



Safety
needs diversity

BAM Report
2023/24

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Editorial

Dear readers,

We are living in troubled times, in a “Zeitenwende”, a period of upheaval. For science and its role in shaping a brighter future, the way forward is clear: Our mission is not to explore ways of living with less, but to find intelligent technology-based solutions. By embracing economic growth – in and through diversity. How can we achieve this?

Science only thrives in open, diverse, democratic systems. Populist and authoritarian approaches, by contrast, dramatically limit the space for progressive responses. They block us from envisioning ideas that help us to build a good future for all. This explains why authoritarian regimes are so keen to limit diversity of science once they seize power. We must help to prevent this.

People from over 50 countries work at BAM today, with diverse biographies, affiliations and identities. In our laboratories, workshops and administrative sections, they are delivering pioneering work. Without their commitment, BAM would not be able to pursue its mission – to ensure safety in technology and chemistry. Open-mindedness, diversity, networking and international exchange are our core values at BAM – and the cornerstones of our success.

Together with scientists from Namibia, we are researching safe infrastructures for tomorrow’s hydrogen economy – a collaborative project that creates benefits for both sides. Driven by an international team, a BAM spin-off is

developing a revolutionary welding technology that can help accelerate wind turbine production. In interdisciplinary teams, we are developing reference materials for more powerful electric batteries. Drawing on machine learning and artificial intelligence tools, BAM employees from diverse professional and cultural backgrounds are accelerating the development of new, tailor-made materials. In all these projects, diversity is an integral and indispensable element.

The 2023/24 BAM Report shines a light on these and many other projects at BAM. Our hope is that they will help to multiply ideas on how to shape a safer future together. And spark initiatives that help us to promote diversity, democracy and openness – to everyone’s benefit. Let’s begin the conversation!

Sincerely
Ulrich Panne



President
Bundesanstalt für Materialforschung
und -prüfung (BAM)





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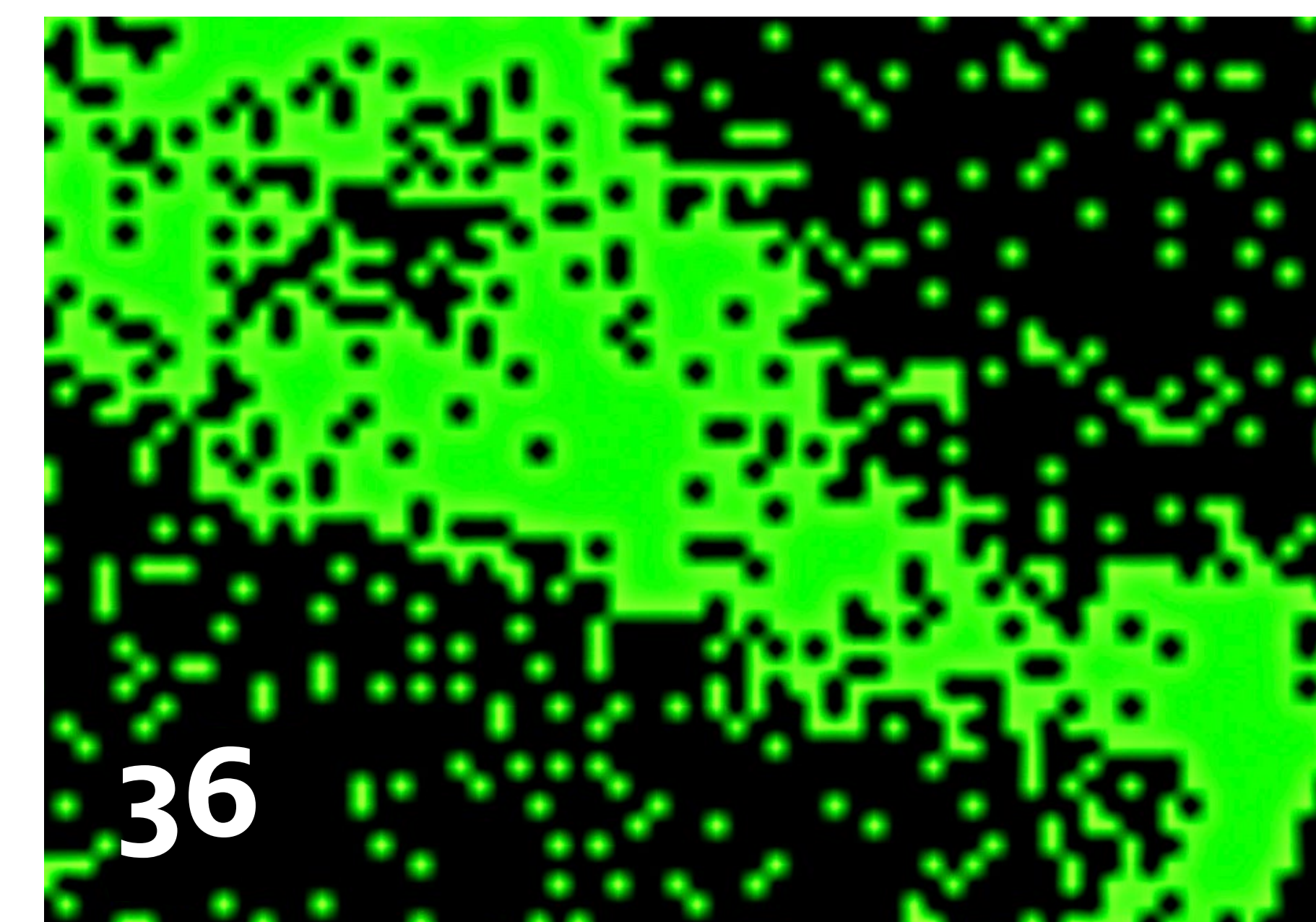
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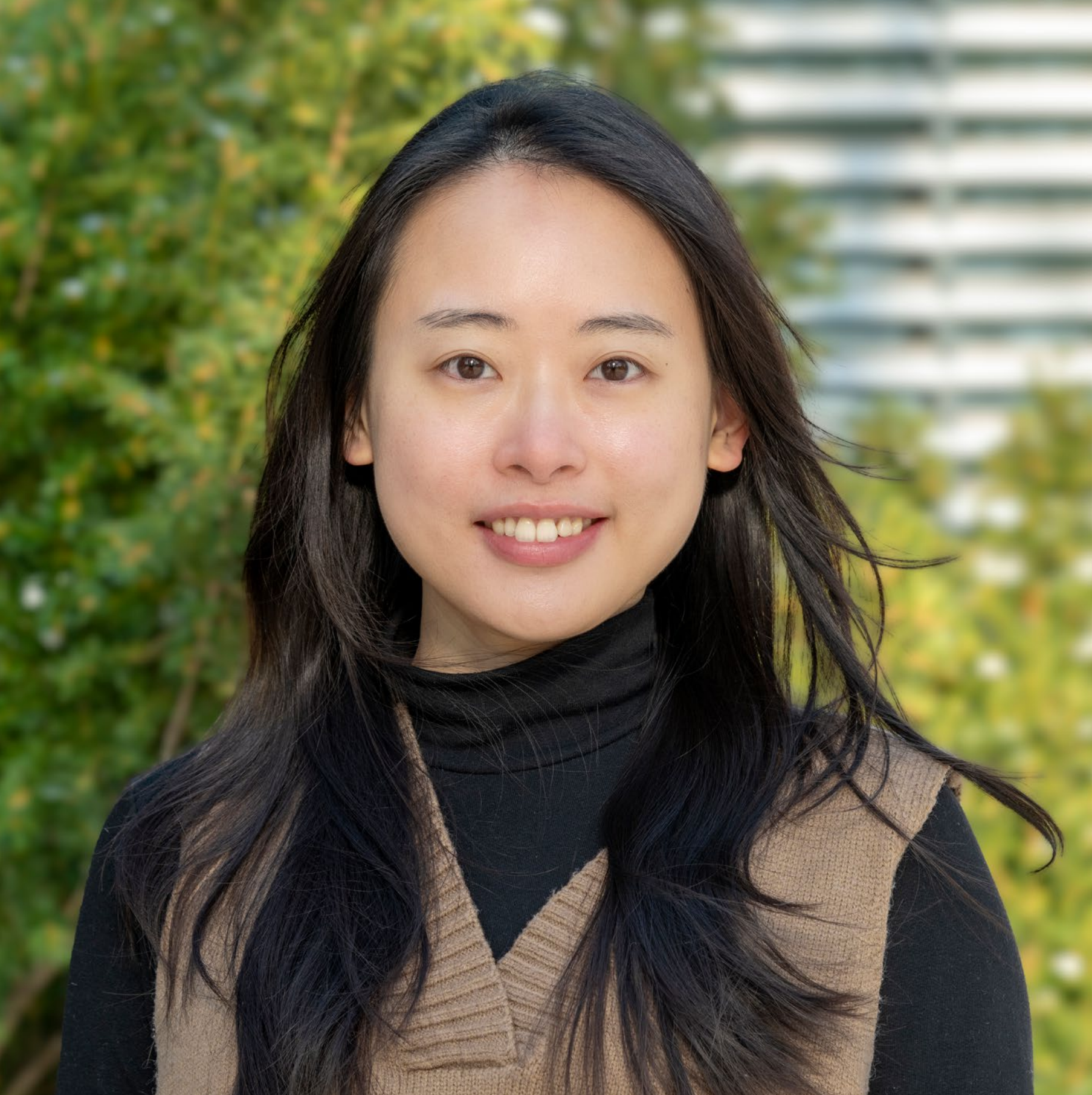
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“Science in diverse teams helps us to leave our comfort zone.”

Shu-Han Wu,
Division Electrochemical Energy Materials



“Cultural diversity enriches not only our work, but also our corporate culture.”

Veli Bingöl,
Head of section Procurement

#Safety needs diversity

Research thrives on diversity and exchange ☑. That’s why people from over 50 countries work at BAM. People with different experiences and biographies. They all enrich our work – regardless of their gender, age, what they believe in or who they love. Without them, we would not be able to fulfill our mission of ensuring safety in technology and chemistry.

#Zusammenland

“Diversity opens up perspectives and leads to more creative results.”

Wiebke Seidel, Personnel development and equal opportunities/
Diversity at BAM



“Diversity enriches our research and strengthens our innovative power.”

Parsa Asna Ashari,
Digitalization of Quality Infrastructure





“Science thrives on networking and the exchange of different perspectives.”

Claudia Eggert, Member of the Presidential Board



“Only together will we (always) get better!”

Reza Darvishi Kamachali, Head of Division Materials Modelling



“Ideas that move us forward need a broad horizon.”

Ulrike Ganesh, Head of Department Non-destructive Testing



“Diversity and inclusion are the foundation of BAM’s scientific excellence.”

Herbert Saul, Representative for Disabled Employees



“Every person has their own dignity and their own value.”


Lucia Casali, Division Structure Analysis



“Successful research means openness to the new.”

Robert Maaß, Head of Department Materials Engineering





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 the five focus areas of Energy, Infrastructure, Environment, Materials, and Chemistry and Process Engineering.

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

Energy

Hydrogen partnership with Namibia



Namibia has almost unique conditions for the production and export of green hydrogen. BAM is working closely with the country to promote research and the training of young scientists.

