumed to have a value, but also a spread, such as the stiffness of the concrete. In addition, a large number of variations can be run through in the simulation models, thus taking a range of eventualities into account. To adapt the model as closely as possible to the real printing process, the simulated parameters are compared with real measurement data. These come from standardized material tests or were collected during a print.

Standards for the future of concrete printing

Simulations with certain parameters can later be used to derive recommendations on how to print a particular design – for example, which layer thickness or speed ensures that a given wall is stable. The results of the modeling should one day be incorporated into standards that enable the widespread use of 3D concrete printing. At present, there are no standards for the 3D printing of construction elements or their use. “Ideally, the simulation models should also be incorporated into the

standards,” says Robens-Radermacher, “and thus guidelines should be developed as to which models can be used to calculate designs and efficiently prepare printing.” –



The model allows pressure parameters such as speed and curing to be simulated in order to achieve optimum component stability.

Rejuvenation for roads

The asphalt layers on roads and highways need to be renewed after around 15 years. So-called reclaimed asphalt is already being used for this purpose. However, this reused asphalt becomes hard and brittle over time. This can lead to cracks and other damage to the road surface. The “Postcarbone Straße” project, funded by the German Research Foundation (DFG) and involving BAM, Ruhr Universität Bochum, and Technische Universität Berlin aims to achieve an unlimited recycling cycle for asphalt. Until now, new bitumen has been added to the old material to prevent hardening. However, the proportion of this petroleum-based, i. e. fossil-based, binder must be increased with each reuse cycle to maintain the viscosity and elasticity of the asphalt. The current process therefore impacts the CO₂ balance of recycled asphalt with each new cycle. Bio-based rejuvenating agents, such as oils extracted from pine resin or cashew nuts, could be a solution here. However, their positive effect is currently limited to a maximum of four reuse cycles. The scientists involved in the project are therefore developing a specially modified bio-based “rejuvenator” as a model. “We want to show how asphalt can be reused for much longer with the help of sustainable rejuvenators,” says Sandra Weigel, an expert in binders for road construction who is leading the DFG project for BAM.



A bio-based rejuvenating agent is set to replace fossil bitumen.

BAM and BAST intensify cooperation

In November 2024, BAM and the Federal Highway Research Institute (BAST) signed a memorandum of understanding to intensify their cooperation. Both institutions will pool their expertise to permanently strengthen the reliability and performance of Germany’s transport infrastructure. In this way, BAM and BAST want to work together to help secure transport infrastructure as a key economic factor. The technical reliability, safety, and durability of infrastructure systems and components will be at the forefront of the cooperation. Prof. Dr. Ulrich Panne, President of BAM, said: “The collapse of the Carolabrücke bridge in Dresden has once again demonstrated how important a robust transport infrastructure is – not only for Germany as a business location, but also for the safety of its citizens.” Professor Markus Oeser, President of BAST, added: “We are pooling our expertise, resources, and passion to further advance the performance and reliability of Germany’s transportation infrastructure. In this way, we are working together to prepare ourselves for the challenges of the future.”

Improved fire protection for historic buildings

In the joint project BRAWA, BAM has developed an innovative sensor system for faster detection of smoldering fires in collaboration with partners from industry and science. Historic buildings are particularly susceptible to fires, the effects of which are usually devastating. One reason for this is the natural materials used in past centuries, such as wood, straw, or grass, which are highly flammable without flame retardants. As part of BRAWA, the BAM team has focused on the early detection of smoldering fires. These release aerosols and gases before visible flames appear or

a noticeable increase in temperature occurs. The scientists have simulated various fire scenarios in the laboratory. The fire gases released were identified using sensors and comprehensively characterized to assess their suitability for early fire detection. In addition, the researchers carried out numerical simulations to model fire development and spread in detail. Based on this data, the project team has developed an innovative sensor system that triggers an alarm in the early stages of a fire.

Energy | Infrastructure | **Environment** | Materials | Chemistry and Process Engineering

Environment

Sustainable steel production with hydrogen



Reduction of iron ore with hydrogen
plasma in an electric arc furnace.

BAM is driving forward the decarbonization of the steel industry in two international projects – one of the key levers for the global energy transition. The focus is on the use of hydrogen and the processing of low-quality iron ores.

The global steel industry is responsible for around eight percent of global CO₂ emissions. To tap into potential savings here, BAM is playing a leading role in two international research projects.

The goal: Climate-neutral steel production

In the **ZEROSTEEL project** [🔗](#), which is funded by the European Union as part of the Horizon Europe program, BAM is conducting laboratory experiments on the hydrogen-based direct reduction of iron ore. The aim is to replace carbon as a reducing agent in the process with hydrogen. BAM scientist Christian Adam and his team are investigating not only direct reduction with hydrogen in the solid state, but also the smelting reduction of iron ore with hydrogen plasma. The advantage of both methods is that only water vapor is released instead of harmful greenhouse gases. The researchers are testing how the process can be scaled up to industry level in a pilot plant. They are also investigating the use of climate-neutral biochar, e.g. for the production of foam slag, to further reduce the CO₂ emissions of the process.

Numerous European partner institutions from industry and research are involved, including the TU Bergakademie Freiberg, the Centre national de la recherche scientifique in France, and TU Wien.

Focus: Low-quality iron ore

The SuSteelAG (Sustainable Steel from Australia and Germany) project with Australia as a partner country is even more comprehensive in terms of overall logistics. It looks at all facets of steel production in order to leverage CO₂ savings potential. The aim is to establish a sustainable bilateral value chain between Australia as a supplier of raw material and green energy and Germany as a location for green steel production. The joint consortium is focusing on a technology that uses green hydrogen to refine low-grade iron ore into iron. These grades of iron ore are also available in large quantities in Australia, from where Germany sources a significant proportion of its imports for steel production.



Analysis of the resulting slag using laser-induced plasma spectroscopy.

The aim is to develop a process that will initially refine low-grade ores into green iron using hydrogen directly on site in Australia. “So far, reduction with hydrogen has only been established for high-grade iron ore,” says Christian Adam, who is also leading this project. “This mainly involves shaft furnaces, in which the ores have to be laboriously processed beforehand. We, on the other hand, want to establish a process that uses a rotary kiln. We have already demonstrated at BAM that this approach is fundamentally feasible. Through SuSteelAG, we are therefore tapping into a new source of raw materials for green steel production.”

The long-term goal is to establish a value chain that supports local climate-friendly steel production while consolidating Germany’s role as a technology leader in green hydrogen solutions.

