e-conversion
The Magazine

Summer 2025

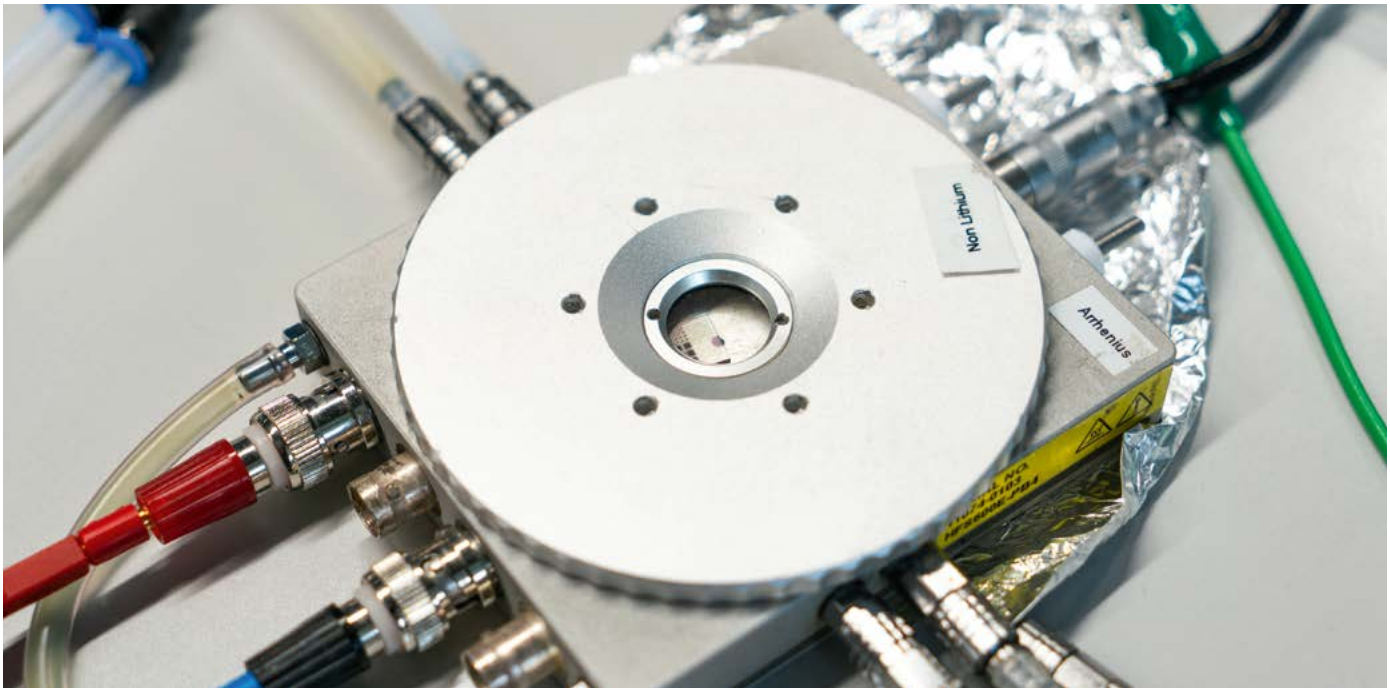
Focus on battery research

Let's charge our future

Content

Photons as a tool: Prof. Frédéric Laquai uses light pulses to unlock the innermost secrets of organic semiconductors.

Escaping the carbon trap: The escape game, which e-conversion helped to develop, focuses on artificial photosynthesis.



Searching for new material candidates: Where does research into redox flow batteries stand? Are solar batteries the future? How can lithium-ion cells be improved even further? And why are there robots at the e-conversion laboratories? Researchers provide answers and insights.

Our driving forces

News from the e-conversion Cluster of Excellence

Dear readers,
While the ongoing transition to sustainable energy conversion and storage includes many remarkable successes, enormous challenges still lie ahead. Overcoming these hurdles will require fundamental scientific advances that push beyond current efficiency and stability limits, often necessitating the discovery and development of not only new materials but also novel concepts.

Within the e-conversion Cluster of Excellence, we recognize that many key energy technologies are rooted in the same set of fundamental physical and chemical principles. By uncovering these shared foundations and unifying mechanisms, our interdisciplinary network of e-conversion researchers works collaboratively to provide novel solutions that can drive the next stage of the energy transition. Breakthroughs that allow us to better understand and control light–matter interactions, electronic excitations, and interfacial reactions, to name just a few examples, open the door to entirely new solutions – ones that are not only scientifically innovative but also technologically viable – and thus accelerate our progress towards a sustainable energy future.

This issue of our magazine shines a spotlight on battery research – a field that epitomizes the demands of future energy systems. Tomorrow's batteries must deliver high performance while also being long-lasting, sustainable, and adaptable to diverse applications. At e-conversion, we are exploring novel materials and concepts for the next generation of energy storage. By combining expertise from many fields, we both improve existing storage technologies and develop entirely new ones. Data-driven approaches, high-throughput experimentation, machine learning, and AI-supported research are central to our efforts.

But innovation needs more than knowledge – it needs spaces where ideas can flourish. Being part of Munich's unique science and technology ecosystem, we benefit from outstanding networks, close ties to industry, and an environment that fosters entrepreneurship. Researchers from e-conversion have already launched highly successful start-ups, and we are confident that many more will follow now that the second funding period has recently been approved for another seven years starting in 2026.

Together with our partners and society, our collaborative team of e-conversion researchers is striving towards a shared goal: making the energy future more sustainable, more flexible, and more efficient – through fundamental research that sparks inspiration and technologies that enable real progress.

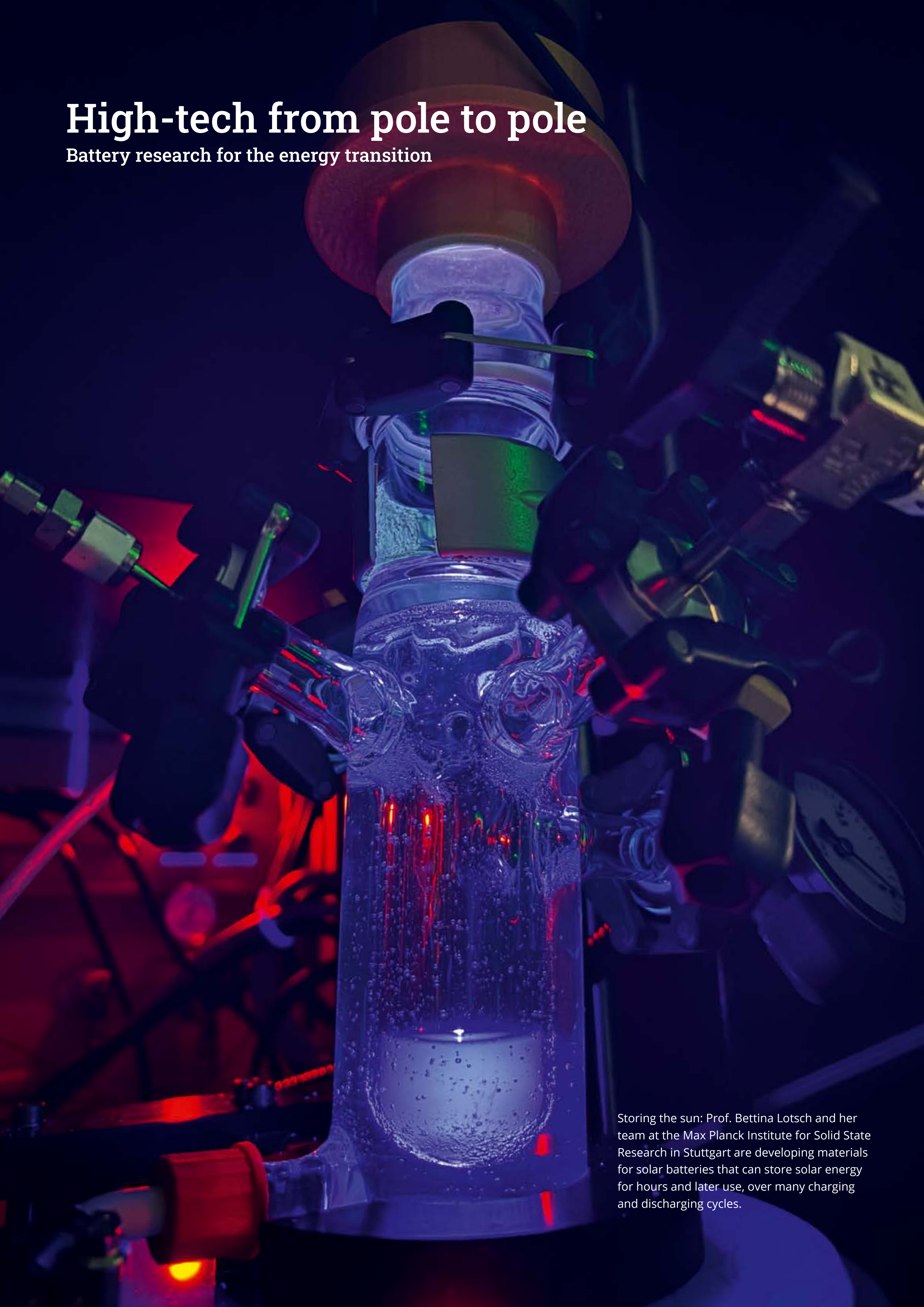
Enjoy reading!