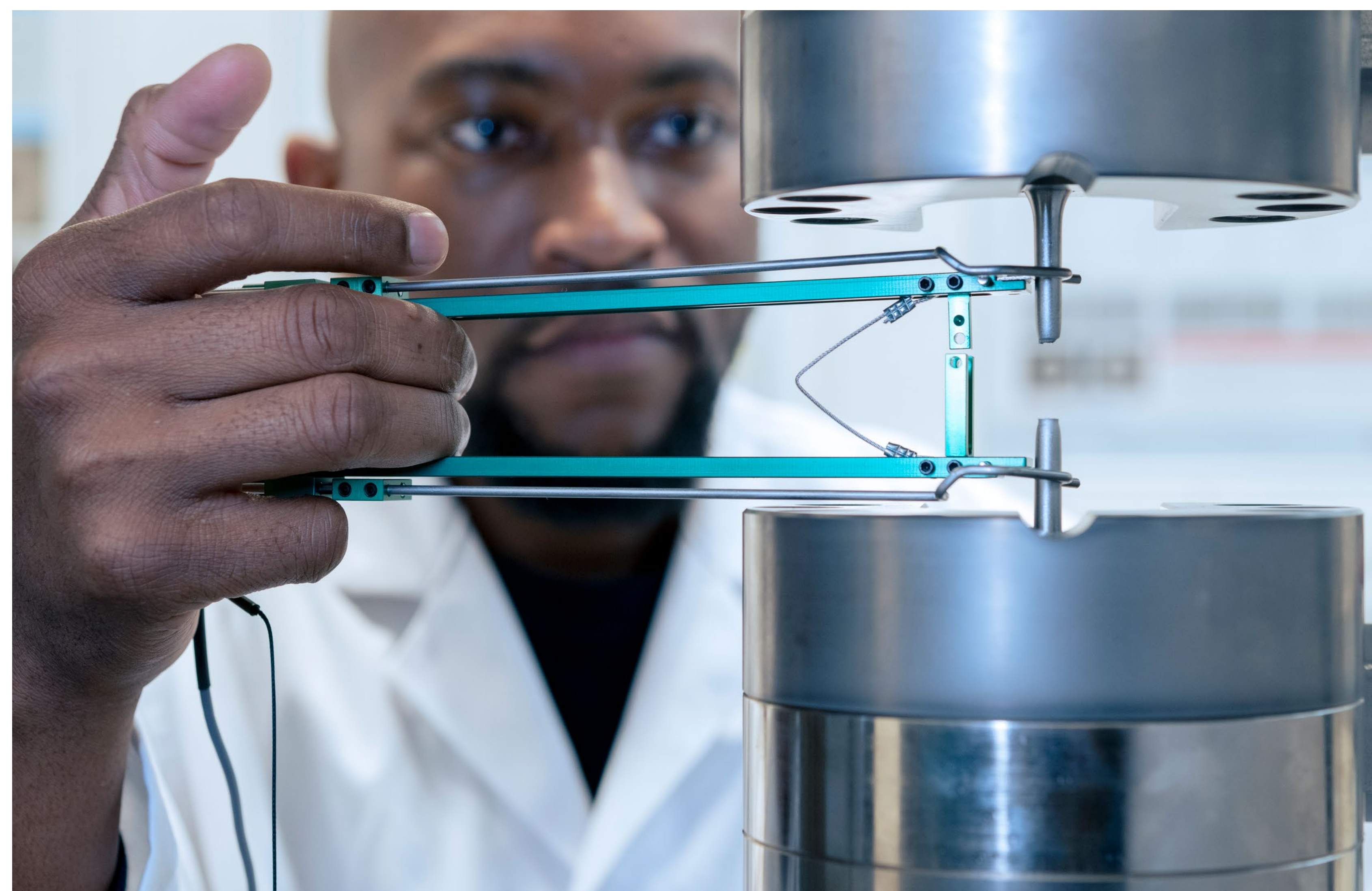
Namibia has set itself the goal of becoming one of the world's leading producers of this climate-neutral energy source. A key project for this is a state-of-the-art 5-megawatt pilot plant for the electrolysis of green hydrogen, which is to be commissioned in 2024 and produce up to 200 tons of green hydrogen per year. For Namibia's port, mining and transportation sectors, for road and rail transport and also for export.

Test field for hydrogen production

The pilot plant is not only intended to cover local energy requirements, but is also an important testing ground for hydrogen production and handling as well as for the associated components and infrastructure. It is being built by Cleanergy Solutions Namibia. Cleanergy has invited BAM and its Namibian counterpart, the Namibia Green Hydrogen Institute (NGHRI) of the University of Namibia (UNAM), to actively participate in the **ground-breaking project**. The focus of the cooperation is on investigations into material compatibility, such as that of flexible connection lines, as required for hydrogen operation in rail transport. The knowledge gained will be used to safely and efficiently scale up

the production of hydrogen and its derivatives, such as ammonia. "In order to harness and leverage the opportunities offered by green hydrogen, Namibia needs to build a set of resilient skills capable of converting Namibia's natural resources into a formida

ble vehicle for economic emancipation. Our cooperation with BAM, is anchored in this understanding," says Kenneth Matengu, University of Namibia's Vice Chancellor. The knowledge gained will be used to safely and efficiently scale up the production of



The laboratory is testing which steels are suitable for hydrogen pipelines.



A pilot plant for the production of green hydrogen is being built near Walvis Bay, Namibia.

hydrogen and its derivatives, such as ammonia. Another research project is investigating the material compatibility of flexible connection lines, such as those required for hydrogen operation in rail transport. The projects are funded by the German Federal Ministry of Education and Research (BMBF), which is supporting the Cleanergy pilot plant in Namibia with more than ten million euros.

Exchanging knowledge across continents

BAM is also helping to build up personnel capacities in Namibia and expand the transfer of knowledge. A scientific exchange program has been set up for this purpose: A group of up to ten PhD students from Namibia will be conducting research at

both [BAM's Hydrogen Competence Center](#) and the pilot plant in Walvis Bay over the next few years. Their knowledge will later help to scale up the hydrogen economy in Namibia.

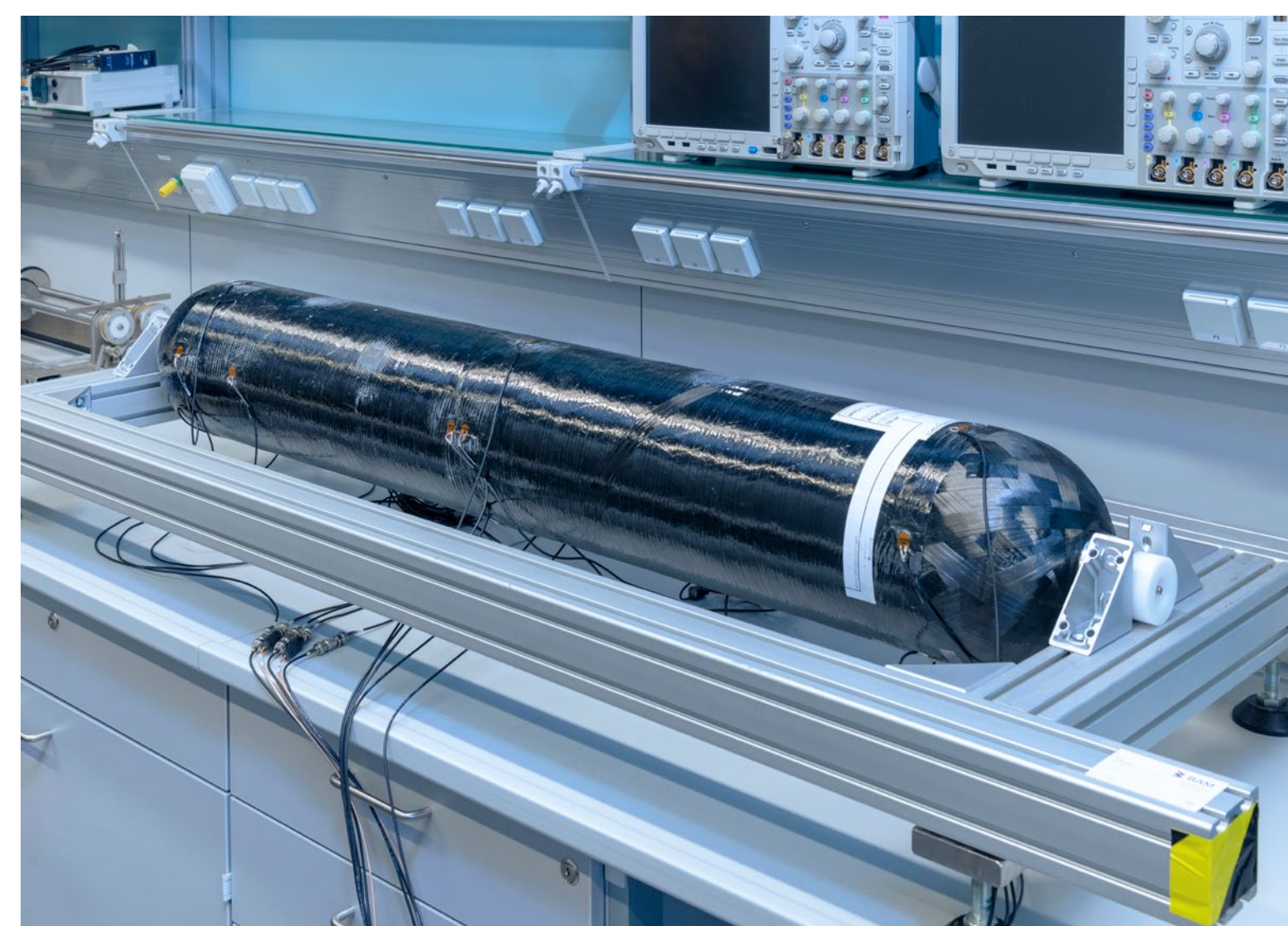
Eike Krafft, Group Manager of Cleanergy Solutions Namibia, explains: "We are using the country's renewable energy resources to produce green hydrogen. In doing so, we are contributing to a climate-neutral future and laying the foundations for the development of a new industry in Namibia. Our collaboration with BAM and UNAM is an essential part of the project. The resulting findings are essential for the efficient and safe expansion of the plant towards the commercial production of hydrogen and ammonia. BAM's scientific exchange

program with UNAM, which trains Namibian doctoral students, also plays a key role. It builds capacities and local expertise that is crucial for the country to implement the projects sustainably."

One of these doctoral students is Sam Shaanika. "Joining BAM, where I am working with a diverse and supportive team, is impressive," says the young scientist. "BAM offers an excellent laboratory environment for researching green hydrogen technologies and looking for smart, cheaper and safer compatible innovative materials and testing methods along the supply chain." –

Smaller CO₂ footprint

In the future, large numbers of pressure vessels for hydrogen will be needed to decarbonize the transport sector and to store and transport the green energy carrier. The storage tanks are made from carbon fiber-reinforced plastics (CFRP). Up to now, the energy-intensive production of each one has released up to two and a half tons of CO₂. BAM is working on a [joint project to significantly improve the CO₂ balance](#). On the one hand, the lightweight material CFRP is to be used more efficiently. So far, the containers have been designed particularly conservatively for safety reasons, i.e. a lot of material has been used. However, studies by BAM indicate that digital process monitoring during production can save up to 20 percent material and even produce safer storage tanks. On the other hand, their service life can be extended: Tests on mechanical and thermal loads show that the storage units can be used for much longer than is usual today. This can also help to save resources: If the storage units were used for ten years longer, for example, this would mean a considerable reduction in their CO₂ footprint – in addition to material savings during production. The project is funded by the Lightweight Construction Technology Transfer Program of the Federal Ministry for Economic Affairs and Climate Action.



Pressure vessels for hydrogen are to become more sustainable and safer.

Cooperation with South Korea

In 2023, BAM further intensified its [cooperation with South Korea in the field of modern hydrogen technologies](#). The focus is on ensuring the safety of hydrogen infrastructures, establishing a quality infrastructure and developing norms and standards to accelerate the market ramp-up of hydrogen. On the South Korean side, the Korea Gas Safety Corporation (KGS), Hoseo University in Cheonan and H₂KOREA, an organization that advises the South Korean government on hydrogen-related issues, are involved in the cooperation. In November 2023,

a BAM research office was officially opened at the KGS headquarters. The intensified cooperation is intended to enable the regular exchange of scientists through workshops and conferences and the expansion of a German-South Korean network, as well as to accelerate the implementation of research projects. The cooperation covers the entire hydrogen value chain, from safe production, storage, transportation to usage of hydrogen. BAM will also provide advice on the development of hydrogen pilot cities in South Korea.