Strong international consortium

SuSteelAG is supported by a strong German-Australian consortium consisting of leading research institutions and industrial partners in their respective fields, who are contributing their expertise in metallurgy, hydrogen technology, plant engineering, and logistics to the project. In addition to BAM, these include Salzgitter Mannesmann Forschung GmbH, TS Group Elinor GmbH, HyIron GmbH, the Fraunhofer Institute for Surface Engineering and Thin Films (IST), the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS), RWTH Aachen University, Heidelberg Manufacturing Deutschland GmbH, HANSAPORT, and Fortescue. The project is funded by the German Federal

Ministry of Research, Technology and Space as part of the 7th Energy Research Program with around 4.5 million euros. —



Iron samples of varying quality (r.), preparation of samples for microscopic examination (b.).





Nikita Gugin helped develop the new in-situ monitoring method.

Green chemistry becomes industrialized

Mechanochemistry is a promising sustainable method in which chemical reactions are triggered by mechanical processes and largely do not require solvents. Previous studies on mechanochemistry, whose “green” potential has increasingly come into focus internationally in recent years, have relied on the use of ball mills. However, these only allow substances to be produced on a laboratory scale. Extruders offer a promising alternative for industrial applications because they enable the transition to large-scale production. Extruders are widely used devices in manufacturing technology for the produc-

tion of food, plastics, building materials, and medical and pharmaceutical products. However, until now, there has been no suitable in-situ monitoring method for controlling and monitoring all process steps in large-scale industrial production. A team at BAM led by Nikita Y. Gugin and Franziska Emmerling has successfully demonstrated that energy dispersive X-ray diffraction (EDXRD) can be used to monitor extruders. This method was developed as part of a research collaboration at the PSICHÉ beamline of the French national synchrotron facility SOLEIL.

Removing PFAS from the environment

Per- and polyfluoroalkyl substances (PFAS) are found in many everyday products, such as water-repellent clothing and firefighting foams, and pose a growing threat to the environment and health due to their longevity and mobility. BAM is conducting research into removing PFAS from the environment. The project, which is funded by the Volkswagen Foundation, is being led by the Free University of Berlin, with the Fraunhofer Institute for Applied Polymer Research (IAP) as a cooperation partner. The project uses biogenic raw materials such as lignin and glycerol. These raw materials will be used to develop so-called functionalized adsorbent beads: Specially designed materials that can bind pollutants such as PFAS to

their surface, thereby removing them from contaminated water. The circular approach of the project also aims to enable the adsorbent beads to be regenerated, i.e., PFAS to be completely removed from them so that they can be reused. At the end of their service life, the beads can be used in agriculture for water and nutrient retention in the soil. BAM and FU Berlin will carry out accompanying analyses throughout the entire project period: They will examine the quality of the raw lignins, the surface properties, the porosity, and the swelling behavior of the finished materials. They will test how much PFAS the beads can actually absorb and check their recyclability.

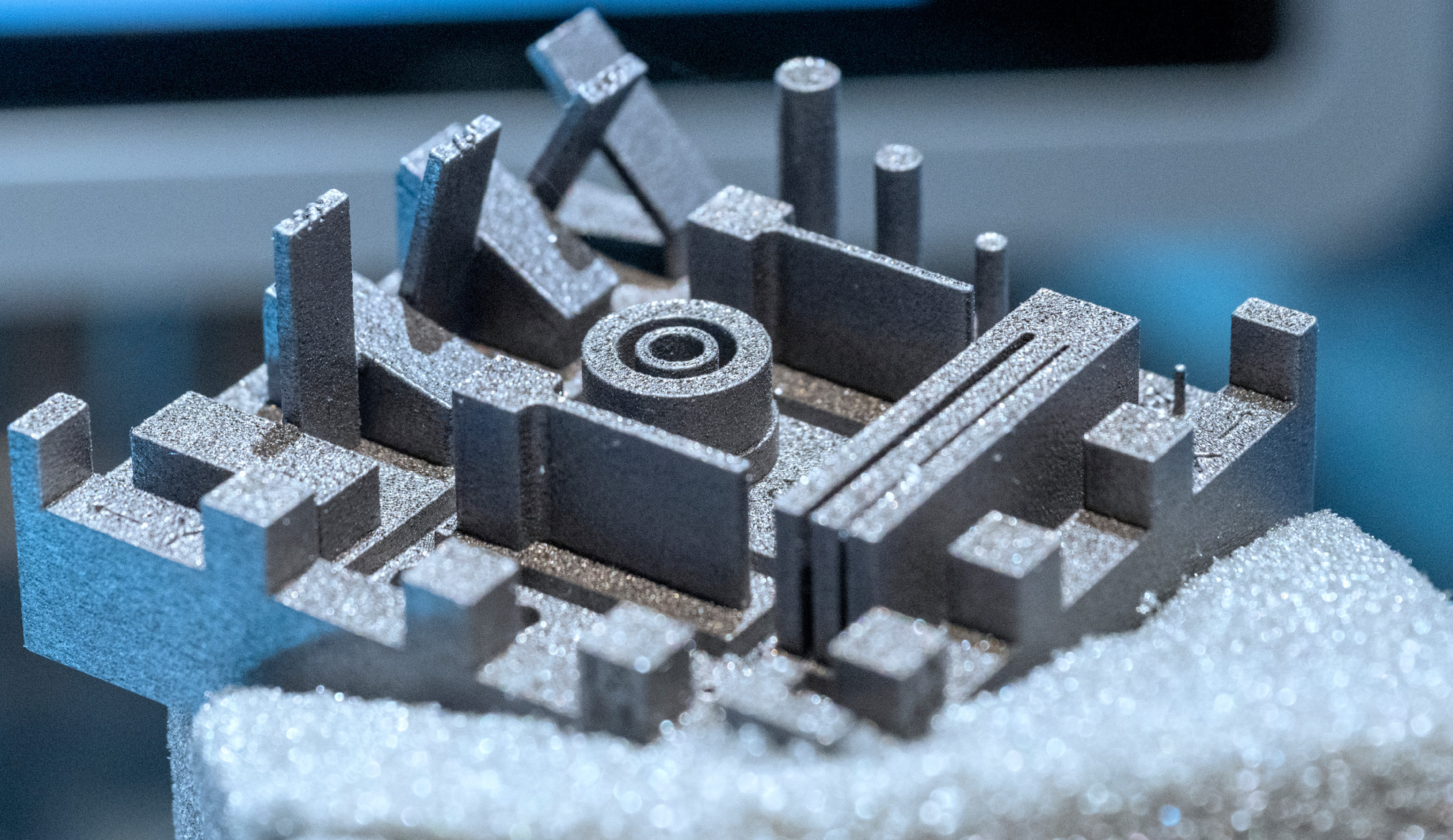


BAM and FU Berlin are responsible for analytics in the project.

Energy | Infrastructure | Environment | **Materials** | Chemistry and Process Engineering

Materials

Data treasures of additive manufacturing



3D printing generates huge amounts of data – but its potential, especially for quality assurance, often remains untapped. BAM wants to change that. And in doing so, ensure greater safety, fewer errors, and transparent traceability.