Prof. Achim Hartschuh, Prof. Ulrich Heiz, Prof. Ian Sharp
Prof. Frédéric Laquai, Prof. Bettina Lotsch, Prof. Jennifer L.M. Rupp

Public viewing in a small circle: Those from the taskforce and review teams who were able to attend eagerly followed along on May 22, 2025, when the DFG announced which Excellence Clusters it would continue to fund from 2026 onwards. At the Franziskaner restaurant in downtown Munich, there was great cheer, relief, and gratitude when the list of selected clusters revealed that e-conversion will continue for another seven years.

High-tech from pole to pole

Battery research for the energy transition



Storing the sun: Prof. Bettina Lotsch and her team at the Max Planck Institute for Solid State Research in Stuttgart are developing materials for solar batteries that can store solar energy for hours and later use, over many charging and discharging cycles.

Batteries conceal something truly magical: a store of energy that can be used as electricity. What was a source of amazement 200 years ago when Alessandro Volta unveiled his first battery – the voltaic pile – has become something we take for granted today. Flexible energy storage is an essential aspect of smartphones, laptops, and vehicles – and at the very core of the energy transition. But the wishlist of attributes for the ideal battery is still long: cheaper, safer, more powerful and durable, free from harmful materials, and easy to recycle. Through their research work, the experts at e-conversion are addressing these challenges and taking batteries to the next level.

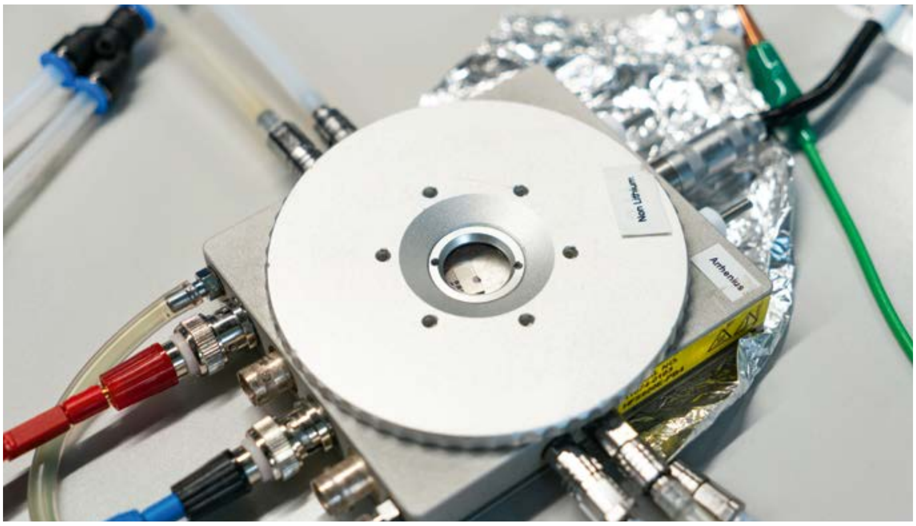
Green power is an unreliable companion – dependable when the sun is shining or the wind blowing, but faithless when neither is available. For renewable energies to become a dependable partner, energy storage capacity needs to be massively expanded, because Germany has set itself an ambitious climate target: it aims to be greenhouse gas neutral by 2045. And there are target milestones along the way: renewables are to be increased to 80 percent of gross energy consumption by 2030. High-performance energy storage devices are key to achieving the climate goal because they compensate for fluctuating energy generation from renewables and help make green power available on demand. Meanwhile it will be important to continue promoting wind farms, solar plants, and climate-friendly mobility. "This goes to show how finding a durable way to store an electric charge is fundamental to the whole transformation process. Not forgetting the transition from fossil to electricity-based industry," comments Jennifer L.M. Rupp. She is Professor of Solid-State Electrolyte Chemistry at TU Munich, Scientific Director of TUMint.Energy Research GmbH, and e-conversion 2.0 coordinator from January 2026. "The fact is the way we currently transform energy using wind and solar power is based on just fifty materials, most of which were invented and developed in the 1970s. We need a new generation of innovative materials for the energy transition 2.0 – a Green Energy Tech revolution, no less," declares the material scientist and founder of the start-up Qkera (see interview with co-founder Dr. Andreas Weis on page 12).

Rethinking battery research

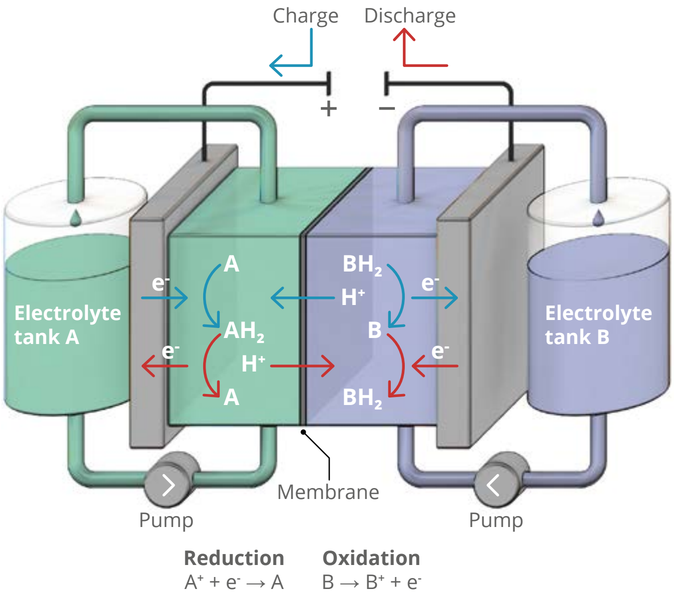
There are plenty of innovative ideas lined up – and the researchers at the e-conversion Cluster of Excellence are pioneering the discovery of new material candidates, stepping up research into the most promising candidates, and designing entirely new battery concepts. "For instance, we're working on technologies to bridge the gap between energy conversion and storage. This could include direct light storage systems," explains Bettina V. Lotsch, Director of the Max Planck Institute for Solid State Research and honorary professor at LMU Munich. "To translate such new concepts into devices, here at the Cluster of Excellence we bring together experts from a wide range of disciplines such as material chemistry, optoelectronics, photovoltaics, and battery research," says the material scientist, who will also join the e-conversion 2.0 team of coordinators from January 2026.