Hydrogen storage tank with forty times the capacity

Liquid hydrogen is transported and stored at -253°C . Due to the extremely cold temperature, thermal insulation is particularly important. Previous storage tanks are spherical and have a double wall. The largest storage facility to date has a capacity of 5 000 cubic meters and took three years to build. In the future, however, storage facilities with a capacity of up to 200 000 cubic meters will be needed. BAM is therefore researching new insulation concepts for liquid hydrogen storage tanks [in the EU-funded NICOLHy project](#). For the first time, the principle of VIP thermal insulation (VIP = Vacuum Insulation Panel) is being tested for hydrogen storage. This could significantly speed up production, increase the quality and reduce costs at the same time. In addition, the tanks can be built prismatically, which would drastically increase their capacity compared to previous storage systems. “Overall, the capacity can be increased by a factor of 40 and the manufacturing costs reduced by 80 percent,” says Robert Eberwein, expert for tanks for dangerous goods and accident mechanics at BAM, who is coordinating the EU project. In addition to BAM, the consortium includes the University of Bologna, the German Aerospace Center, the Norwegian University of Science and Technology and the National Technical University of Athens.

Energy

Making batteries safer

Testing how damaged batteries
can be transported more safely
through deep-freezing.

Anita Schmidt is head of BAM's battery test center. In this interview, the hazardous goods expert explains which technologies can be used to make batteries even safer without compromising on performance.

At BAM's Battery Test Center [📍](#), the focus is on the state of safety of rechargeable batteries. What current developments are there to make batteries even more reliable?

Our work focuses on safety against fires or dangerous reactions of damaged lithium batteries, the "thermal runaway". Research investigates the different levels: at the materials level the battery components can be made safer, e.g. the electrolyte. Some solid-state electrolytes are advantageous, as they are non-flammable and particularly chemically stable. At the cell level, protection systems are being optimized – for example against overpressure. Electronic battery management systems that use sensors to monitor the entire lithium battery seem particularly promising. In an emergency, they initiate cooling systems or shut down the battery.

What projects are currently underway at BAM?

At our battery test center, we are developing innovative diagnostic and sensor systems that indicate the risk of thermal runaway as early as possible. To do this, we measure the internal resistance of a cell. We are also investigating how critically damaged batteries can still be transported safely, e.g. with the

help of deep-freezing. And we are carrying out investigations into the ageing of batteries and developing models that can be used to predict their safety status.

A new battery regulation has been in force in the EU since February 2024. What are the consequences?

One new requirement is that batteries for e-bikes or e-scooters must be replaceable. This is not trivial in terms of safety, as lithium batteries can differ significantly in their properties. It can therefore be problematic if the "wrong" cells are installed or safety-relevant parts are damaged during replacement. We are also conducting research into this at BAM.



Anita Schmidt advises the German government and the United Nations on battery safety.

The new digital battery passport, which will be mandatory for all larger batteries with a capacity of over two kilowatt hours, e.g. for batteries in electric cars, from 2027, is also important. It enables the traceability of a battery over its entire life cycle and facilitates later second-life applications, for example as intermediate storage for wind or solar power.

Compositional retraceability is a key focus at BAM's battery test center. What does this mean?

Depending on the type, lithium batteries sometimes differ greatly in their chemical composition and design – and therefore also in their safety behavior. It is therefore necessary to know the ingredients, morphology and structure of a cell in detail. We investigate all of this in an interdisciplinary approach using a variety of analytical methods. The results also contribute to the development of new cell types.

In 2023, fires on large container ships transporting electric cars made the headlines. How can such incidents be avoided in the future and what contribution is BAM making?

The United Nations (UN) is currently developing a system to classify lithium batteries according to their hazardousness. This will result in specifications for safe transportation. BAM represents the Federal Republic of Germany and contributes its many years of expertise in this field. Our investigations show, for example, that thermal runaway can usually no longer be triggered in batteries with a state of charge of less than 20 percent. A heat-dissi-

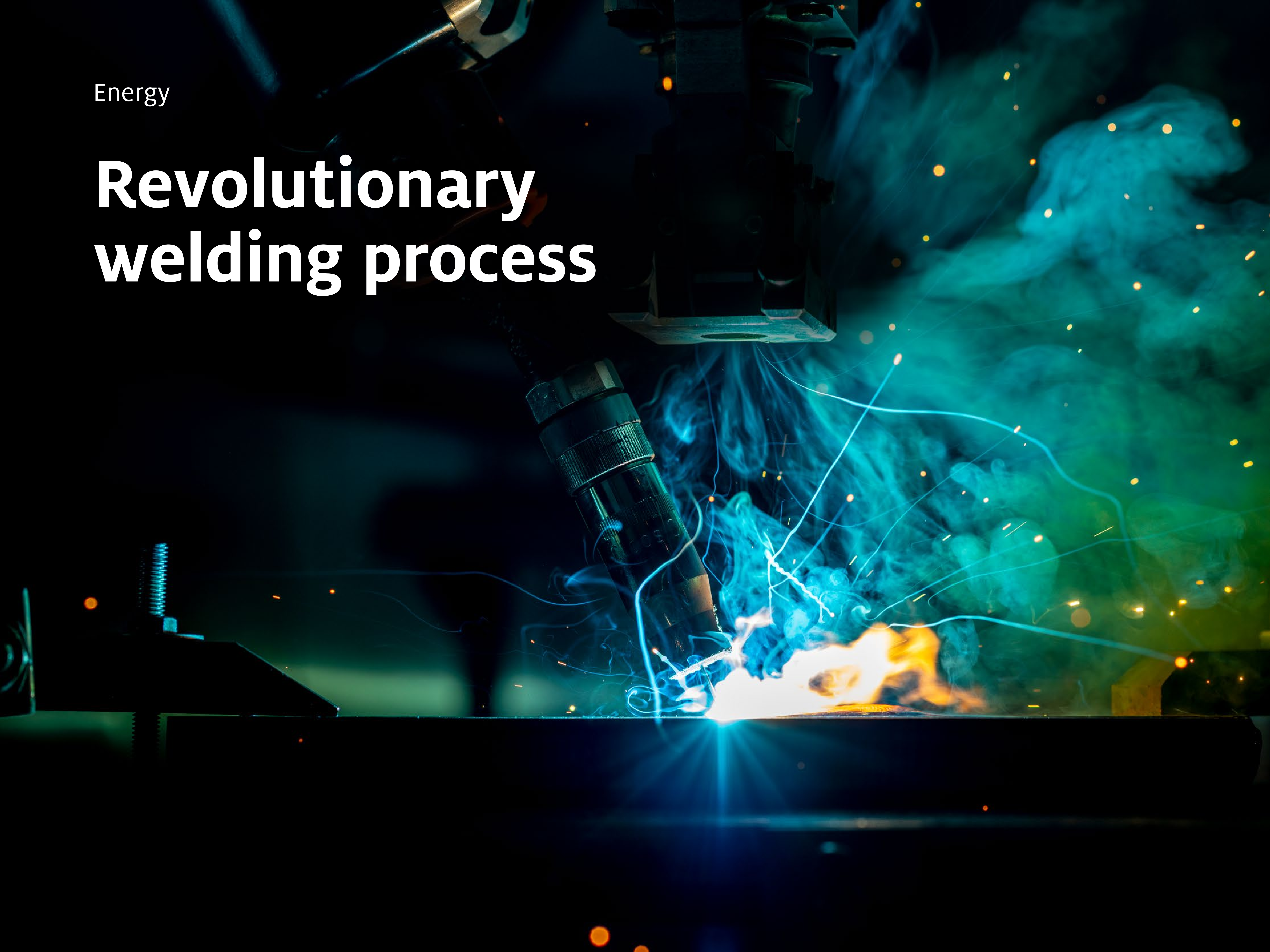
pating battery housing can also prevent the entire battery from catching fire. An appropriate solution could make the transportation of new cars safer, for example. At the same time, we are in discussions with the international shipping associations in order to achieve better safety precautions for transportation at sea. All of this can help to significantly reduce the risk of fires. –



At its battery test center, BAM is researching whether cooling stops the thermal runaway of batteries.

Energy

Revolutionary welding process



The BAM start-up WeldNova GmbH wants to speed up the welding of wind towers by a factor of eight. The technology could secure decisive competitive advantages for the German wind industry.

Modern wind towers consist of hundreds of individual parts. Steel sheets up to 120 millimetres thick have to be joined together in several layers during production using the so-called submerged arc welding process. Welding a single tower takes almost 100 hours. This alone limits the capacity of German production sites to around 520 steel towers per year – just over half of the German government’s expansion targets on land. Additional systems are currently mainly purchased from China, where production is particularly cheap due to low labor costs.

Acceleration through laser hybrid welding

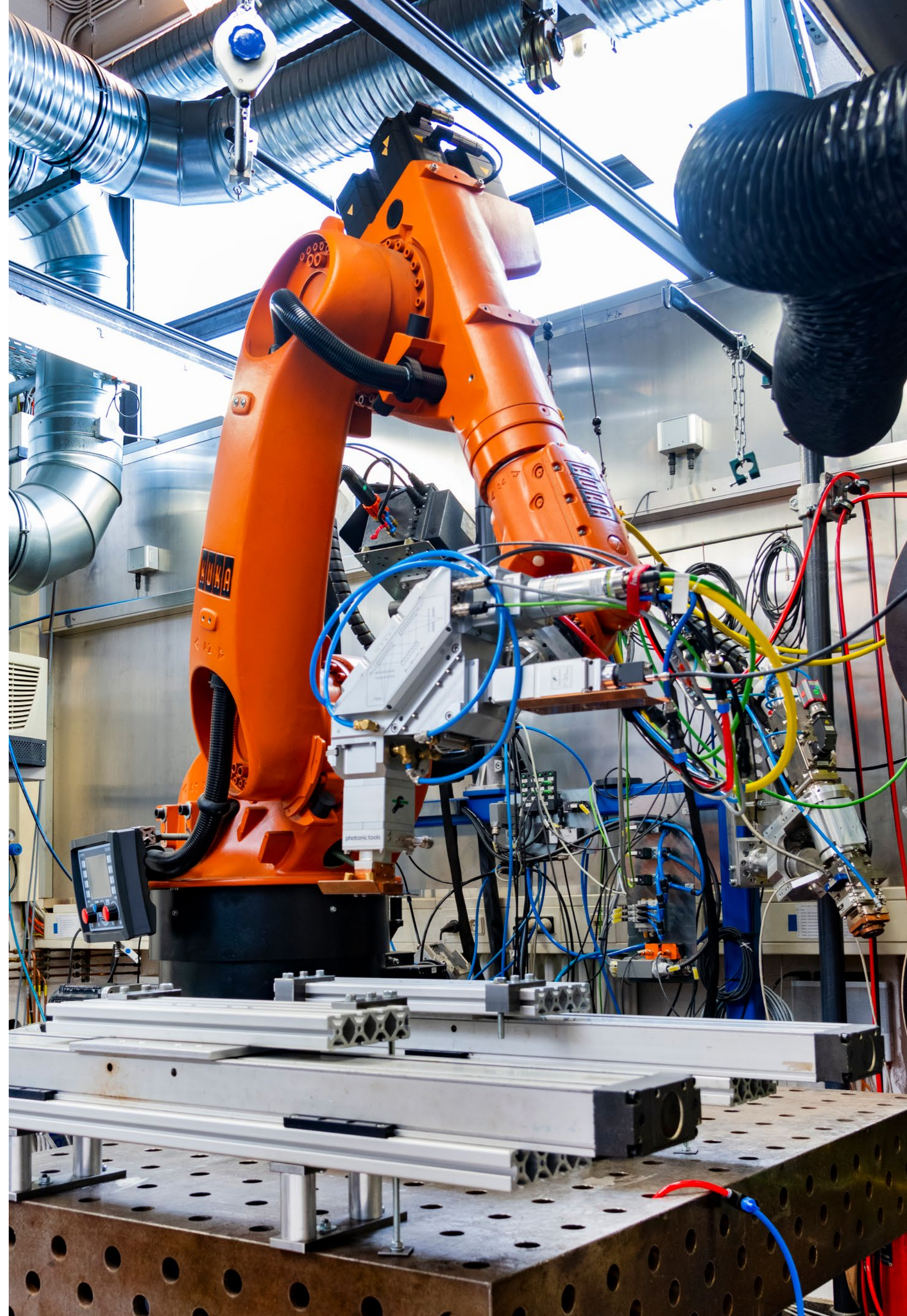
The systems could be manufactured much faster – and at the same time more cost-effectively – using the laser hybrid welding process, which only requires a single welding layer. So far, however, this process has only been approved in the industrial sector for sheet metal with a maximum thickness of twelve millimetres. When welding thicker sheets, gravity causes droplets to form underneath the weld seam. They jeopardize the stability of the system and would therefore require costly reworking.