Data is essential for creating 3D models, which in turn serve as the basis for the printing process. It enables the precise design and adaptation of components as well as the control and monitoring of the entire printing process. Continuous analysis allows quality problems to be identified and rectified at an early stage. It also enables the efficient identification of affected products in the event of a product recall. However, this potential has hardly been exploited to date.

Analyzing data correctly

“Those who analyze data correctly in 3D printing can avoid errors, save material and costs, and optimize processes,” explains Martin Epperlein from the [BAM Competence Center for Additive Manufacturing](#) [\[1\]](#). However, collecting and analyzing this data has been a major challenge to date. “Every material behaves differently, and every additive manufacturing technology has its own peculiarities – that’s what makes data analysis so complex,” explains Epperlein.

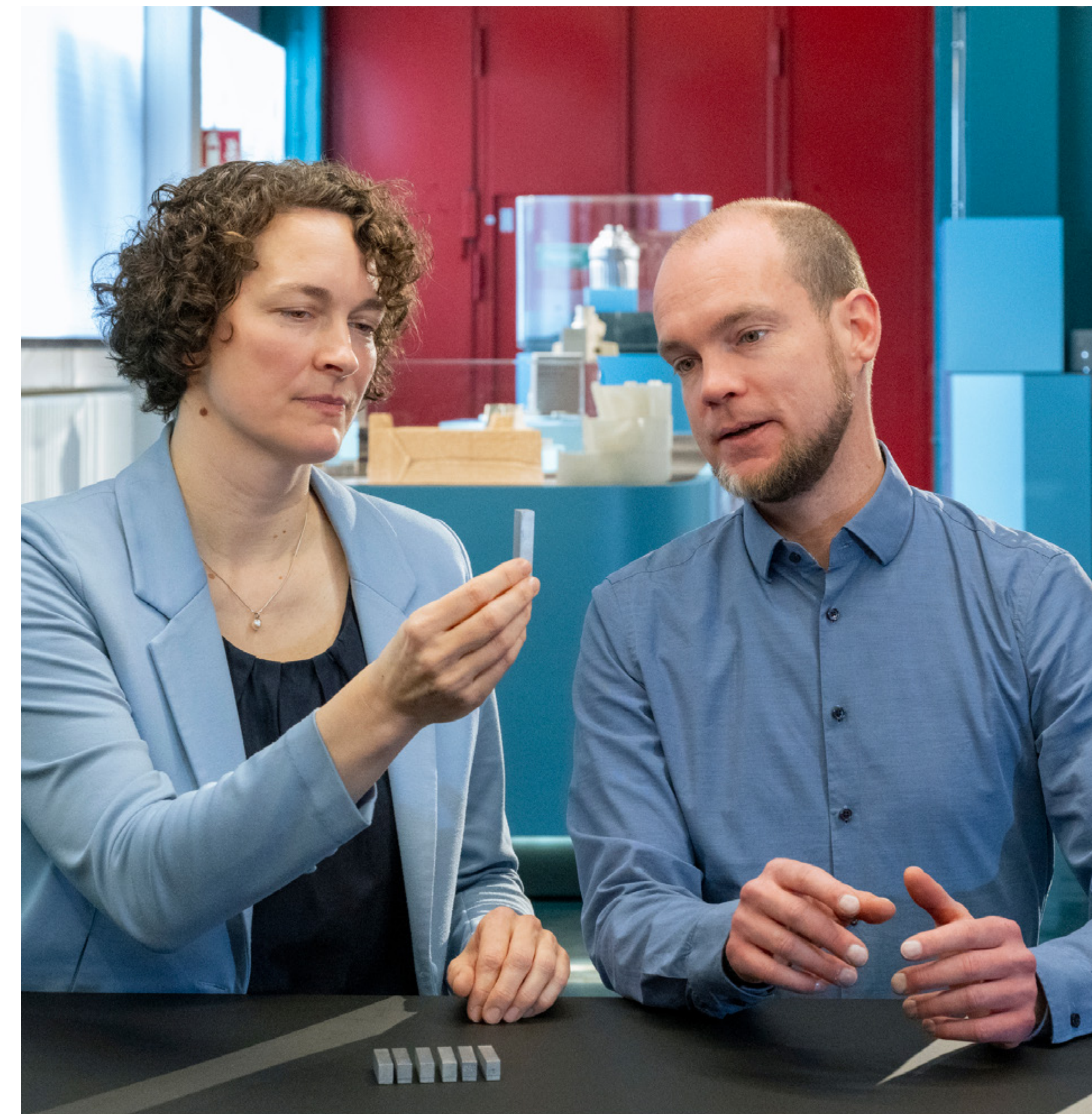
The potential of this data becomes clear when it comes to issues such as traceability and quality

control for 3D-printed components. In safety-critical industries such as aviation and aerospace, manufacturing conditions must be precisely documented and regulatory requirements complied with. Seamless digital identification can help to ensure transparency and safety in this context.