Storage technologies: the backbone of the energy transition

Anyone who has looked at the options for energy storage will have quickly realized that the components feature a vast array of technologies, designs, and materials – and demand continues to grow. "Batteries are the backbone of green electrification. But they need to become more efficient, more sustainable, and cheaper if they are to meet the rising demand for storage capacity," adds Rupp. "How can this be achieved? What are the innovative energy conversion and storage concepts? Which mechanisms are critical? What are the most promising materials or material combinations for solutions 10 to 20 years hence? These are some fundamental issues that are the very essence of what we're doing at e-conversion." The chemist is researching solid-state materials and how they might be used as functional



Driving the Green Energy Tech revolution – that's the goal Prof. Jennifer Rupp (left) is consistently focused on. She investigates solid-state materials and how they can be used as functional components in energy conversion and storage systems. A thin-film sample (right) is tested on a temperature-controlled stage under atmospheric conditions. This setup enables the researchers to analyze how the material's properties respond to changes in temperature and environment.



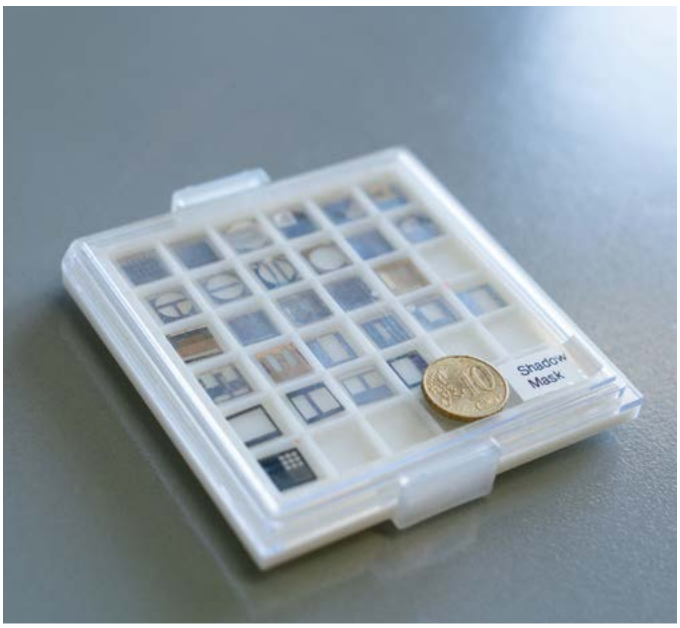
How a redox flow battery works

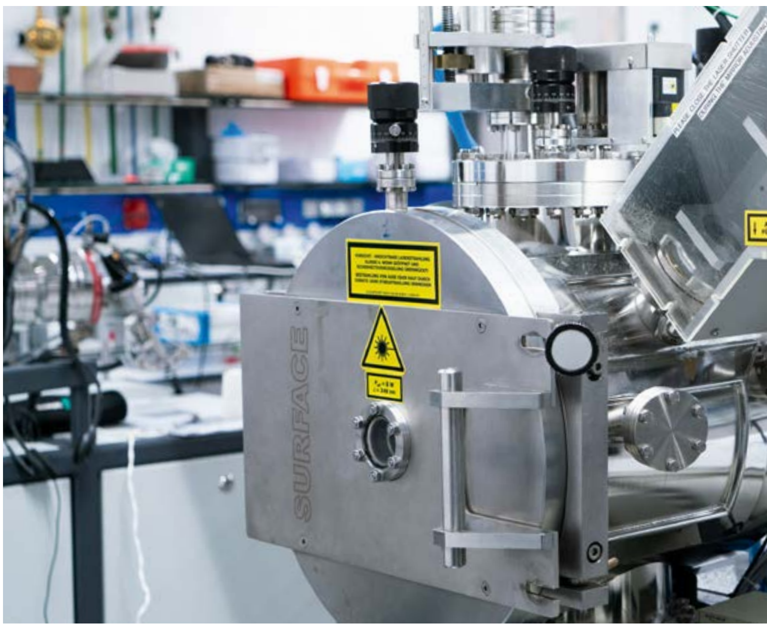
Redox flow batteries store electrical energy in two separate liquids that are stored in external tanks. These liquids, known as electrolytes, contain chemical substances that can absorb or release electrons. When discharging, the electrolytes are pumped through a reaction cell, which is divided into two halves by a membrane. In one half, the electrolyte releases electrons (oxidation), while the second electrolyte in the other half absorbs them (reduction). The electrons flow through an external circuit to the second half – thus generating a usable current. When charging, the reaction takes place in the opposite direction. As the energy is stored outside the reaction cell, there is hardly any self-discharge. In addition, the storage capacity can be easily increased by using larger tanks. The batteries also have a long operating life with many charging cycles. All these advantages make redox flow batteries particularly interesting for long-term wind and solar energy storage.

components for energy conversion and storage concepts. Rupp and her team are also working on the development of innovative lithium solid-state conductors and low-cost synthesis pathways for new hybrid and solid-state cells. Their aim is to create high-performance batteries with a higher energy density, but suitable for low-cost manufacturing at scale. The expert from TU Munich and her team are also looking at another technology for addressing the challenge of energy storage: sustainable redox flow batteries (see infographic above). Such batteries are especially good at storing high amounts of energy, making them an efficient way to hold surplus wind and solar energy for later use.

Revolution with redox flow batteries

Redox flow batteries feature two different liquid electrolyte circuits. The liquids converge in two reaction chambers that are separated by a membrane and house the electrodes. There the electrolytes exchange ions and generate a flow of usable current. During charging the system absorbs energy, at the electrodes the reactions are reversed and the system stores electric current. The special characteristic of these batteries is that the electrolyte tanks – and therefore storage capacity – can be freely scaled up, independently of the electrodes' areas. Such electrochemical energy storage systems have previously depended on vanadium, however, a costly and environmentally harmful metal with a volatile supply. "We are therefore doing research into a cheaper, more sustainable alternative – redox flow batteries based on iron compounds, which are a readily available, low-cost waste product of the steel industry," explains Rupp. The membranes also play a key role because they are responsible for charge transport between the electrolytes. Conventional systems use polymers. Their drawbacks are their operating life and cost. "That is why we are developing ceramic materials that are more robust, efficient, and environment-friendly," says Rupp, who aims to bring the concept into industrial operation in partnership with Prof. Fikile Brushett at MIT (Massachusetts Institute of Technology).





New materials and new ideas

The TU Munich expert sees interdisciplinary research partnerships as a vital source of inspiration and the e-conversion community as an enriching opportunity. “That inspires me to keep exploring new paths. We are working in close partnership with Prof. Thomas Bein’s research team at LMU Munich, for example. They have developed a covalent organic framework that could be a very useful material for pioneering energy storage devices,” continues Rupp. “That material is special because it can act as both anode and cathode. We and our groups have used it to develop a bipolar electrochemical storage system.” It consists of a single, uniform electrode material, with one side serving as the anode and the other as the cathode. The advantage is a simpler construction using sustainable materials.

Research power in a new light

Another research approach at e-conversion is exploring a completely new storage concept: the convergence of solar and battery technology. TU Munich and the Max Planck Society recently pooled their research power in establishing the MPG TUM SolBat Center (more on page 14), the world’s first Center for Solar Batteries and Optoionic Technologies – with the support of the Bavarian Ministry for Economic Affairs, which is providing eight million euros in funding. The center’s activities focus on solar batteries, which are still largely unexplored and are therefore intensively investigated by e-conversion expert Bettina Lotsch and her team. “Solar batteries combine solar cells and batteries in a single component and can store the energy from sunlight directly in electrochemical form – and then release it again as electrical energy,” explains Lotsch, who was awarded the 2025 Gottfried Wilhelm Leibniz Prize for her outstanding work in the field of materials chemistry. The SolBat Center is the brainchild of Prof. Bettina Lotsch, Prof. Jennifer Rupp, and Prof. Karsten Reuter (FHI Berlin) and conducts research into optoionics, an emerging interdisciplinary field of research at the intersection of optoelectronics and solid-state ionics that investigates how to control ions using light. “Improving light-controlled processes in

Ingenious scaffold molecules: Together with her team, Prof. Bettina Lotsch (right; left: Dr. Tigmansu Pal) has developed a material that can store sunlight for up to 48 hours, allowing the captured energy to be used later.

energy materials is one area of focus, along with creating new types of energy systems at the interface of batteries and photovoltaics. There could be immense potential in direct light storage devices for various solar and optical applications,” adds the Max Planck scientist.