Fatma Akyel from the WELDNAVA team checks the laser head.

The **start-up WeldNova GmbH** from BAM’s **Wind Competence Center** has found a smart solution to this long-known problem: The team of four scientists has developed a system of electromagnets that is closely positioned to the welding zone. The

magnets release a so-called Lorentz force, which counteracts gravity and “supports” the molten liquid. This prevents droplets from forming at the weld root. This innovation makes it possible for the first time to use the significantly faster laser



BAM's 60-kilowatt laser is unique in Europe.

hybrid welding process without compromising on safety, even for the thick steel sheets used in wind turbines.

The invention is to be transformed into a **market-ready system for industry** by 2025. The team of developers is supported by the EXIST funding program of the Federal Ministry of Economics and Climate Action (BMWK). At the same time, the team can continue to use BAM's excellent research infrastructure, which includes a 60-kilowatt high-performance welding laser that is unique in Europe.

Enormous savings potential in terms of time and costs

According to Christian Brunner-Schwer, Managing Director of WeldNova, time and cost savings

would be enormous with a modern 120-meter wind tower: welding time could be reduced from 96 to just under twelve hours – an acceleration by a factor of eight. At the same time, only 900 instead of 4 000 kilowatt hours of energy would be required. The costs for welding could be reduced by 90 percent overall. CO₂ emissions during the production of a wind tower would even be reduced by 93 percent.

“Experts from the wind industry are already confirming that our system could become a game changer,” says Fatma Akyel, who is responsible for research and development in the team. “Steel wind towers are just one field of application for our innovation. It is interesting wherever thick-walled steel sheets are joined together: in the construction of hydrogen pipelines, containers for liquid gas or chemicals, in ship and bridge building.” –

“ **Experts from the wind industry are confirming that our system could become a game changer.** ”



The WeldNova team plans to launch its innovation in 2025.

New alloys for wind towers

To make offshore wind turbines even more efficient, they need to be equipped with longer rotor blades. At the same time, the towers are growing in height. Tackling the economic and technical challenges involved in building such gigantic turbines is impossible without switching to lightweight construction methods using modern high-strength steels. This would also allow up to 20 percent of the steel to be saved. Until now, the weld seams were considered to be the weak point. Wind turbines at sea are exposed to enormous loads from wind and waves, which subject the material to oscillating, i.e. cyclically changing, stresses. However, the fatigue strength of modern high-strength steels in particular is impaired by the welding process. In a collaborative project, BAM is testing special alloys that are intended to strengthen the weld seams. The aim is to enable the industry to process these special welding consumables safely. At the same time, the findings are to be incorporated into the relevant regulations so that they can be adapted. The project, in which the Fraunhofer Institute for Mechanics of Materials (IWM) and the Research Association of the German Welding Society (DVS) are also involved, is being funded by the Federal Ministry for Economic Affairs and Climate Action as part of a program to promote joint industrial research (IGF).



Construction of the seawater laboratory directly on the North Sea.

Better offshore corrosion protection

In 2023, BAM and the Elbe-North Sea Waterways and Shipping Authority set up an innovative seawater laboratory at the Eider barrage near Tönning. In the laboratory, corrosion protection on offshore foundation structures can be tested under real conditions. This allows protective measures to be designed in a more targeted manner and the planned service life of wind turbines to be safely achieved. One focus is on the transition area from seawater to sediment, because particularly heterogeneous conditions prevail here, meaning that the success of a protection system cannot be predicted to date. The laboratory will also conduct research into the interaction between marine fouling in the underwater area and cathodic corrosion protection. For this purpose, the corrosion laboratory has been equipped with a specially designed circulation system for seawater. Exploration tools are also being developed for more accurate description of the corrosiveness of the sediments on the seafloor. In the future, this should make it possible to avoid highly corrosive areas for the foundations of offshore structures or to adapt corrosion protection to environmental conditions.

Greater energy yield

In a feasibility study, BAM and the Marburg-based start-up LATODA have successfully tested [a new inspection method for wind turbines](#). This involves using an infrared camera to visualize erosion damage on rotor blades. This damage causes turbulence in the air flow and is responsible for performance losses. The turbulence is made visible using thermograms. It only takes around ten minutes to produce the images. Compared to conventional inspections with industrial climbers,

which can take up to three days, this alone represents a significant increase in efficiency. The thermograms are then analyzed using complex image processing and AI algorithms. Automated data evaluation allows damage to be detected and rectified at an early stage before more costly repairs are required. Maintenance can also be carried out in a more targeted manner. Overall, the performance of wind turbines can be increased by up to two percent on an annual average.

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

Infrastructure

Time machine for road safety



Joints are considered to be the most vulnerable point on highly stressed federal highways and motorways. A new research test facility at BAM is designed to minimize the maintenance costs of roads and increase their safety and durability.

Joints cross the concrete slabs of motorways and trunk roads every five meters. They are intended to compensate deformations resulting from fluctuations in temperature and humidity as well as subsidence of the subsoil and thus prevent cracks in the road surface. However, this essential construction element is easily vulnerable. While the concrete for road surfaces has been continuously developed over the last few decades and designed for ever greater loads, the joints have simply been forgotten. “If damage occurs to this inconspicuous component, the entire road system suffers,” explains Christoph Recknagel from **BAM’s Road Construction and Sealing Technology department** [↗](#): As a result, many trunk roads often have to be repaired after a short time or maintained at high cost and traffic flow suffers.

Current regulations are outdated

The legal regulations on joint materials are based on technical assumptions, some of which date back to the 1950s and which in turn are only based on isolated empirical observations. The actual performance of the joint construction and materials is not recorded in this approval methodology. “As a

result, this leads to joint systems with completely inadequate function – especially in terms of durability,” says Christoph Recknagel.

His team wants to bring about a “paradigm shift” and push for an assessment methodology that focuses on actual performance. To this end, they have designed an innovative test facility on behalf of the

Federal Highway Research Institute that has been constructed with the help of the BAM test facility construction department. The container-like and accessible facility, which development, manufacturing and special configuration was supported by a special program launched by the Federal Ministry of Transport, has since been patented. It makes it possible for the first time to test the actual service



The climate in the “time machine” can be observed from the control room.

behavior and thus the long-term performance of complete joint constructions under real conditions.

A wheel is suspended from each of two test modules, which can roll in real time over a realistic concrete road section with a joint construction. Mechanical loads are also simulated in several axes and at varying speeds.

At the same time, the complex test facility is a climate chamber and time machine in which an entire year is condensed into one week. This allows the slow temperature transition between spring, summer, fall and winter to be simulated (the scale ranges from minus 30 to plus 60 degrees Celsius), as well as the sudden drop in temperature during a thunderstorm in summer. The joints are exposed to a whole year's worth of precipitation, from drizzle to heavy rain. UV lamps replace solar radiation.

Avoiding damage with innovative joint systems

“With our measurement technology, we can observe the actual mechanical behavior of a joint material in use as well as its movements and changes,” explains Janine Buchheim from the team. “This makes it possible to specifically adapt innovative joint materials in optimized designs to changing stresses, for example as a result of climate change, or to reduce noise emissions.”

The road structure can thus be protected better and longer by more efficient joints. Road safety, driving comfort and noise protection increase. At the same time, the time and costs involved in

maintaining highly stressed concrete road surfaces on trunk roads are reduced – and the flow of traffic remains undisturbed. –



Thunderstorms can be simulated, as can heavy rain and a sudden cold snap in summer.



Infrastructure

Lightweight granules from construction waste



Lightweight concretes can make a significant contribution to CO₂ savings in the construction sector. It has now been proven that construction and demolition waste is also suitable for the required lightweight granules.

The use of lightweight concretes in the construction sector offers several ecological and economic advantages: They provide excellent insulation and minimize heat or cold loss through walls, floors and ceilings, often making additional insulation superfluous. This improves the energy efficiency of buildings. The low weight of lightweight concretes also enables energy and CO₂ savings during transportation and facilitates processing on a construction site.

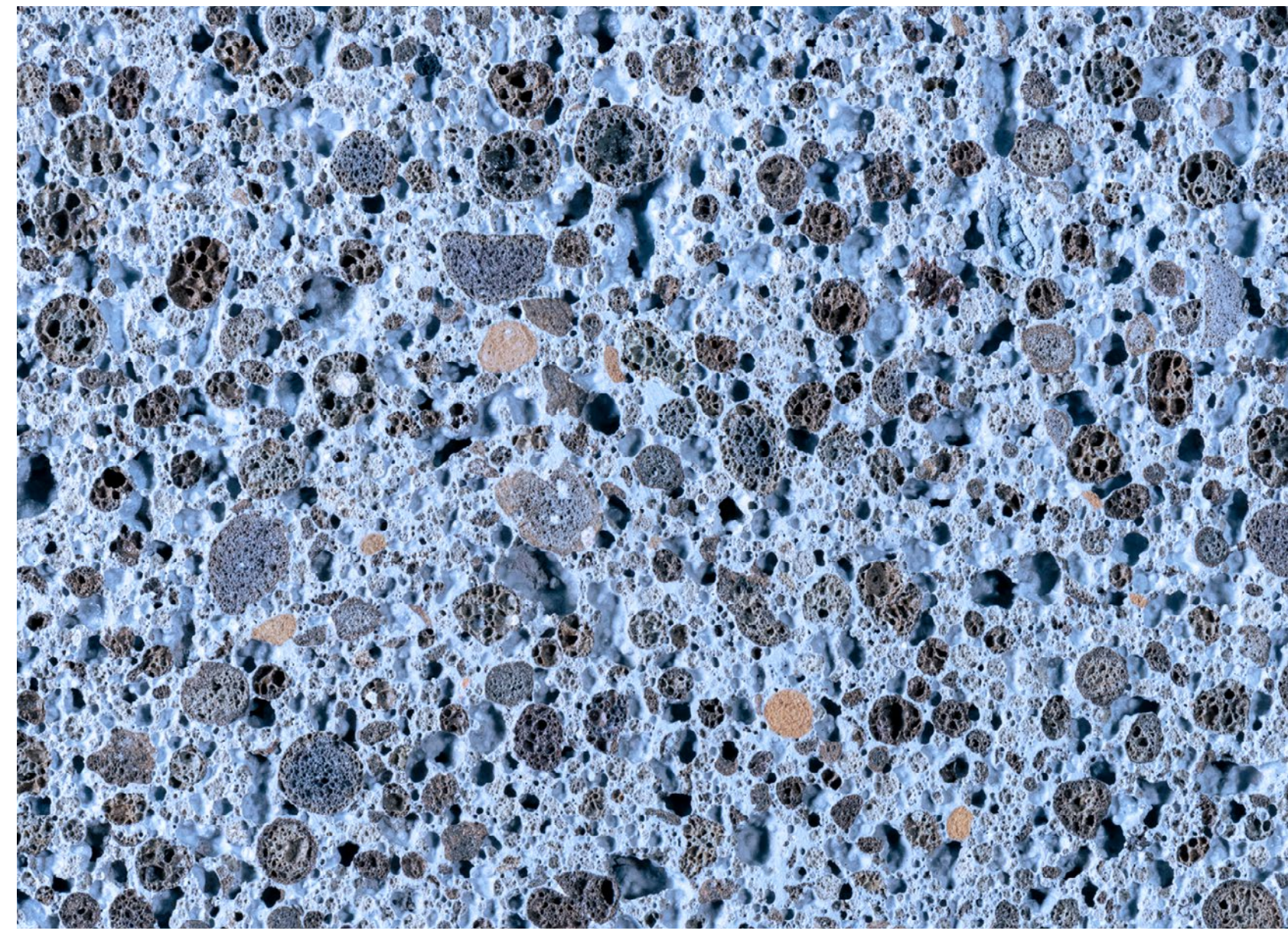
So-called lightweight aggregates are added to concretes and mortars in order to obtain lightweight building materials. These are volcanic rocks such as pumice, tuff or perlite – or expanded clay, which is obtained by heating and thus expanding natural clay. However, the resources of volcanic rocks and types of clay that are suitable for the production of lightweight aggregates are finite. Clay is also urgently needed in the brick and cement industry.