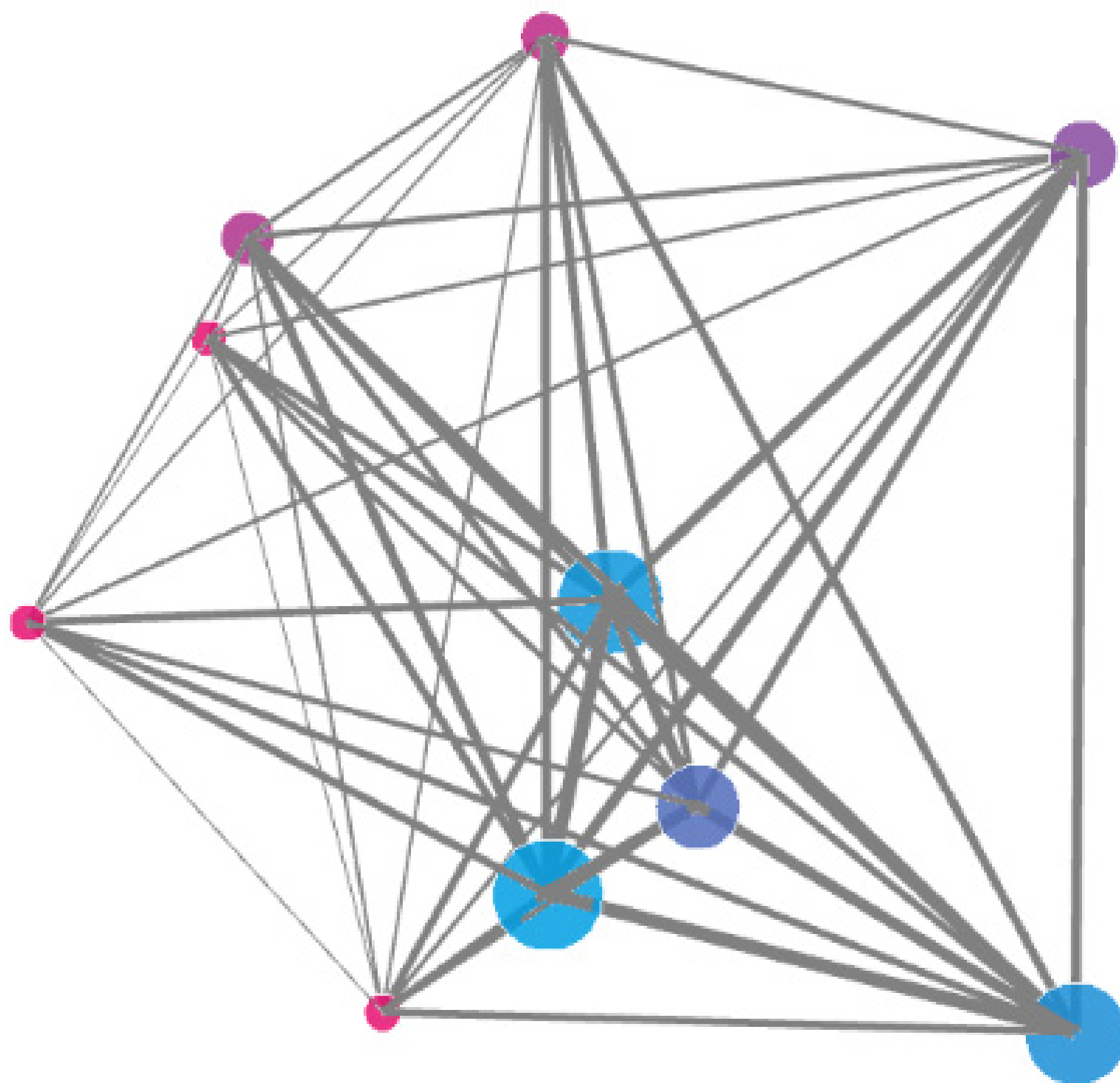
Unique digital fingerprint

BAM has developed a method for assigning a unique digital “fingerprint” to a 3D-printed component: X-ray scans capture the internal microstructures of an object and use the 3D image data to calculate a geometric pattern – an identifier. “It is as unique as a human fingerprint,” explains Anja Waske, head of the project..

To put the technology into practice, the team is working with Additive Marking GmbH, a German company based in Paderborn, Germany, that specializes in innovative solutions for additive manufacturing and is working on solutions for component traceability in order, to develop software that takes into account not only the microstructures of an object but also serial numbers and machine-readable codes. “Our goal is a digital ID that creates a unique



Every component from the 3D printer is unique, and traceability is particularly important in safety-critical areas.



The digital fingerprint, a geometric pattern, is calculated from the internal microstructures.

“ Our goal is a digital ID that creates a unique and tamper-proof link between digital and physical components. ”

and tamper-proof link between digital and physical components,” says Anja Waske. In the future, this would make it possible to clearly determine the origin of a 3D-printed component in the event of damage and clarify liability issues.

Certified real-world laboratory as an ideal test environment

The project is just one of many examples of BAM’s research into data-driven quality assurance in additive manufacturing. To this end, BAM operates its own real-world laboratory, which is open to small and medium-sized enterprises in particular for joint testing and optimization of new processes.

The BAM real-world laboratory is the first facility of its kind worldwide to receive official certification for quality assurance in additive manufacturing. “The certification by the International Organization for Standardization (ISO) not only underscores the importance of data-driven quality assurance. It also ensures that the methods developed in our real-world laboratory meet industrial requirements. This greatly facilitates the subsequent transfer of technology,” explains Martin Epperlein.

To make the latest developments in additive manufacturing more tangible and accessible, BAM has also set up an interactive showroom. Here, inter-

ested parties from industry can follow the entire additive manufacturing chain – from raw material to finished component. And they can experience first-hand how data-driven, digital quality assurance makes 3D printing safer and more efficient. —

Materials

New materials from the supercomputer



Janine George in front of the “Lise” supercomputer at the Zuse Institute Berlin, which she uses for her calculations.

Janine George heads the junior research group “Computational materials design” at BAM and teaches materials informatics at the Friedrich Schiller University Jena. She has received numerous awards for her work, most recently a Starting Grant from the European Research Council for her new project “Multibonds”.

What is materials informatics and how does it differ from traditional materials research?

Materials informatics is a very young discipline at the interface between chemistry, physics, materials science, and computer science. In contrast to conventional materials research, which relies heavily on experimental methods, it uses large amounts of data, machine learning, and simulations to predict how materials behave and what properties they might have with the help of supercomputers. The aim is to reduce the number of laboratory experiments and narrow down the search space for new materials – of which there are theoretically billions upon billions. This can significantly reduce the time to market for new materials, for example for more efficient solar cells or more sustainable batteries.

How exactly do you go about searching for materials?

Often, we know what properties a new material should have. For example, we are looking for crystal structures with good thermal conductivity. The ability to conduct heat is important for semiconductors and electronic components of all kinds to pro-

tect them from overheating. However, there are only a few databases with data on the properties of real crystalline materials. Therefore, in materials informatics, it is common to first generate this data based on physical theories and using supercomputers.

What happens next?

In the next step, we analyze this data to identify patterns and correlations, for example, which crystalline materials result in particularly good thermal conductivity. We then perform simulations to combine this property with other desired characteristics. Finally, the most promising candidates are produced in the laboratory and tested to verify the predictions.

Has materials informatics already achieved any concrete successes?

My team and I were involved in the search for a new solar cell material that, among other things, should be non-toxic. We were able to identify several suitable copper-based materials. There have been successful searches by other groups that lead to an experimental verification. At the moment,



Supercomputer calculations accelerate material development.

however, materials informatics is mainly concerned with the basics, i.e. the development of methods, codes, and workflows that can be used to generate and check large amounts of data.