A pulsed laser deposition system (right) is used to produce ultra-thin material layers with exceptional precision. This enables Prof. Jennifer Rupp’s research team to control composition, thickness, and crystallinity at the nanometer scale. Using various masks (left), researchers in Rupp’s team precisely control metal deposition on samples to study electrochemical transport properties on thin films or ceramics.

Solar batteries: a double benefit

Her team, which extensively researches the conversion of sunlight into chemical energy by photocatalysis, came across the idea of creating a solar battery (see infographic on page 8) with optoionic materials while conducting an entirely different experiment: the research team had come up with a very promising material and wanted to find out whether it behaved like a typical solar cell in exciting *just* electrons – or whether the incident light also set ions into motion, as in a battery. “An experiment revealed that the yellow material turned blue under irradiation with visible light,” explains Lotsch. “The exciting discovery was that when the light source was turned off, the blue color persisted for quite some time – a phenomenon that could be linked to the optoionic storage of solar energy.” Since then the chemist has kept coming back to this serendipitous discovery, one of her research highlights, because this kind of optoionic material has potential for a dual function: energy generation from sunlight and the storage of solar energy.

Caging light energy

Her team has now developed such a bifunctional cell. It has the same structure as a conventional battery with an anode, cathode, and electrolyte. The difference is a thin layer of a two-dimensional carbon nitride as photoanode that incorporates potassium ions. The crucial process takes place in that material.

"When its color changes we see that electronic charge carriers are formed," she explains. "Light-induced electrons accumulate in the carbon nitride layer as they are screened by the potassium ions. As such, they prevent the charge carriers from reacting and allow the electrons to accumulate – a process we call photocharging." The system can be charged like a battery – using light as its energy source. Lotsch and her team, together with researchers from TU Munich and the University of Stuttgart recently increased the scope of optoionic materials further: They developed a new organic framework material known as COF (short for covalent organic framework) that captures sunlight and stores its energy for 48 hours (more on page 15). Again, the material combines the functions of a solar cell and a battery in a single system. Thanks to its high performance and stability, it can supply power even after the sun has set – without the need for rare or critical elements.

A new branch of research: optoionic materials

But the top priority for Lotsch and her team is to identify the fundamental mechanisms at work in such materials. How does charging with light work in different optoionic materials? How relevant is the composition and structure of the material? Which ingredients are needed for electrons to accumulate? These questions, and others, are what the researchers are seeking to answer in order to use that knowledge to develop new candidates for the emerging research field of optoionic materials. TU Munich researcher Rupp, who leads the SolBat Center together with Lotsch and Prof. Karsten Reuter, Director of the Fritz Haber Institute in Berlin, is confident: "The combination of solar and battery technologies will open up a new dimension in pioneering a sustainable energy supply. The concept of this globally unique center is based on the close integration of basic research and technology development. We see it as an opportunity to create much more compact and efficient energy systems."

The limits of lithium-ion batteries

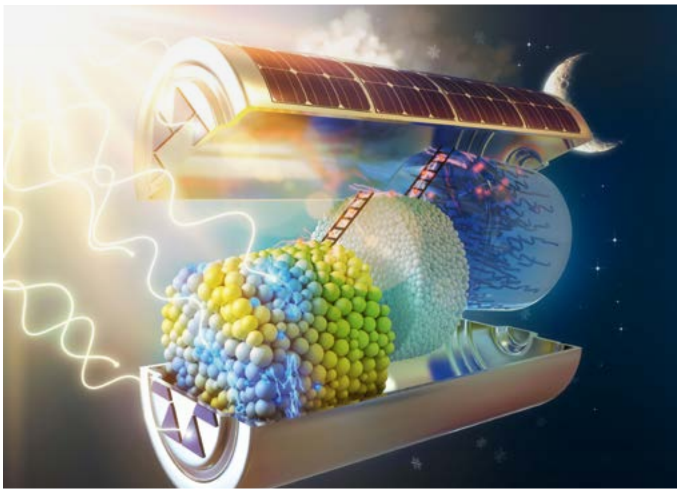
While solar batteries are still at the basic research stage, lithium-ion batteries can already boast a brilliant research career. This mainstay of electric mobility has undergone a remarkable transformation. The first lithium-ion batteries that came on the market in the early 1990s were heavyweights with relatively little energy storage capacity. The versions we encounter today are slimline high-tech devices. The difference in performance between then and now is like comparing a steam engine to a jet engine. The impressive development of lithium-ion batteries highlights just how efficient modern batteries already are. But they need to become even better, in other words energy-richer, safer, cheaper, more durable, and more sustainable. So where are their limits? What scope is there to get even more from the materials? That is what preoccupies Hubert Gasteiger, Professor of Technical Electrochemistry at TU Munich. The work of the chemical engineer and his team includes the development of new battery materials for lithium-ion, sodium-ion, and solid-state batteries. "We want to understand how new materials affect the battery cells and how durable they are. That puts us at the interface of basic research and applied research with industry-relevant cells," comments Gasteiger. "We employ a range of characterization methods in our work in order to understand the fundamental ageing processes." That, especially, plays an important part in boosting the energy density of lithium-ion batteries. "In trying to increase their performance even further, we're effectively pushing the materials to the limits of their stability," explains the expert from TU Munich. "Identifying those limits and how they affect durability and safety is one focus of our research work."

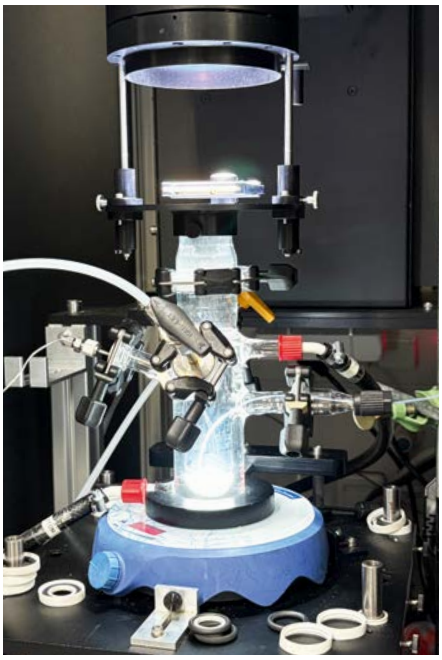
Why there's a catch to more energy

Quite often, this is a balancing act, because one way to increase the energy density of lithium-ion batteries (see infographic on page 10) involves progressively delithiating the active materials in the positive electrode by raising the potential. Because in every cycle of charging and discharging, lithium ions move between the electrodes and store electric current or release it again. That makes it such a game changer if the electrodes – the anode (negative) and cathode (positive) – can store and release lithium ions reversibly. "Storing more energy in a battery means more lithium ions need to be extracted from the cathode active material during charging and stored in the anode. The maximum amount of retrievable ions dictates the battery's capacity," explains Gasteiger. "But that makes the material thermodynamically more unstable – at the expense of safety and operating life." The higher the voltage applied and the more rapid the charging processes, the faster the cathode material and electrolyte age.

How solar batteries work

Solar cell and battery are not separate but are integrated into a single component. This enables the direct conversion of sunlight into electrochemical energy and its storage. The process begins when photons (light particles) hit the light-absorbing layer and excite electrons. The key innovation of solar batteries is that the light not only excites the electrons but also influences the movement of ions, enabling the simultaneous absorption of light and the storage of electrochemical energy in a single component.