Construction waste as a substitute?

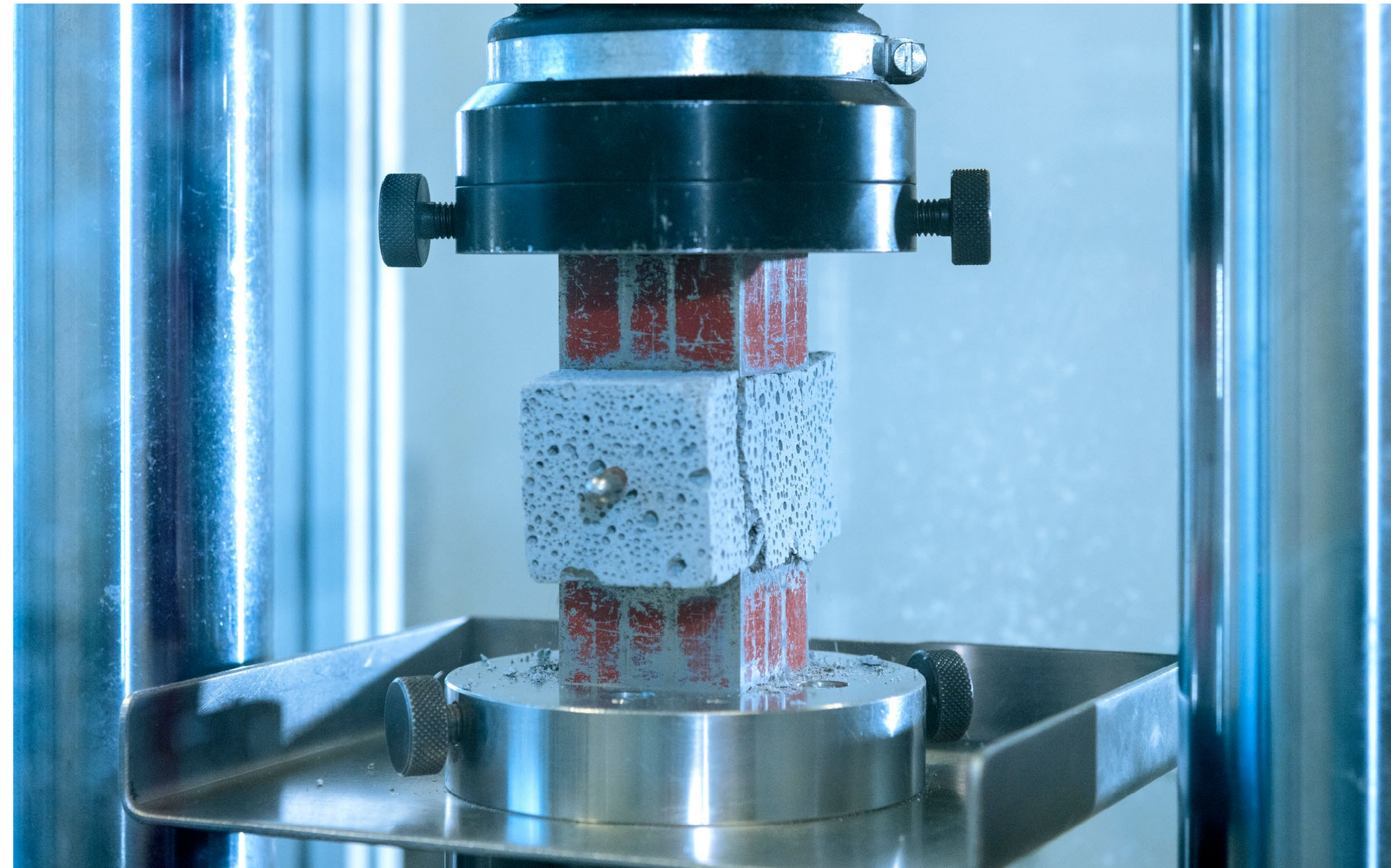
In principle, aggregates can also be produced from mineral construction and demolition waste – and around 900 million tons of this waste is produced annually in the European Union alone. However, there is currently a lack of suitable recycling options, particularly for fine-grained masonry rubble. The waste is often used as filling material for road construction or simply disposed of in landfill sites. In principle, however, it could be used to produce fully-fledged aggregates for lightweight concretes; experts refer to this as lightweight granule. However, this has not yet been attempted due to various technical challenges. “In most cases, the waste has a very heterogeneous composition or is contaminated with components such as sulphates,” explains Katrin Rübner, an expert in waste recycling at BAM. “It must also be proven that lightweight granules have the same properties as expanded clay.” And a process had to be found for the thermal expansion, the “blowing up” of the residual materials.



The granulate is processed into lightweight concrete in the intensive mixer.



The new lightweight concrete is tested for strength.



Breakthrough at new pilot plant

In the [joint project REALight](#) with BAM and other partners, funded by the Federal Ministry of Education and Research as part of the “Resource-efficient circular economy – construction and mineral material cycles (ReMin)” program, the Weimar Institute of Applied Construction Research (IAB) initially successfully developed a pilot plant for the production of lightweight granules from mixed construction and demolition waste. “We extensively tested the lightweight granules obtained with the plant in the BAM concrete laboratory for their constancy of performance and also tested whether they pose any risks to health or the environment,” says Katrin Rübner.

In the next step, the BAM team also tested lightweight concretes, infra-lightweight concretes and

mortars, which they had produced using the lightweight granules, in accordance with the prescribed German and European standards: The focus was on mechanical properties such as strength and durability.

The result: The lightweight granulates produced from construction waste in the project are fully competitive with conventional expanded clays. They can be used without hesitation for the production of lightweight concrete, infra-lightweight concrete and lightweight mortars.

Together with the Bauhaus University Weimar, the IAB Weimar and the other project partners, BAM has thus created an important prerequisite for the desired technology transfer of a new, sustainable construction product. —

Paving the way for climate-friendly earth masonry

It has long been known that earth is a particularly sustainable building material. Unlike conventional bricks or cement, earth blocks are not fired but dried. Their production therefore requires up to 85 percent less energy and has a good CO₂ balance. However, earth masonry is rarely used. “This is mainly due to current regulations, which are very restrictive,” says Philipp Wiehle, BAM expert for building materials. “Earth blocks may only be used in buildings with a maximum of two storeys. In addition, a wall thickness of at least 36.5 centimeters is required – more than twice as much as usual. This makes the use of earth masonry expensive and unattractive. The regulations do not reflect the performance and load-bearing capacity of modern earth building materials and unnecessarily hinder their use.” In a project funded by the German Federal Environmental Foundation, Philipp Wiehle investigated the mechanical properties and, in particular, the load-bearing capacity of earth blocks. The result: the strength of earth masonry is in the same range as masonry made from autoclaved aerated concrete blocks. The investigations were incorporated into a new DIN standard in 2023. Earth masonry is now applicable for buildings with up to five storeys and, for the first time, the DIN standard provides planning offices with a reliable source that precisely specifies how it can be used technically. At the same time, it makes it easier for the industry to bring climate-neutral earth products to market.



The triangular “paving stones” can be used to create solid surfaces.

Lunar roads from the 3D printer

A joint study funded by the European Space Agency, BAM, Clausthal University of Technology and Aalen University in 2023 has shown that the construction of roads and landing sites for future lunar bases using 3D printing would be possible in principle. The dust on the Earth’s satellite could be used for this. Swirling lunar dust actually poses a challenge for lunar missions, as it damages machinery and equipment. Permanent lunar bases are therefore dependent on fixed infrastructures to minimize the dust problem. At the same time, the fine substance can be used for 3D printing. The researchers experimented with laser beams of different strengths and spot sizes of up to 100 millimeters in diameter to transform a mate-

rial similar to moon dust into a robust building material in a single operation directly in the powder bed. The interdisciplinary team ultimately developed triangular “paving stones” that interlock perfectly and form a solid surface. On the moon, the laser, which would be too heavy to transport into space, could be replaced by a highly refractive lens based on foil. It is able to focus the sunlight in such a way that it replaces the intensity of the laser. “Our results show the great potential of additive manufacturing. They bring us a significant step closer to building a reliable infrastructure on the moon,” says Jens Günster, project coordinator and head of the Multimaterial Manufacturing Processes department at BAM.

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

Environment

New life for used LED



LED contain valuable raw materials that have hardly been recycled to date. A new reference material from BAM aims to driving forward the circular economy in this area.

Millions of tons of electronic waste are generated worldwide every year, including precious metals such as gold and platinum, rare earths such as neodymium and the metal gallium. Many of these are technology-critical elements (TCEs), which are found in high-tech applications and whose deposits are mostly located outside Europe. A particularly large number of TCEs are used in light-emitting diodes (LEDs).

Recycling limited so far

In 2020, the European Union made the recycling of TCEs a particular priority in its circular economy strategy. “However, the problem lies in accurately measuring the content of TCEs in waste. This in turn limits the ability of small and medium-sized companies in particular to develop and carry out cost-effective recycling,” says Jochen Vogl, inorganic trace analyst at BAM. “They simply lack the ability to assess how much neodymium is contained in a particular batch of waste, for example, in order to decide whether recycling would be profitable.”

Together with his colleague Marcus Oelze, Vogl is conducting research in [the EU project “Metro-CycleEU”](#), which has set itself the goal of developing a reference material for certified values for up to 14 TCEs. The aim is to enable SMEs to calibrate their analysis methods and measuring devices in the future in order to increase circularity in this area and develop new recycling routes. Metrological institutes and non-university research institutions from a total of eleven countries are involved.

Within this project, the two BAM scientists have for the first time developed a reference material for LED waste, which will be available via the [BAM webshop](#). LEDs are used in countless applications today: Not only in lamps, but also in smartphones, screens and car headlights. Due to their energy efficiency, demand for them is increasing



The coarsely crushed LED material is cooled and then finely ground.

rapidly – which will lead to high waste streams in the future. However, LEDs and their electronics contain valuable raw materials such as gold, silver, lithium, cobalt, nickel, lanthanum and gallium. The latter is used in the production of semiconductors, but is rarely found in Europe. This is why over 70 percent of it is currently imported from China.

Down to a millionth of a gram

So far, there are hardly any established recycling routes for LEDs. The recycling rate for gallium, for example, is less than one percent. The reason: “Many of these raw materials are densely packed in LEDs and their chips within a complicated matrix of plastics, ceramics, glass and metal. The amount of TCEs within LED is just a few milligrams, which are difficult to extract – that’s what makes recycling so complicated,” explains Marcus Oelze. To acquire a LED reference material candidate, researchers at BAM employed a method involving LED scrap obtained from various sources. The process began by cooling coarsely pre-shredded LED scrap with liquid nitrogen, followed by grinding it into small particles. Subsequently, the resulting powder was melted with sodium peroxide, and the resulting mixture was subjected to analysis using a mass spectrometer.

The result is a reference material with the exact values for several TCEs: gallium, gold, silver, lithium, cobalt, nickel, lanthanum and neodymium – in some cases accurate to a millionth of a gram. With the new reference material, small and me

dium-sized recycling companies can now validate their analytics and calibrate their measuring devices. “At first glance, the differences may seem marginal,” says Jochen Vogl. “But scaled up to the expected waste volumes, they make a difference. They can determine whether or not it is worthwhile for a company to recycle LED scrap.” –



The reference material developed by Marcus Oelze (l.) and Jochen Vogl (r.) contains more than ten valuable raw materials.





Green facades can cool cities in times of climate change.