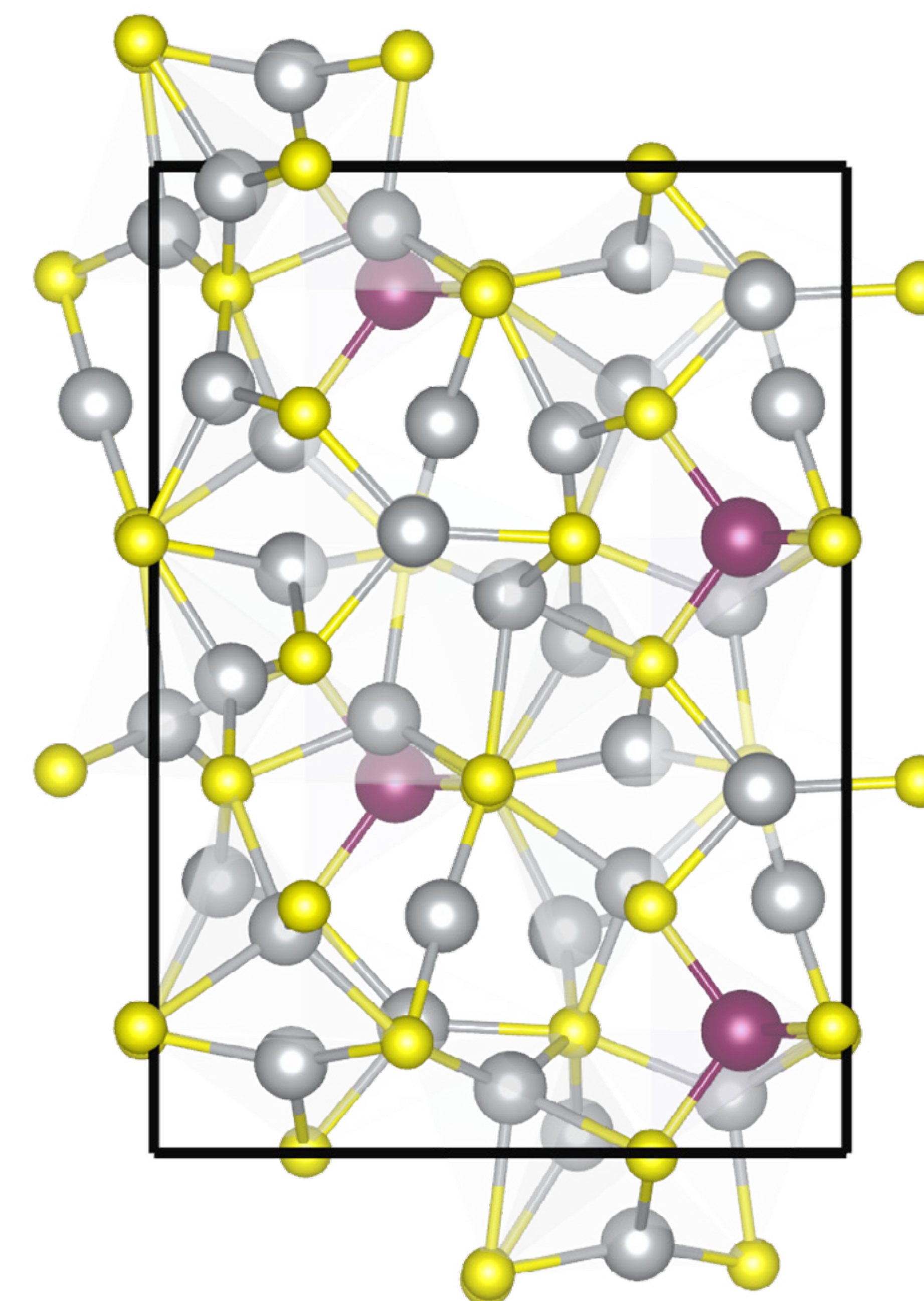
Which developments in materials informatics could be particularly promising?

Materials informatics also allows us to put established chemical rules to the test. For example, in an earlier paper, I tested the so-called Pauling rules, which were established in the 1920s by the American chemist and later Nobel Prize laureate Linus Pauling and predict the stability of crystal structures, on a data set of 5,000 compounds. It showed that the rules have significant weaknesses. First of all, this advances our chemical understanding in this area – even if we are not yet ready to establish new rules.

Will this be possible one day? What role does the EU's Multibonds project play in this context?

With “**Multibonds**” , we are actually taking our first steps in this direction by trying to find further connections between material properties and the chemical bonds between atoms. To do this, we have created a database of over 1500 materials to study the connection with magnetism, hardness, and thermal conductivity. We have already been able to show that there is a correlation of bond strength descriptors and materials properties such as the vibrational density of states. This makes us optimistic that in the future, by analyzing chemical bonds, we will also be able to accelerate the predic-

tion of other material properties and derive new rules from them. All in all, materials informatics is currently poised to significantly change the development of new materials and help us as a society to find answers to pressing questions around the energy transition, sustainability, and the fight against climate change. –



This compound of silver, tin, and sulfur has low thermal conductivity due to its bonding properties.

“ **All in all, materials informatics is currently poised to significantly change the development of new materials and help us to find answers to pressing questions.** ”

High-tech ceramics from a 3D printer

A scientific junior research group funded by the German Federal Ministry of Education and Research is developing transparent ceramic microcomponents using 3D printing at BAM. The aim is to manufacture ceramic structures for technical, optical, and medical applications more efficiently and in a more customized manner. Ceramic materials have unique properties such as temperature stability, chemical resistance, and wear resistance. However, processing technical ceramics poses a particular challenge for industry, especially as components become smaller. The 3D printing developed at BAM offers new possibilities for manufacturing customized structures in micro- to millimeter formats. To achieve this, printing parameters, material mixtures, and post-processing must be precisely coordinated. A particular difficulty lies in adapting the material mixture to the respective 3D printers. Transparent “inks” are particularly necessary for high resolutions. The research group led by Johanna Sängner is developing inks that are transparent even though they contain ceramic particles. This is possible when the particles are particularly fine, i. e. only a few nanometers in size. “With our research, we want to open up new fields of application for the 3D printing of ceramic micro-components and bring this technology to industry,” says Johanna Sängner.