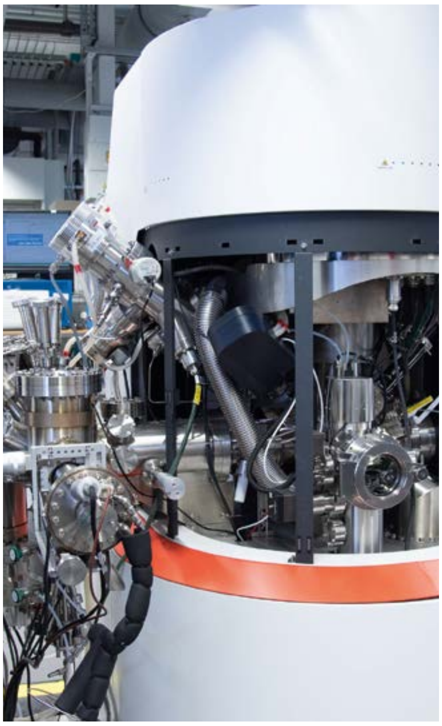


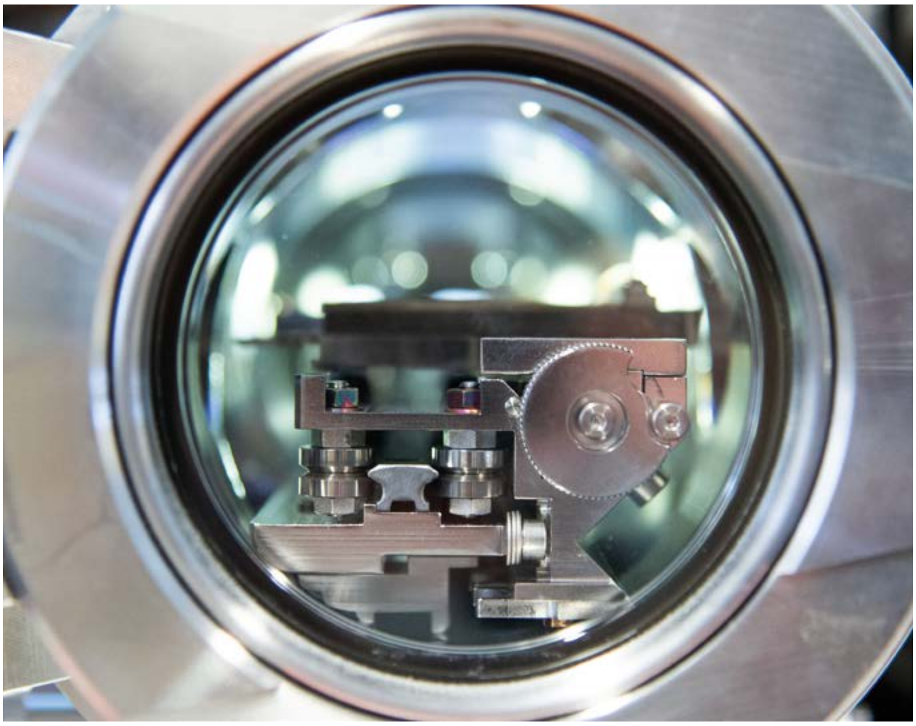
Captured electrons: How materials can be charged with light (left) and which conditions must be present in the solid-state lattice are key questions which are being investigated by Prof. Bettina Lotsch (right) at the Max Planck Institute in Stuttgart. Her team hopes to use this knowledge to find new material candidates for the emerging research field of optoionic storage materials.

Keeping tabs on the ageing of lithium-ion batteries

Gasteiger's team wants to gain a better understanding of what mechanisms are at work in the ageing of the cathode active materials, which are made from a lithium transition metal oxide. "We know the electrolyte oxidizes and the cathode active material partially dissolves at higher potentials. We've been able to demonstrate that there are two independent processes that have different dependencies on temperature and voltage," explains the TU Munich expert. "The electrolyte's oxidation depends merely on its composition, the temperature, and the applied voltage. The oxidation and decomposition of the cathode active material take place in a different potential range and depend primarily on the absolute extent of the delithiation of the cathode active material." The research group obtains its findings using high-resolution operando / in situ measuring techniques for which the team develops and optimizes the required electrochemical cells itself. These techniques include electrochemical impedance spectroscopy, operando X-ray absorption spectroscopy, and online gas measurements. "We actually know less about lithium-ion batteries than many people realize – considering how long they have been around," remarks Gasteiger. "Many improvements have just resulted via trial and error, in other words achieved purely empirically, because battery tests are relatively cheap and efficient to run. Combined with

Testing batteries: The research team led by Prof. Hubert Gasteiger (right) can test up to 100 battery cells simultaneously in the climatic chamber (left). Under controlled temperature conditions, they undergo repeated charging and discharging cycles to examine their behavior and operating life. The cells vary widely in type – from small laboratory cells to cells that are already very close to real commercial batteries.



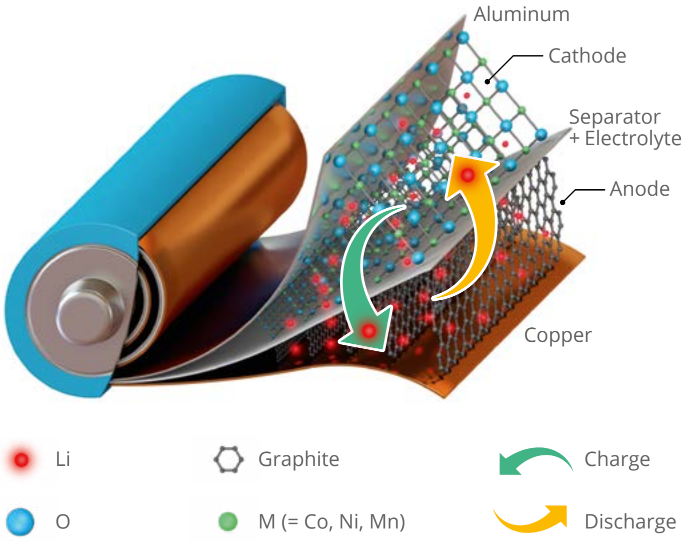


Insights thanks to the X-ray check: The researchers place their material samples in the X-ray photoelectron spectroscope (left) using an ultra-high vacuum lock (right). With this method, Prof. Hubert Gasteiger's team can analyze the elemental compositions and oxidation states of substances, among other things.

knowledge-based research, we aim to obtain valuable mechanistic insights that will help us understand these batteries even better and intelligently tailor improved materials."

New battery materials in record time

In tracking down promising new material candidates much faster and specifically optimizing them, researchers increasingly employ a combination of automated platforms, artificial intelligence (AI), advanced simulations, and robotics. Material experts firmly believe such technologies can bring on a paradigm shift in research practice. One pioneer in this field is e-conversion researcher Helge Sören Stein, Professor of Digital Catalysis at TU Munich. "Instead of spending years testing individual components, we use a platform that directly optimizes the entire system," remarks the physicist and doctor of mechanical engineering, who has specialized in automated research systems. "This way we can now uncover trends in material composition that would otherwise take years of work in the lab," explains Stein. His research brings together a range of disciplines, from chemistry and physics to engineering and IT. The basis of his work is the Materials Acceleration Platform (MAP), which he believes will significantly speed up material development. Stein's team has been instrumental in developing and implementing this platform. The distinguishing feature of this system is that it combines the basic measurements with simulations and autonomously learns from the results.



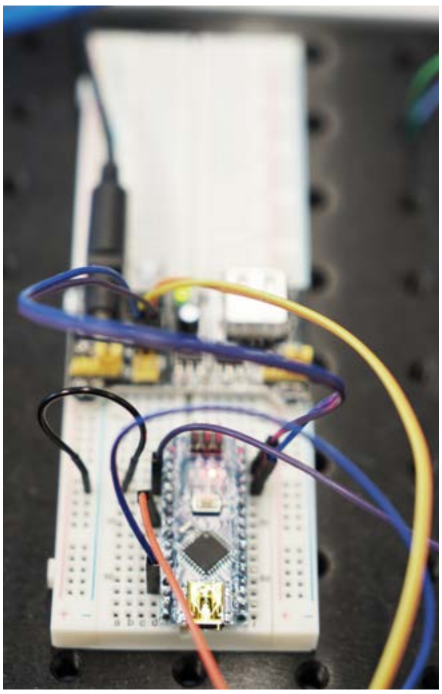
How lithium-ion batteries work

Lithium-ion batteries store electrical energy through the movement of lithium ions between two electrodes: the anode (usually graphite) and the cathode (typically made of lithium metal oxides). During charging, lithium ions travel through the electrolyte from the cathode to the anode, where they are stored – effectively storing energy in the battery. During discharging, the lithium ions return to the cathode, with electrons flowing to the cathode via an external device, such as a smartphone or electric car. This flow of electrons generates the usable electric current. The chemical reactions in the electrodes are reversible, allowing the battery to be repeatedly charged and discharged.