Microplastics in the marine ecosystem

Millions of tons of microplastics are floating in the world's oceans. But what exactly are the interactions between the ecosystem and the tiny foreign bodies? And are microorganisms possibly able to break down the plastic? [Sonja Oberbeckmann, an expert in material-microbiome interactions at BAM](#), is researching these questions. She and her team have discovered that plastic in aquatic environments is colonized by a variety of bacteria, algae and fungi. "For the most part, this type of colonization is called opportunistic," says Oberbeckmann. "The plastic itself plays no particular role for the microbes. They just use it as a kind of habitat." The researchers did not detect any biodegradation of plastic by the microbes. The long carbon chains of the material with their complex synthetic structure are simply difficult for the microorganisms to digest. The best strategy to reduce the amount of plastic in the sea is therefore to reduce the amount entering the environment. Nevertheless, the biofilms that form on plastic are an exciting subject of research. Some microorganisms develop strategies to protect themselves against the high-energy UV radiation on the sea surface, where a large proportion of plastic particles float. These microorganisms produce a wide range of photoreactive molecules, some of them even providing the ability to utilize the energy from sunlight. "We may discover molecules in the plastic biofilms to be used in sunscreen or that show us new ways of generating energy from sunlight," says Sonja Oberbeckmann.

Better urban climate through algae biofilms

The greening of façade surfaces is a promising approach to counteracting air pollution. It could bind pollutants such as nitrogen oxides and particulate matter whilst simultaneously reducing air temperature and noise pollution. However, green façades have rarely been implemented to date as they are expensive to maintain. Julia von Werder, BAM expert for mineral building materials, is therefore developing [innovative façade elements made of concrete that are covered with algae biofilms all year round](#). Compared to conventional green façades, they require less maintenance and are easier to install. The Berlin-based biotech company Solaga provides mi

croalgae biofilms that bind fine dust and other air pollutants particularly well. BAM optimizes the porosity of the concrete for good colonization and improves the biofilms through the targeted selection of different algae species. Together, concrete façade elements colonized with algae biofilms are being developed that offer an attractive appearance all year round. "Instead of combating unwanted algae growth with biocides, we want to consciously shape the urban habitat and contribute to the reduction of air pollutants and the reduction of inner-city overheating through large-scale biofilms," says Julia von Werder.

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

Materials

Reference data for optimal 3D printing

3D-manufactured metallic materials are made to vibrate by pulses.

A team at BAM has published reference data on additively manufactured materials made of titanium, nickel and stainless steel for the first time. This is a prerequisite for ensuring and improving the quality and safety of components.

Additive manufacturing has made great progress in the production industry in recent years. The ability to create components layer by layer opens up unique design options and material properties. The safe use of materials plays a key role, particularly in industries such as aerospace and medical technology. Defects in components can have serious consequences here.

Precise data on elastic properties

“The special microstructures created by additive manufacturing influence the mechanical, thermal and chemical properties of a component, such as its strength or corrosion resistance,” explains Birgit Skrotzki, materials scientist at BAM. “For example, highly stressed parts of an aircraft turbine can be made particularly strong and resistant.”

In order to better understand the relationship between these microstructures and the material properties, precise data is essential. On the one hand, they form the basis for achieving the desired properties. On the other hand, they enable the continuous improvement of manufacturing processes. Until now, however, there has been a lack of comprehensive data collection.

Significant differences in mechanical properties

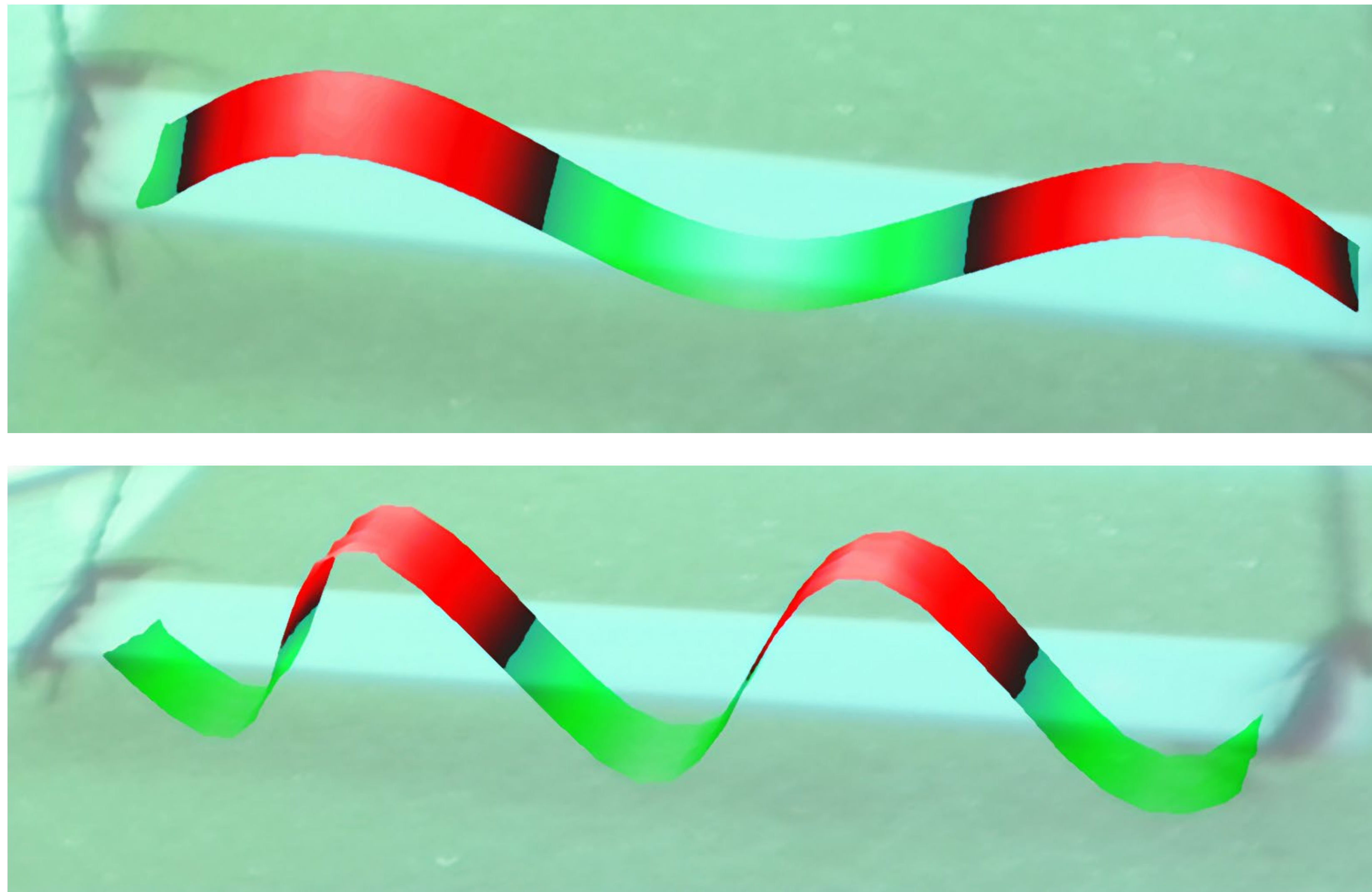
The team led by scientists Birgit Skrotzki and Birgit Rehmer has characterized three metal alloys precisely for the first time using the dynamic resonance method. To do this, they first excited the samples with a periodic mechanical pulse and then measured the resulting resonance frequencies. The investigation revealed that 3D-manufactured components can exhibit very different elastic properties depending on their orientation during printing and the manufacturing parameters.

This has implications for certain applications such as turbine components. The directional dependency can lead to the material being stiffer and more resistant in one direction than in another. This results in uneven stresses and deformations, which in turn can impair the performance and service life of the components. “The parameters of the additive manufacturing process naturally also influence the mechanical properties,” says Birgit Skrotzki. “For example, a thinner powder layer thickness leads to greater elasticity in stainless steel.”

The data sets obtained by the team contain extensive information on various 3D printing processes as well as material and test parameters such as



Birgit Rehmer positions the sample in the measuring apparatus.



The vibration curves provide information about the elastic properties of the material.

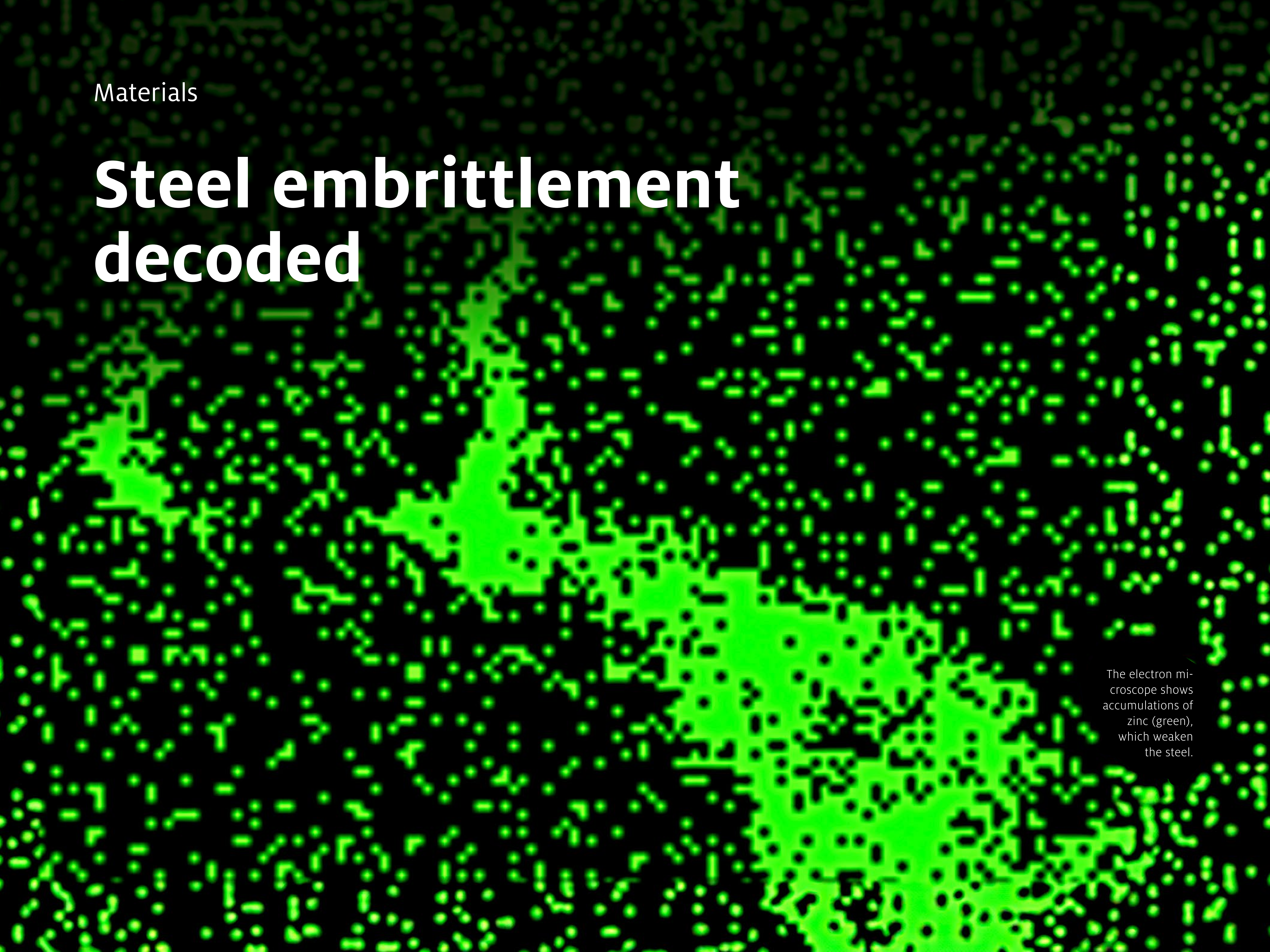
temperature, grain size of the metallic material, specimen dimension and weight and the measurement uncertainties of the results. “They provide test laboratories and designers with a valuable basis for evaluating the performance of additively manufactured materials, carrying out quality tests and improving simulations. They give industry the opportunity to optimize their manufacturing processes and products and to pursue innovative paths in 3D printing,” says Birgit Rehmer.