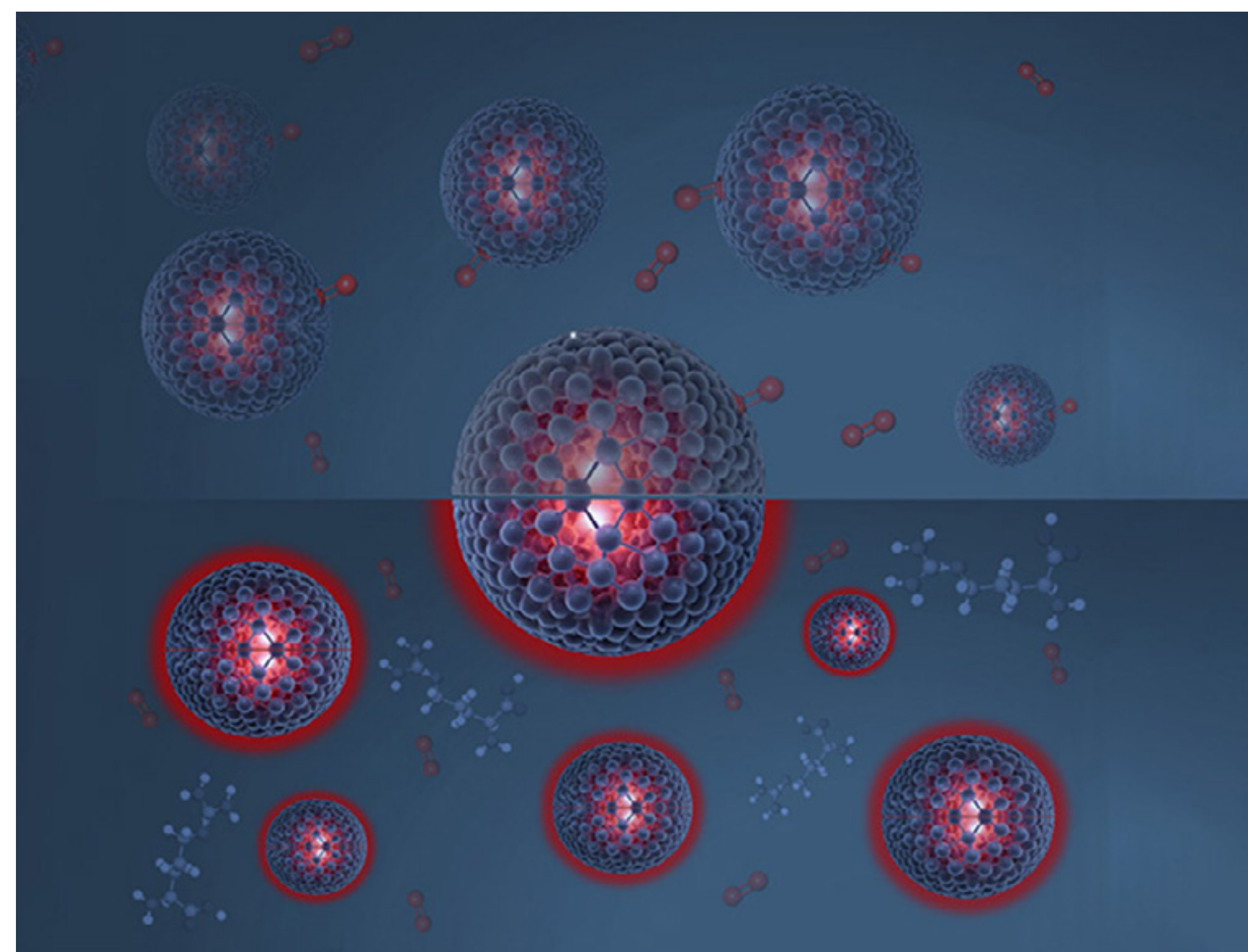
Aging of metallic glasses

Metallic glasses hold great promise for high-tech applications. They combine typical metallic features such as electrical conductivity with exceptional strength and elasticity. The material owes these properties to its glass-like, i. e. amorphous structure, which is disordered on the atomic scale. As a material class, metallic glasses often outperform conventional industrial steels. However, their tendency to become brittle over time has limited their potential applications for decades. In several recent studies, researchers at BAM and ETH Zurich have investigated the microstructural processes of metallic glasses during

aging and under mechanical stress. Through synchrotron experiments at the Advanced Photon Source at Argonne National Laboratory in Chicago, the scientists succeeded in detecting the atomic networks of these materials not only in simulations, as has been the case to date, but also in real metallic glasses. “The discovery of this microstructural ‘ordered disorder’ is our starting point for tailoring the mechanical properties of metallic glasses and advancing them toward use in safety-critical applications such as in robotics, medical devices, construction, and aerospace,” says BAM scientist Birte Riechers.

Protective shield made of nanoparticles

They are tiny, but they emit intense light: Special light-emitting molecules that are used in energy research, environmental analysis, and medical diagnostics. However, their luminescence has been severely limited in the air by oxygen acting as luminescence quencher. An interdisciplinary research team from BAM, Johannes Gutenberg University Mainz, and the TU Wien has now found a solution to protect the sensitive molecules from oxygen: Building on the expertise of BAM researcher Isabella Tavernaro, the scientists have embedded the luminescent molecules in tiny silica nanoparticles. Nanoparticles made of silicon dioxide (SiO_2), the main component of quartz glass, are chemically stable and biologically compatible. By encapsulating the light-emitting molecules, these specially manufactured silica nanoparticles, made by an underexplored sol gel synthesis, form a protective shield against external influences. This universal strategy preserves their strong luminescence.



Silica particles shield luminescent molecules from oxygen, allowing them to retain their luminosity.

Energy | Infrastructure | Environment | Materials | **Chemistry and Process Engineering**

Chemistry and Process Engineering

Simulation creates safety



Digitalization, flexibilization, and the energy transition are presenting chemical plants with new challenges. Process simulation combined with complex experiments can ensure greater safety in design and operation.

In the past, chemical plants operated continuously – with stable parameters, known raw materials, and a constant energy supply. The energy and raw materials transition is creating new challenges in industries such as petrochemicals, pharmaceuticals, fine and specialty chemicals, as well as energy generation and storage. These industries process substances such as hydrogen, chlorine, and ammonia, which potentially pose a high safety risk. Furthermore, the German plastics industry is increasingly working with recycled materials. This means new uncertainties in the composition and availability of raw materials as well as variability in the operation of chemical plants.

Flexibility instead of continuous operation

At the same time, energy supply is becoming more volatile: In order to be able to respond to fluctuating supply from wind and solar power or price signals on the electricity market, many operators are now running their plants more flexibly and with frequent starts and stops – which also poses new challenges for plant safety.

“In the past, a maximum of 1,000 start-stop cycles in 30 years was assumed – today, plants need 10,000 or

more. This fundamentally changes the requirements for equipment and safety technology,” explains Katharina Löwe, Head of the **Process and Plant Safety Department** at BAM. “Safe plant operation must be guaranteed under all boundary conditions.”

Simulation meets reality

To help companies better meet these challenges, BAM analyzes how dynamic operating strategies affect the safety of process engineering plants – and how risks can be reduced in a targeted manner.

To this end, a team led by Erik Esche, who heads the **Process simulation division** at BAM, has developed simulation models that can be used, for example, to analyze the effects of frequent load changes or variable temperature profiles on the thermodynamic and mechanical behavior of plant components. “Digital twins” of the plants virtually map these complex processes and enable precise risk analysis as early as the design phase.

In addition, explosive substances, pressure vessels, and hydrogen systems are tested under realistic conditions at the **BAM Test Site for Technical**



Simulation models can be used, for example, to analyze the effects of frequent load changes on the behavior of systems.

Safety  south of Berlin. The data obtained in these tests is fed directly into the digital models, improving their predictive power.

“The hybrid approach combining simulation and experimentation enables us to clarify safety issues at an early stage and make processes more efficient and resilient,” says Esche.

Clear added value for practice and policy

The interaction of different BAM departments in process and plant safety allows a holistic view of chemical processes and products from the laboratory to real-world scale. This approach offers decisive advantages for industrial partners: They can identify risks at an early stage of development and plan investments more precisely. The simulations provide them with a sound basis for technical decisions, minimize the risk of failure, and accelerate approval processes.

The authorities involved also benefit: BAM advises them on the safety assessment of new process concepts and contributes reliable test results and independent expertise to complex evaluation procedures. In addition, BAM formulates proposals for improved regulation.