Clever use of digital data resources

Another objective of the TU Munich researchers is to create a decentralized infrastructure and make the valuable research data from battery research accessible and viewable. This could massively speed up the development of battery materials. If these data resources are standardized, an AI can work effectively with them and generally support the research teams. "We therefore want to incorporate the FINALES framework (the abbreviation stands for *F*ast *IN*tention-*A*gnostic *LE*arning *S*erver). It can link up various research institutes throughout Europe without requiring central oversight. Each lab retains control of its own experiments," explains Stein. The MAP assures optimal exchange of data and smart control of experiments. This improves the efficiency and reproducibility of experiments. The advantage is that the platform covers every relevant step, from formulating and characterizing new electrolytes, through the composition and testing of battery cells, to predicting their operating life. One use of the system is in optimizing the ionic conductivity of electrolytes and investigating the effect of electrolyte formulations on the operating life of lithium-ion button cells. Stein is convinced: "Digital research data management, the use of AI, and automation will undoubtedly be able to eliminate the bulk of those time-consuming measurements in the lab of the future, leaving much more space for creativity. I think the networking of experiments and data across several sites and labs will take research to an entirely new level because we will suddenly be able to correlate things that previously weren't visible."

Turbo for materials discovery: Prof. Helge Stein combines high-throughput experiments with artificial intelligence to identify promising battery materials faster and accelerate the development of high-performance energy storage systems.



Automated for better batteries: In Prof. Helge Stein's laboratories, robots mix various active powders and liquids to create battery pastes, so-called slurries. These are then applied to a copper foil (above). Conbined with further tests, AI-assisted data evaluation and temperature analyses, the system accelerates the development of high-performance battery materials.

Shaping tomorrow's world today

The chance to make modern society more sustainable through scientific innovations is a huge goal and motivation for the e-conversion researchers. Together, they address the challenge of developing new materials, mechanisms, and methods that could provide a real impetus in the future. "Now is the time to think big, act boldly – and keep questioning ourselves. Sometimes, you also need to reinvent yourself," believes Jennifer Rupp. "At the end of the day, what matters to me is that our research makes a difference." The e-conversion researchers already have a decent track record in that regard. In the first funding period of the Cluster of Excellence nearly 1,300 articles were published (as of July 2025). Seven start-ups were also successfully spun off from e-conversion (see interview with Dr. Andreas Weis from Qkera on page 12) in wide-ranging fields – from batteries and catalysis to renewable fuels and innovative measurement techniques. The spin-offs demonstrate the horizontal orientation of the Cluster of Excellence across the boundaries of individual technologies. The entire team at e-conversion was delighted with the announcement on May 22, 2025 that the e-conversion success story is set for a new chapter – the next seven-year funding period will start with renewed vigor on January 1, 2026. The priorities for e-conversion 2.0 are to integrate photovoltaics, catalysis, and batteries, conduct research into shared fundamental principles, and drive the development of new applications. Whether in nanoscience or material design, high-throughput screening or AI-assisted learning, the interdisciplinary team of researchers is working very hard at crucial interfaces to smooth the way for the energy transition – and to make green power a dependable partner.

Boosting solid-state battery breakthroughs

Higher energy densities, greater safety, and a longer operating life – that's what solid-state batteries promise. They are considered one of the most promising approaches to taking electric mobility and advanced energy storage solutions to a whole new level in the near future. But there is still a long and challenging way to go before they can be widely used on a large scale. In this interview, Dr. Andreas Weis, co-founder and CTO of the Munich-based start-up Qkera, explains why their development of oxide-ceramic solid electrolytes could be a decisive factor in bringing the technology to market not only faster but also far more reliably and efficiently.

What sparked the idea of founding the start-up Qkera together with Prof. Jennifer L.M. Rupp?
You could say Qkera exists because of e-conversion. The key moment was a talk Jennifer gave in Munich shortly after she had been appointed to the Technical University of Munich. I was working on my PhD at LMU Munich in the group of Prof. Thomas Bein. My research focused on the nanostructuring of thin films and how they can be deposited cost-effectively from solutions. Jennifer uses a spray-based process for film formation. I learned a lot about this method during a several-month stay in her research group. Working as a team, we realized how complementary our research approaches were and joined forces to deposit nanostructured ceramic films via roll-to-roll processing. My doctoral advisor, Thomas Bein, encouraged us to found the start-up because he saw great potential in our idea. The networking opportunities offered by the excellence cluster were in many ways very beneficial!

Qkera has been officially active since the beginning of 2024. What are the company's main focus areas?
Our overarching goal is to help solid-state batteries make a breakthrough. The crucial difference compared to the currently dominant lithium-ion batteries is that they use a solid electrolyte instead of a liquid one. This is exactly where Qkera comes in: we are developing solid electrolytes based on oxide ceramics. When used in batteries, they could increase energy density by 30 to 50 percent compared to conventional lithium-ion batteries. In addition, we aim to develop a scalable manufacturing process that is compatible with existing roll-to-roll processes, making it also very cost-effective.

What are the advantages of using oxide ceramics as solid electrolytes in batteries?
One major advantage is their robustness, even in chemical terms. Very few substances can degrade them. Unlike sulfides, which are another class of materials considered for solid electrolytes, oxide ceramics can be processed without cleanroom conditions. They are also extremely hard, which helps prevent the formation of dendrites – a problem that also occurs in lithium-ion batteries. This is a key benefit for new concepts that use pure lithium anodes. A drawback is that ceramic materials tend to be brittle. We try to compensate for this with very thin layers and a finely tuned microstructure, which we can achieve through our process.

How does Qkera's technology differ from previous methods?
Until now, oxide ceramics have typically been produced through sintering, requiring high temperatures and pressures. These are the main cost drivers in solid electrolyte production. Our process significantly reduces the use of energy by operating at much lower temperatures. We can also produce very thin and homogeneous oxide layers – just two to ten micrometers thick, which means we use less material. To achieve this, we use various dissolved metal salts as precursors and deposit them onto a substrate using a special heating and drying process. The substrate can be a porous glass fiber, ceramic mesh, or polymer carrier to obtain a flexible membrane. We can ensure very uniform crystal growth by precisely controlling the drying and densification process. This is the technological core of Qkera and the result of our development work over the past year. We have very quickly achieved convincing results – one technical milestone followed another.

That sounds promising! Are you already in talks with industry partners?
Yes, we are currently engaged in discussions with a major German battery manufacturer and an automotive company to define a development partnership. These companies became aware of us because our innovative approaches have already won several awards. For example, we were recognized as one of the 25 best science

start-ups worldwide at the Falling Walls Science Summit. It is incredibly exciting and motivating to see that we are on the right track – and that there is real interest in our technology.

Launching a start-up is never easy. What has been the key to Qkera's success?
We were fortunate to have a strong team early on – and business angels from our field with deep expertise who believed and invested in us. Then there is the unique infrastructure for entrepreneurs at TU Munich: we went through all the stages at UnternehmerTUM, which was extremely valuable. The XPRENEURS incubator was particularly helpful, as was the network we built with other start-ups. That gave us access to a wealth of knowledge, from how to pitch to investors to understanding public funding options and patent law. The TUM Venture Labs also gave us a significant boost by providing lab space, which is why we plan to continue investing in facilities there.