BAM’s reference data is available via the [Zenodo](#) open data platform. –

“ Our data give industry the opportunity to optimize their manufacturing processes and products and to pursue innovative paths in 3D printing. ”

Materials

Steel embrittlement decoded

The image is a high-resolution electron microscope scan of a steel surface. It displays a complex, interconnected network of bright green and yellow-green spots and lines against a dark background. These bright features represent accumulations of zinc atoms, which are known to cause embrittlement in steel. The pattern is irregular and appears to follow certain structural features of the steel, such as grain boundaries or dislocations.

The electron microscope shows accumulations of zinc (green), which weaken the steel.

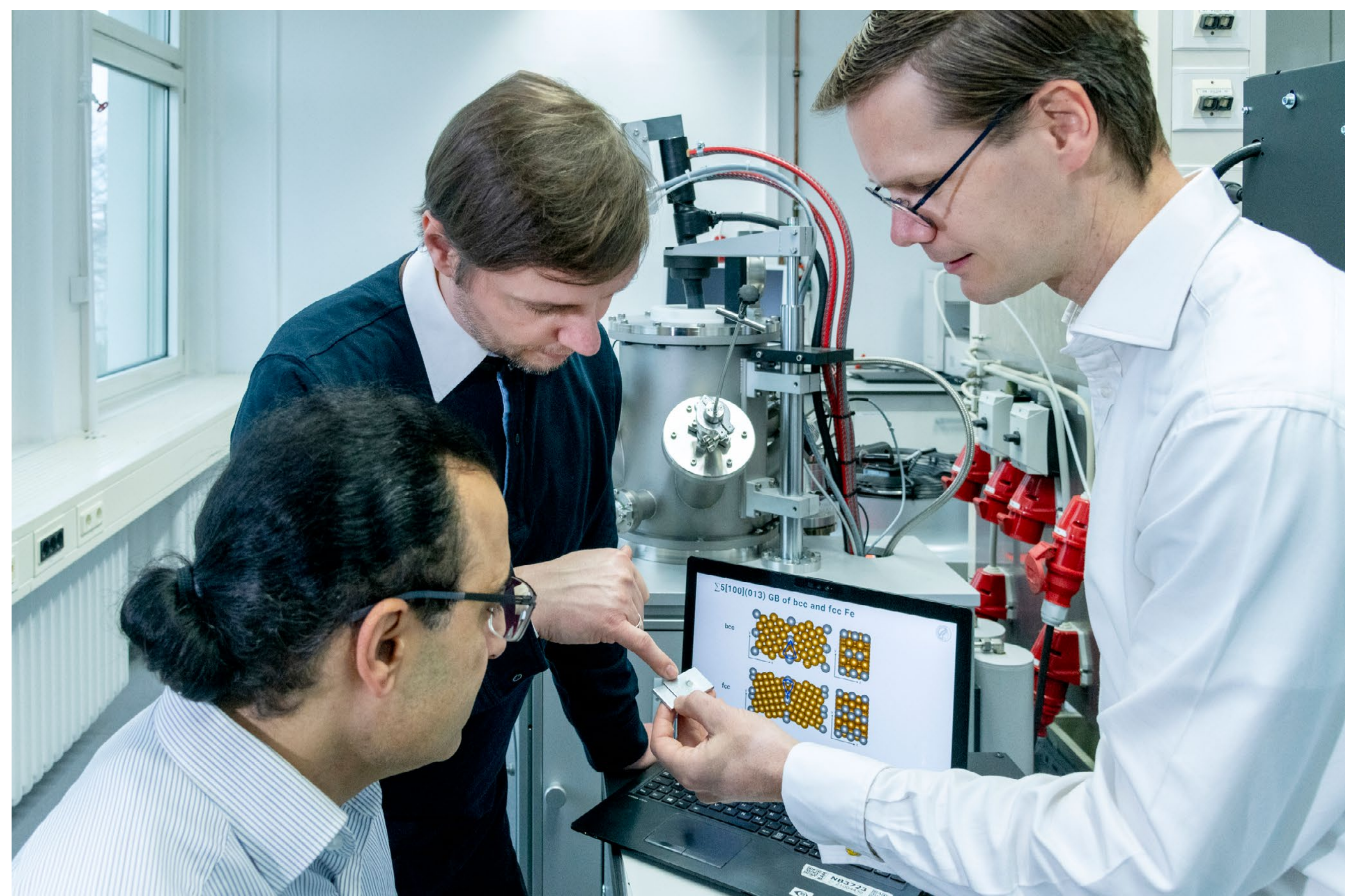
Microscopically fine cracks in welded steel sheets are a problem in the automotive industry. A team at BAM has deciphered their origin and is now searching for crack-free alloys.

Zinc coatings are crucial for protecting steel sheets in the automotive industry from corrosion. Immersion in a bath of molten zinc forms a robust surface that provides excellent protection and extends the service life of the steel. However, when the individual steel sheets are later joined by welding in production lines, so-called liquid metal embrittlement can occur.

Upon zinc coating, zinc atoms penetrate the steel component and are deposited at the interfaces. As a result, the mechanical properties of steel components are permanently impaired. The material becomes brittle and forms fine microcracks under load. This is a particular problem for safety-critical components. “Liquid metal embrittlement has been known for decades,” says Robert Maaß, an expert in high-performance materials at BAM. “Particularly in the automotive industry, where vehicle bodies made of galvanized steel have up to 5 000 spot welds, the integrity and safety of the used materials are of great importance.”

Microcracks at the interfaces

A clear understanding of the origin and mechanisms is crucial to make precise predictions about



Reza Darvishi Kamachali, Tilmann Hickel and Robert Maaß analyze defects in spot weld seams.

susceptibility to cracking and initiate preventive measures. Robert Maaß and his colleagues Reza Darvishi Kamachali and Tilmann Hickel have therefore investigated the early stages of liquid metal embrittlement. Using a combination of electron microscopy methods and computer-aided simulation models, the scientists were able to identify an origin of the undesirable effect. They discovered that before microcracks occur, nanoscopic “intermetal

lic phases” are formed at the interfaces between the grains of the steel. This is a brittle reaction product of the two metals iron and zinc, which is formed during the welding process and significantly weakens the interfaces of the steel. “Through simulations, we have discovered an unexpected zinc segregation at grain boundaries that promotes the formation of intermetallic phases and cracking,” explains Reza Darvishi Kamachali, “and this understanding allows

“ Our knowledge is the prerequisite for developing effective countermeasures against liquid-metal embrittlement. ”



Yuki Ikeda and Anna Maria Manzoni examine the material under an electron microscope.

us to now think about how to mitigate liquid-metal embrittlement.”

“Our electron microscopy studies were crucial in identifying the formation of these intermetallic phases at the grain edges of the steel. This knowledge is the prerequisite for developing effective countermeasures against liquid-metal embrittlement,” adds Tilmann Hickel from the team.

The vision: long-lasting high-performance steels

The three BAM scientists now want to specifically modify the chemical composition of steel alloys in such a way that zinc segregation and thus the formation of problematic intermetallic phases can be

controlled in order to prevent embrittlement. The materials scientists are working closely with national and international partners such as Arcelor-Mittal Global Research, the Max Planck Institute for Iron Research and the Department of Materials Science and Engineering at the University of Illinois. Their successful [work](#) was awarded a research prize by the American Iron and Steel Institute in 2024. —

Materials

Turbo for new materials



Platform for the automated development of new nanomaterials

Climate change is forcing an acceleration in materials development. Materials Acceleration Platforms are a disruptive, promising approach.

To meet the challenges of the green transformation, innovative and sustainable materials are needed in many areas – within a very short space of time. Unlike in the past with lithium batteries, fuel cells or solar cells, we cannot afford to spend several decades on development and commercialization.

Revolution in materials research

Scientists around the world are therefore working on Materials Acceleration Platforms (MAPs), which are intended to significantly accelerate the development of application-tailored materials. “MAPs represent a disruptive, even revolutionary approach to materials science,” explains Özlem Özcan, **who is coordinating the development of several of these platforms at BAM**. “In the past, researchers synthesized materials by hand in the laboratory, characterized them extensively, tested them in applications and then, if in doubt, started all over again. We no longer have that time today. MAPs combine robot-assisted, i.e. fully automated, synthesis, analysis and characterization of new materials with AI-controlled experiment planning and data evaluation in a closed learning cycle. This allows us to accelerate the development of new materials at least tenfold.”

In practice, this means that in a MAP aimed at developing surface treatment technologies for offshore wind turbines, the robotic platform is used to test the effectiveness of different concentrations of a substance fully automatically. The crucial difference to previous laboratory work is that evaluation and AI-supported feedback takes place after each individual measurement, not just after a com

plete series of tests. The system can therefore make adjustments at any time. “Concentration is just one of many parameters that are recorded,” says Özlem Özcan. “The platform registers all measurable parameters, including the speed and sequence in which the starting substances are mixed together – who knows, they may be the decisive factor for more effective corrosion protection. Overall, we



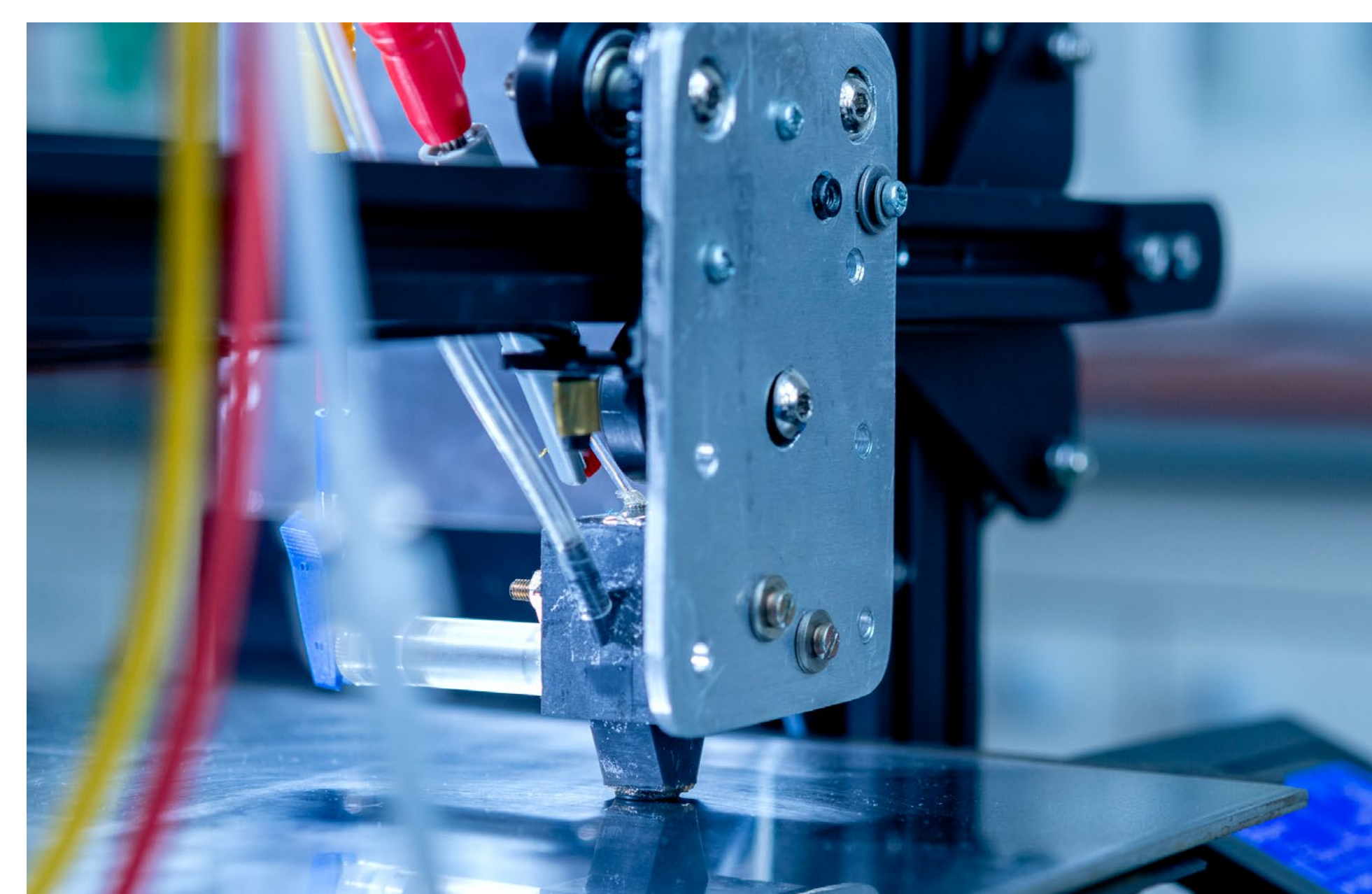
Özlem Özcan configures the experiment on the computer, then the platform takes control.

have a much larger data space with a MAP than it would be possible to create in a traditional experiment. At the same time, the experiments can be reproduced anywhere in the world at any time.”