For Esche, one thing is clear: “If we want to make industrial plants more flexible, resilient, and sustainable, we need to take a holistic view – technically and economically, but also from a safety perspective.” Only then can companies produce efficiently and responsibly in the long term – and bring new technologies to market faster. –

“ **The hybrid approach combining simulation and experimentation enables us to clarify safety issues at an early stage.** ”

Volatile energy supply, flexible operation:
chemical plants are facing new challenges.



Digital workflows for safe materials

Digital workflows are key to bringing innovative materials into use more quickly, robustly, and safely. As part of the MaterialDigital project, BAM is working with partners to develop structured data processes for materials research. The aim is to process research and test data in a standardized, traceable, and automated way – for example, in simulations in additive manufacturing, where temperature profiles influence material properties. Instead of scattered individual tools, digital workflows ensure a continuous data chain, improve reproducibility, and enable machine processing of the recorded information. They also facilitate the integration of AI. BAM contributes its expertise in data management, software integration, and standardization, thus creating a solid foundation for safe, efficient, and sustainable materials in industry and research.



In the digitally controlled system, material synthesis, purification, and analysis take place with virtually no manual intervention.

Material development in the “Self-Driving Lab”

BAM is developing an automated platform for the synthesis, characterization, and AI-supported optimization of nano and advanced materials: the Self-Driving Lab (SDL). In this digitally controlled system, material synthesis, purification, and analysis run in parallel and with virtually no human intervention. The entire process is documented in a reproducible manner, controlled autonomously, and supported by AI algorithms. The aim is to develop novel materials – for example, for catalysis, coatings, or gas storage – more quickly and safely. The SDL minimizes sources of error, improves quality assurance, and creates digital interfaces for secure transfer to industrial processes – an important step toward a sustainable, data-driven chemistry.

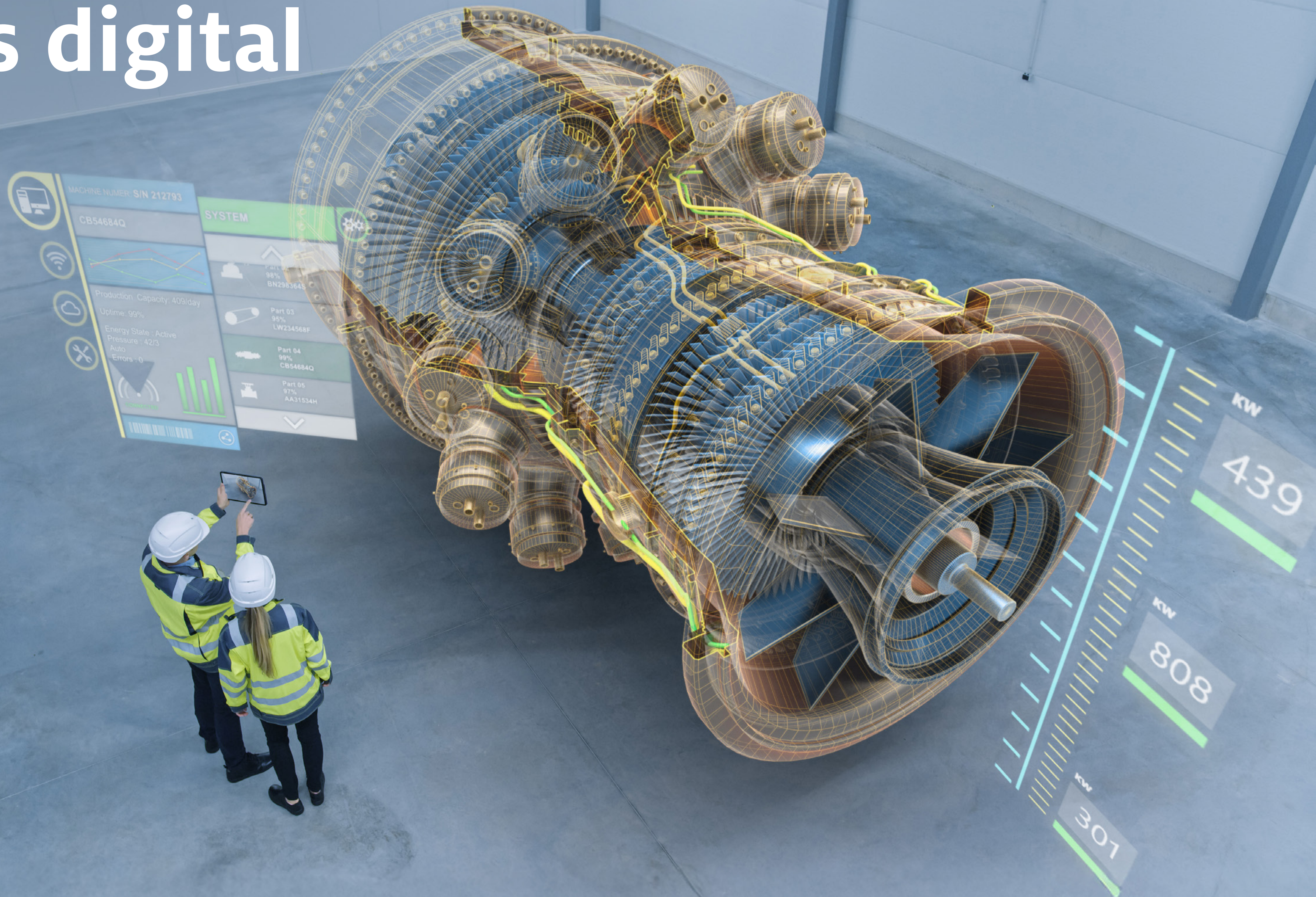
Mixed reality ensures greater safety

Maintaining and operating chemical plants places high demands on safety and precision – especially in potentially hazardous environments. As part of the MR4SafeOperations project, which is part of the WIR alliance MR4B (Mixed Reality For Business), BAM has teamed up with the Technische Universität Berlin to develop a mixed reality-based assistance system that makes real-time data from process control technology visually accessible and provides digital support for work steps. The sys-

tem enables critical manual workflows to be carried out safely and in a structured manner, reducing human error. “The combination of the Internet of Things, i.e., the networking of machines, sensors, and systems, standardized interfaces, and user-centered design not only promotes process reliability but also the efficiency and quality of the work performed by operating and maintenance personnel,” says Hernán Darío Muñoz Gil, a research assistant on the project.

Quality infrastructure digital

Made in Germany goes digital



Made in Germany stands for highest quality, reliability, and technical precision, but also for safety and trust. Now it is time to adapt Made in Germany to the digital age. BAM is committed to this as a key player in the QI-Digital initiative.