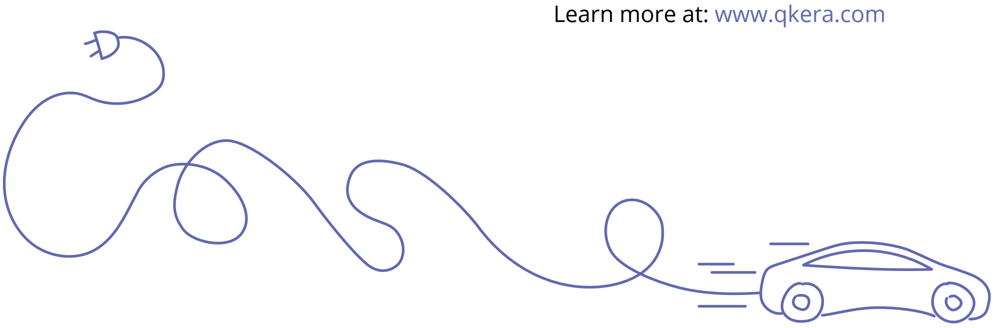
Looking ahead: where do you see Qkera in five years?
That's an exciting question. I firmly believe in the potential of solid-state batteries – they could be a real game changer. It would be a dream to build a competitive battery in Europe that can stand up to concepts from Asia. But I'm also realistic: we are developing this technology straight from research, and it's a hugely complex challenge. There is still a long road ahead. However, we have already reached some significant milestones in the lab and with potential customers. What gives me real optimism is our progress in scaling. We started with films just one square centimeter in size, and in under a year we have increased that area more than twenty-fold! That means we have solved one of the biggest industrial application problems of this material class.

Qkera: next-generation batteries

Rethinking solid-state batteries: The Qkera team produces oxide-ceramic solid electrolytes that can be processed with industrial methods (from left: Steffen Weinmann, Lea Schulz, Dr. Andreas Weis, Marcel Arnold, Prof. Jennifer L.M. Rupp).

The Munich-based start-up Qkera – founded in 2023 by Prof. Jennifer L.M. Rupp and Dr. Andreas Weis – develops innovative solid electrolytes based on lithium-ion-conducting oxide ceramics. These materials are nonflammable and free of rare-earth elements, and can enable energy densities up to 50 percent higher than those of conventional lithium-ion batteries. A central focus is scalability: the manufacturing process is energy-efficient and compatible with industrial roll-to-roll techniques. This makes the technology suitable for applications in electric mobility, portable electronics, and stationary energy storage. Qkera has already received international recognition for this approach, including being selected as one of the world's top science start-ups at the Falling Walls Science Summit 2023.

Learn more at: www.qkera.com



News

In a nutshell: the diverse research at e-conversion

The management team of the world's first center for solar batteries (from left to right): Prof. Jennifer L.M. Rupp, Prof. Bettina V. Lotsch, and Prof. Karsten Reuter.

The world's first center for solar batteries and optoionics technologies is being established in Bavaria. The TU Munich and the Max Planck Society (MPG) have set the course for this with the support of the Bavarian Ministry of Economic Affairs. With the SolBat Center, a unique research ecosystem will be formed to conduct research on new types of energy storage systems and develop applications to use solar energy even more efficiently and flexibly. The focus is on solar batteries, which are still largely unexplored (more from page 4). They combine solar cells and batteries in a single component and can chemically store the energy from sunlight directly – without the detour of converting it into electricity. The technology can be used, for example, to compensate for daily and weather-related fluctuations in solar power and, at the same time, increase energy efficiency through an improved ion cycle. Optoionics – an interdisciplinary field between optoelectronics and solid-state ionics, which deals with the control of ions by light – offers enormous potential for solar and optical applications.

The new SolBat Center will be headed by Prof. Jennifer L.M. Rupp, holder of the Chair of Solid State Electrochemistry at TU Munich and Fellow at the Fritz Haber Institute of the Max Planck Society, Prof. Karsten Reuter, Director at the Fritz Haber Institute of the Max Planck Society and Distinguished Affiliated Professor at TU Munich, and Prof. Bettina V. Lotsch, Director at the Max Planck Institute for Solid State Research in Stuttgart and honorary professor at LMU Munich and the University of Stuttgart. All three are also board members of the e-conversion Cluster of Excellence, on whose results, expert network, and interdisciplinary basic research the new center is primarily based. Jennifer Rupp emphasizes: "The fusion of solar and battery technologies will open up a new dimension for the future of sustainable energy supply. The concept of our globally unique center is based on the close integration of basic research and technology development. We see this as an opportunity to make energy systems significantly more compact and efficient." According to Bavaria's Minister of Economic Affairs Hubert Aiwanger, the Free State of Bavaria is funding the SolBat Center with up to eight million euros: "Today, we are facing unprecedented challenges in the areas of energy and sustainability. In order to develop new energy solutions, modern materials are just as important as new concepts for energy conversion and storage. I am convinced that the SolBat initiative will make a strong contribution to finding solutions for the massively increased energy storage requirements of the future. With our financial support for infrastructure measures at TU Munich's Garching campus, we are helping to place Bavaria at the forefront of innovation in solar energy storage."

Optoionics: a new branch of research with impact

The center focuses on optoionics. Bettina Lotsch explains: "Optoionics not only enables us to improve light-controlled processes in energy materials, but also to produce new types of energy systems at the intersection between batteries and photovoltaics, which act as direct light storage devices. Optoionics can be a key factor in increasing the efficiency of solar batteries and the functionality of future energy systems." The management team also hopes the center's research will provide new impetus for photocatalysis, sensor technology, and artificial intelligence (AI). Karsten Reuter emphasizes the importance of theoretical modeling for developing solar batteries: "With the help of precise simulations, we can better understand the complex interactions between light and ion movements in the materials. This understanding will be incorporated into AI systems from the outset, which will increasingly take over the planning of experiments in order to optimize materials and processes in a targeted manner and develop new functionalities." The SolBat Center's approach of combining experimental, theoretical, and AI-based research and considering the entire value chain up to the development of components creates a unique innovation platform for the next generation of energy storage systems.

Partnership and support

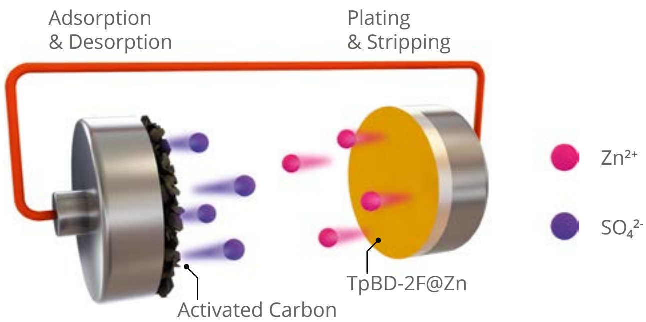
The SolBat Center is the result of a joint strategic cooperation between TU Munich and the Max Planck Society, funded by the Bavarian State Government. TU Munich President Prof. Thomas F. Hofmann emphasizes: "The center is unique in its structure. It aims to position Bavaria and Germany internationally as innovation leaders in the field of solar energy storage. It benefits from the outstanding energy research landscape on the Garching campus, such as the DFG-funded e-conversion Cluster of Excellence, the Walter Schottky Institute of TU Munich (Center for Nanotechnology and Nanomaterials), and TUMint.Energy Research." The SolBat Center is doing pioneering work in energy research and sees itself as a driver of innovation for the energy transition 2.0.