Tailor-made MAP solutions in weeks

BAM is already using MAPs to find more efficient energy materials for electric batteries, develop high-performance glasses, nanomaterials, customized reference materials, materials for better hydrogen storage or low-CO₂ high-performance building materials. The next step is to bring all existing MAPs together at one location, link their hardware, standardize the modules and create shared data rooms. “In the future, we want to be able to offer the industry, with which we are already cooperating, a customized MAP solution within six weeks.

Many start-ups and small and medium-sized enterprises do not have the expertise and equipment to build their own acceleration platforms and would thus benefit significantly from a collaboration with us. In addition, we are also seeing strong interest from larger industry players,” says Özlem Özcan. –



In a MAP, all steps are robot-supported, automated and controlled by AI.



Sustainable conversion of gypsum into bassanite

In 2024 an international consortium led by BAM and the Spanish Instituto Andaluz de Ciencias de la Tierra developed [a sustainable method for converting gypsum into bassanite](#). Bassanite, which is obtained from gypsum, is one of the most commonly used building materials. However, its production has so far required temperatures of up to 200 degrees Celsius. At the same time, it can only be synthesized from high-purity gypsum. BAM and its Spanish partner have investigated how gypsum waste, which has often been disposed of in landfills due to concerns about contamination, can be used more efficiently for bassanite production. The researchers developed a method that significantly reduces energy consumption and thus greenhouse gas emissions when converting gypsum into bassanite. They achieved this by using water solutions with a high salt content, which enables the process to take place at significantly lower temperatures than before. It can also be applied to gypsum waste. This opens up new avenues for a genuine circular economy for gypsum.



Prof. Janine George teaches at the University of Jena alongside her work at BAM.

Outstanding materials research

Janine George was honored as a “Young Scientist” in 2023 by the Werner-von-Siemens-Ring Foundation. The award is presented every two years to outstanding talents in the fields of technology and natural sciences. George received the prize for her research into computer-aided methods in the search for new and improved materials to meet the challenges of energy conversion. Through her work, information from the analysis of chemical bonds can be combined on a large scale with other material properties in order to check chemical rules, derive new ones, or develop models for material properties on the basis of ma

chine learning. The application of such rules and models accelerates the search for optimized materials, e.g. for thermoelectrics, electric batteries or solar cells. According to the Werner-von-Siemens-Ring Foundation, Janine George’s work is making “an important contribution to the energy transition”. She [heads the junior research group “Computer-aided material design” at BAM](#) and has also been teaching at Friedrich Schiller University Jena as a professor of materials informatics since the winter semester 2023/24.

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

Chemistry and Process Engineering

Quality boost for lithium batteries



Lithium batteries are currently the most successful type of battery. The world's first reference material for their cathodes enables further quality improvements.

Cathodes are an essential component of electric batteries. As the “positive pole,” they play a key role in the performance and efficiency of rechargeable batteries. In order to further improve the performance of batteries, it is crucial to know the exact composition of high-quality cathode materials down to the particle level. Until now, however, there has been no reference material that allows the composition and therefore also the quality, service life and performance of cathode materials to be tested.

Developed according to international standards

BAM was able to close this gap in 2023 with the world's first certified reference material for cathode material for lithium batteries. It was developed according to strict international standards as part of a round robin test with 16 experienced laboratories and in close cooperation with the battery industry, tailored to their needs.

The **new reference material** [\[1\]](#), which is available in **BAM's Webshop** [\[2\]](#), consists of nickel-manganese-cobalt cathode material, which is used in many lithium-ion batteries in electric cars or mobile devices.

The certificate supplied states the exact mass percentages for lithium, nickel, manganese, cobalt and seven other components, as well as the particle size distribution and the specific surface area of the powder.

The BAM reference material will serve as a reliable benchmark for the characterization and evaluation of nickel-manganese-cobalt cathode material in the future. “At the same time, it will enable companies



The team around Dalia Morcillo (l.) and Carlos Abad (r.) developed the material in collaboration with the battery industry.

“ **Our reference material will enable companies to check the quality of cathode materials during production, compare them with each other and continuously improve them.** ”

to check the quality of cathode materials during production, compare them with each other and continuously improve them,” says Carlos Abad, expert for inorganic reference substances, who developed the material together with a team from the “Inorganic Reference Materials” department.

Recycling becomes easier

In particular, it gives the industry the opportunity to precisely determine and optimize the proportion of cobalt, the most expensive component in the cathode material. This makes it possible to manufacture the battery more economically. Impurities that have a negative impact on the performance and service life of a battery can be prevented during production.


BAM’s reference material is of particular importance due to the new EU Battery Regulation adopted by the EU Parliament in 2023. After a transitional period, this will stipulate fixed recycling quotas for the components of lithium-ion batteries. In future, BAM’s reference material will make it easier for recycling companies to identify high-quality components such as cobalt, nickel and manganese in used batteries, sort them and check their quality and reusability as part of a circular economy. In this way, resource consumption in the battery sector can also be reduced while optimizing performance. –

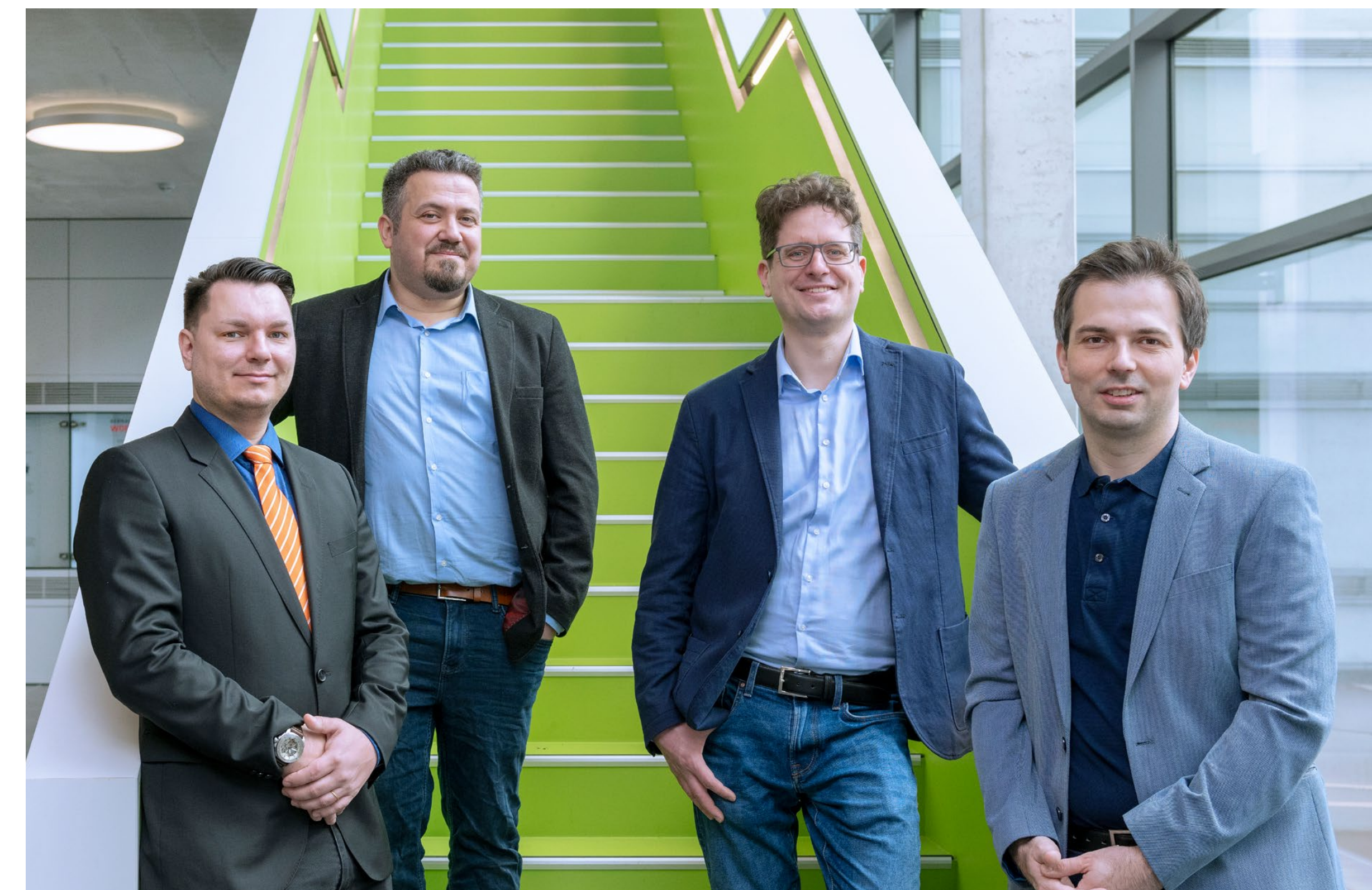


The reference material allows the industry to make e-batteries more economical and durable.

BAM spin-off develops explosives detector

In the civil security sector, explosives, for example at airport security gates, have so far mainly been detected using stationary devices. The few portable devices available on the market are heavy and expensive. “They are also not compatible with water and are therefore prone to false alarms in high humidity,” says Mustafa Biyikal, an expert in chemical sensors at BAM. Years ago, Biyikal set himself the goal of developing an explosives detector that is more powerful, lighter and cheaper than existing devices. Together with Knut Rurack, his mentor at BAM, he developed a new type of detection chemistry based on chemical-optical measurement technology. Special dyes are used

to detect explosives. Detection takes place in a matter of seconds. In 2023, Mustafa Biyikal has joined  with his BAM colleagues Martin Kaiser and Bruno Jan Rycek, experts in artificial intelligence and finance and marketing respectively, and Christopher Walter, an engineer from the aviation industry. Their spin-off is supported by the EXIST funding program of the Federal Ministry for Economic Affairs and Climate Action. Together, the team wants to bring their innovative explosives detector to market maturity and initially offer it in the EU and the UK from 2025. It will later also be launched in the USA, Canada and Asia.



The team around Mustafa Biyikal (top left).

Innovation award for sensor platform

BAM researcher Martin Paul has won the Berlin-Brandenburg Innovation Award 2023 with the start-up HyPhoX. The prestigious award recognizes the outstanding achievement in the development of a mobile sensor platform for the real-time detection of pathogens. The jury particularly emphasized the “transformative power and potential of this breakthrough in sensor technology”. With its patented photonic biosensor, HyPhoX is able to detect bacteria, viruses or proteins in liquids such as water, blood and urine within a few minutes. The mobile sensor platform enables on-site analyses in laboratory quality and promises a revolutionary change in the field of pathogen detection. The

jury of the Innovation Award explained further in its statement: “This innovation combines optical, electronic and biochemical components on a microchip with impressive integration density. The double-sided functionalization of the microchip is particularly noteworthy: While one side has biofluidic properties, the other is electronically oriented. Thanks to the use of silicon-based semiconductor technology, cost-efficient mass production is also possible.” “The award gives us further impetus to successfully bring our patented idea to market maturity,” says Martin Paul, co-founder of HyPhoX and scientist in BAM’s Protein Analytics department.



At the award ceremony in November 2023.

BAM at a glance

1550 Staff

55 Nationalities

46 Trainees

140 PhD students

200 Postdocs

25 Professorships and junior professorships

70 Lectureships

500 Refereed publications

800 Lectures

30 Patents

47 Certified reference materials

171 million € Basic funding

19 million € Third-party funding

4 Research facilities in Berlin/Brandenburg

(Figures for the 2023 calendar year)

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