The high quality of products, services, and processes from Germany is a key factor in the success of the German economy. Fundamental to this is the proven quality infrastructure (QI) system comprising standardization, conformity assessment, accreditation, market surveillance, and metrology. A recent study confirms the high economic value of this system: Without QI, Germany's gross domestic product would shrink by 7.8 percent – equivalent to 320 billion euros annually.

Digitally ensuring and verifying quality

In order to continue meeting the requirements of an increasingly networked industry, the QI must be modernized. To this end, BAM joined forces with the key players in German QI – the Deutsche Akkreditierungsstelle, Deutsches Institut für Normung, Deutsche Kommission Elektrotechnik Elektronik Informationstechnik and the Physikalisch-Technische Bundesanstalt – to form the QI-Digital initiative in 2021. Supported by the Federal Ministry for Economic Affairs and Energy (BMWE), solutions for the digital transformation of QI are being developed jointly.

“Our goal is to digitalize established structures and processes in the quality infrastructure in order to secure the long-term competitiveness of the German economy,” says Claudia Koch, who coordinates QI-Digital activities at BAM.

Technologies such as integrated sensor networks, digital twins, and artificial intelligence open up many opportunities for QI: More precise testing procedures, real-time monitoring, and predictive maintenance increase transparency, efficiency, and reliability along the entire value chain.

The integration of QI into industrial digital ecosystems enabling the management and secure sharing of data and information is particularly promising. International data spaces and digital administration shells – important building blocks of Industry 4.0 – form the foundation of the digital ecosystem for QI. Based on this, the shared vision is being implemented: Requirements are automatically fed into production and quality assurance processes from machine-readable SMART standards and their conformity is automatically checked. Certificates and other results reports are made available



The quality assurance of the future is being tested at BAM's digitally networked H₂ filling station.

in machine-readable form and shared seamlessly via data spaces along the value chain – an essential contribution to the “digital product passport” as well.

Focus on transfer

Two specific use cases from Industry 4.0 and the energy transition serve as test platforms: Solutions are being developed, tested, and demonstrated at BAM in the “Additive Manufacturing Real-World Laboratory” and at a digitally networked hydrogen filling station. The hydrogen filling station went online in June 2025. A showroom for additive manufacturing has also been making the technology tangible, especially for small and medium-sized enterprises, since October 2024.

In addition to creating the necessary framework conditions, the successful leap into application requires close exchange with stakeholders. In this



context, BAM focuses on targeted accompanying research projects, standardization activities, and dialogue formats.

Parallel to the research and development work, the QI-Digital initiative has also brought companies, industry associations, standardization bodies, and regulatory authorities together over the past four years to identify requirements and develop joint solutions.

In October 2024, 300 interested participants, visitors, and stakeholders gathered at BAM for the QI-Digital Forum. The initiative presented the first smart tools and processes, illustrating how digital innovations in QI can lead to greater transparency, security, and noticeably less bureaucracy for business and administration. “With our activities, we are giving the quality infrastructure the digital update it needs to maintain our prosperity in the digital age,” said Claudia Koch. —

Claudia Koch (l.) coordinates BAM activities at QI-Digital. The additive manufacturing showroom (r.).



History of BAM

Departmental research during the National Socialist era



The main building of the State Materials Testing Office in Berlin-Lichterfelde at the end of the war in 1945.

A research project has investigated the history of BAM's of predecessor institutions during the Nazi era and the immediate post-war period. It became clear how deeply the institutions were involved in the Nazi regime's armament and warfare.

From October 2020 to September 2024, a team of historians investigated the history of the two predecessor institutions of BAM – the Staatliches Materialprüfungsamt (StMPA) and the Chemisch-Technische Reichsanstalt (CTR) – during the Nazi era and the immediate post-war period. The project was commissioned by BAM together with the Federal Ministry for Economic Affairs and Energy (BMWE), to which it is subordinate as a departmental research institution. As part of the overall project, the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and the Physikalisch-Technische Bundesanstalt (PTB), also departmental research institutions of the BMWE, whose origins date back to the 19th century, have also had their history during the Third Reich and the first post-war decade researched.

Internal conformity and the “Führer principle”

For four years, the team of historians, led by Prof. Dr. Carsten Reinhardt (University of Bielefeld) and Prof. Dr. Helmut Maier (University of Wuppertal), evaluated files from BAM and many other archives and traced biographical clues. At the end of their research, it was clear that the StMPA and the CTR,

from which today's BAM emerged after the war, were heavily involved in the rearmament of the Third Reich and supported the waging of the war of aggression with their research.

In 1933, they quickly carried out internal “Gleichschaltung”, and the “Führer principle” was established in both departmental research institutions. Numerous senior employees and civil servants joined the NSDAP or other Nazi party organizations. The Jewish scientists, who were very few in number, were expelled, and there was hardly any resistance to the Nazi dictatorship in either institution.

The StMPA and CTR participated in the establishment of a “self-sufficient military state.” They took on numerous contracts for the army, navy, and air force, often proactively. The StMPA conducted research on fire and air protection, tank tracks, gun barrels, bunkers and fortifications, and night vision devices, among other things. The CTR conducted research on tank armor, rifle bullets, technical gases, incendiary bombs, and explosives, among other things.



MPA employees during the Nazi era (undated photograph).

Forced laborers were employed on the StMPA premises in Berlin-Dahlem from 1942 at the latest. Furthermore, both agencies participated in the occupation regime in occupied Europe through their branch offices.

Denazification and self-narration

In 1945, the CTR was dissolved by decision of the Allies and some departments were merged with the StMPA. The new departmental research institution initiated an internal denazification process. In order to keep the office “operational,” many former party members were able to continue their careers. At BAM’s East German counterpart, the Deutsches Amt für Material- und Warenprüfung (DAMW), founded in 1950, any doubts about Nazi involvement were also overlooked in favor of professional expertise.

The self-narrative developed and cultivated at BAM in the post-war decades did not adequately reflect the full extent of the institution’s involvement in the war economy. It was only through the current research project that this entanglement was comprehensively and systematically examined.

Commitment to democracy and diversity

The results were presented in March 2025 at a public symposium at the Federal Ministry for Economic Affairs and Energy.

BAM President Prof. Ulrich Panne praised the results of the project as an important contribution to the institution’s critical self-assessment. He emphasized: “These findings oblige us today even more to consistently stand up for democracy, diversity, and tolerance as an institution and to actively fulfill our responsibility for an ethically sound research culture.”

The results of the overall project will be published in ten volumes in the course of 2025 and will then be available to all interested parties in digital form. —



Presentation of research results at the Federal Ministry of Economics (l.) and at BAM (r.).

BAM at a glance

1550 Staff

55 Nationalities

42 Trainees

120 PhD students

200 Postdocs

18 Professorships

70 Lectureships

500 Refereed publications

925 Lectures

58 Patents

55 New certified reference materials

176 million € Basic funding

25 million € Third-party funding

4 Research facilities in Berlin/Brandenburg

(Figures for the 2024 calendar year)

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