This material acts like a solar reservoir – storing energy and releasing it as electricity long after sunset. The captured solar energy can thus also be used to supply electricity in the dark. For the first time, it has been possible to combine solar harvesting and long-term energy storage in a single, metal-free molecular framework – effectively merging the functions of a solar cell and a battery into a single, lightweight, and sustainable system. Researchers at TU Munich, the Max Planck Institute for Solid State Research in Stuttgart, and the University of Stuttgart have developed a highly porous, two-dimensional covalent organic framework (COF) based on naphthalenediimide. This framework not only absorbs sunlight but also stabilizes the resulting photo-induced charges, enabling energy storage for more than 48 hours in aqueous environments. The stored charges are not merely retained but can be actively discharged to power an external load, enabling real energetic use. “This material has a dual function and acts as both a solar absorber and a long-term charge reservoir,” explains Dr. Bibhuti Bhusan Rath,

Solar batteries: Dr. Bibhuti Bhusan Rath investigates long-term charge storage in organic framework compounds (COFs).

postdoc in the research team of Prof. Bettina Lotsch, Director at the Max Planck Institute for Solid State Research. “Its performance exceeds that of many existing optoionic materials – and it does so without relying on metals or rare elements.” By combining advanced optical, electrochemical, and computational techniques, the researchers discovered that water stabilizes the stored charges. It creates an energetic barrier, effectively preventing recombination of the light-generated trapped charges and preserving the energy for later use. The material exhibits a charge storage capacity of 38 mAh/g, outperforming similar frameworks. The theoretical mechanism behind this behavior was elucidated together with the team of Prof. Frank Ortmann (TU Munich). Through extensive simulations, they evaluated different mechanisms of charge stabilization. They also collaborated closely with the experimental team to understand the interplay between the COF structure, electronic states, and the surrounding water environment. “The beauty of this system lies in its simplicity and robustness,” says Ortmann. “It stores light-induced charges in a stable state, resulting from the unique interplay of molecular design, framework architecture, and environment, and releases them as needed.” The system also shows excellent cycling stability, with over 90 percent capacity retention after multiple charging cycles, pointing to a powerful new platform for solar batteries. “This work highlights the potential of organic frameworks to be fine-tuned for advanced energy applications – using only organic building blocks and water,” says principal author Lotsch. “It marks a significant step toward sustainable, materials-based energy storage solutions and off-grid applications.”

The transition to renewable energy requires efficient methods for storing large amounts of electricity. Researchers at TU Munich have developed a new method that could extend the lifespan of aqueous zinc-ion batteries by several orders of magnitude. Instead of lasting just a few thousand cycles, they could now endure several hundred thousand charge and discharge cycles. The key to this innovation is a special protective layer for the zinc anodes. This layer addresses previous issues such as the growth of needle-like structures, known as zinc dendrites, as well as unwanted chemical side reactions that trigger hydrogen formation and corrosion. The research team led by Prof. Roland A. Fischer uses a unique material for this purpose: a porous organic polymer called TpBD-2F. This material forms a stable, ultra-thin, and highly ordered film on the zinc anode, allowing zinc ions to flow efficiently through nanochannels while keeping water away from the anode. Da Lei, PhD student in Fischer’s team, explains: “Zinc-ion batteries with this new protective layer could replace lithium-ion batteries in large-scale energy storage applications, such as in combination with solar or wind power plants. They last longer and are safer, while zinc is both cheaper and



more readily available than lithium.” While lithium remains the first choice for mobile applications like electric vehicles and portable devices, its higher costs and environmental impact make it less attractive for large-scale energy storage. Fischer adds: “This is truly a spectacular research result. We have shown that the chemical approach works and is controllable. We have already developed a first prototype in the form of a button cell. I see no reason why our findings couldn’t be translated to larger applications. Now, it’s up to engineers to take up the idea and develop appropriate production processes.”

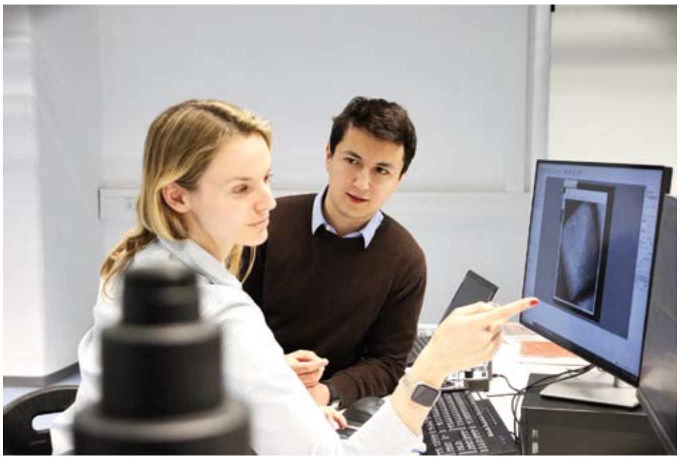
News

In a nutshell: the diverse research at e-conversion

LMU Munich and TU Munich researchers have developed an innovative method to make porous, DNA-based nanostructures suitable for a wide range of applications. This technique bridges the gap between wet and dry chemistry, significantly expanding the application potential for three-dimensional nanomaterials. The teams of Prof. Tim Liedl, Prof. Thomas Bein (both LMU Munich), and Prof. Ian Sharp (TU Munich) report on their method and its opportunities in a scientific article.

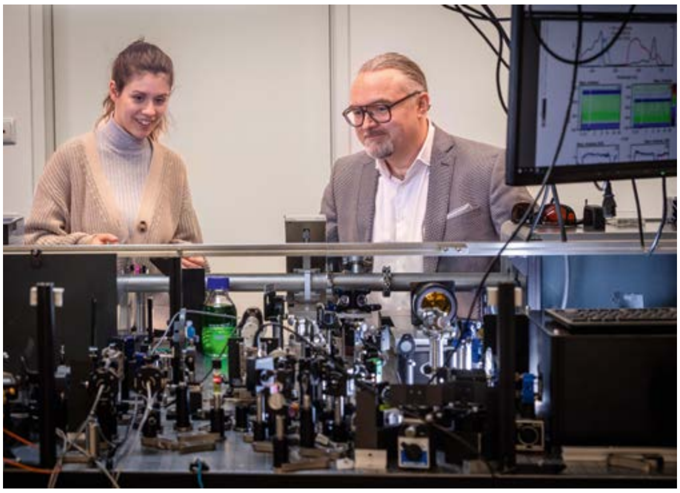
The focus is on constructing large porous structures with homogeneous, precisely defined, and tunable pore sizes, which can play a key role in energy storage, electrocatalysis, and photonics. However, producing such delicate structures on a large scale poses a significant challenge. Prof. Liedl's team has been using the DNA origami technique for years to achieve this. "The crux, however, is this: to precisely functionalize the complex nanomaterials with metal oxide layers, dry chemistry processes are necessary, which involve high temperatures. These can create undesirable stress within the 3D scaffold," explains Arthur Ermatov, PhD student in Prof. Liedl's group. Until now, protective layers of silicon dioxide were used. "We have now developed an alternative method using supercritical drying to gently extract the structures from the aqueous solution," says Ermatov. "The advantage is that we can preserve the DNA crystals without any protective coating and without deformation from surface tension, while maintaining their complex, open structure."

The material showed a significant increase in hydrogen production and remained stable under reaction conditions. "Our method opens up entirely new possibilities for material design in hydrogen production via electrolysis," says Prof. Liedl. Another advantage is that the technique is robust, flexible, and modular. This makes it a promising platform for producing custom-designed nanomaterials with broad applications ranging from photonics to catalysis and beyond.



Discussing the results: Melisande Kost (left) and Arthur Ermatov (right) are reviewing the recorded X-ray spectra (visible on the screen), which are used to analyze the materials deposited on the crystals.

Photosynthesis is based on a remarkably efficient energy conversion process. To generate chemical energy, sunlight must first be captured and transported further. This happens practically loss-free and extremely quickly. A new study by TU Munich led by Erika Keil and Prof. Jürgen Hauer shows that green plants use quantum mechanical processes to harness the energy of the sun, as Prof. Hauer explains: "When light is absorbed in a leaf, the electronic excitation energy is distributed over several states of each excited chlorophyll molecule; this is called a superposition of excited states. It is the first stage of nearly loss-free energy transfer within and between molecules, enabling efficient transport of solar energy. Quantum mechanics is therefore central to understanding the initial steps of energy transfer and charge separation." This process, which cannot be understood satisfactorily by classical physics alone, occurs constantly in green plants and other photosynthetic organisms, such as photosynthetic bacteria. However, the exact mechanisms have still not been fully elucidated. Hauer and first author Erika Keil see their study as an important new basis in the effort to clarify how chlorophyll, the pigment in leaf green, works. For the study, the researchers examined two specific sections of the spectrum in which chlorophyll absorbs light: the low-energy Q region (yellow to red spectral range) and the high-energy B region (blue to green). The Q region consists of two different electronic states that are quantum-mechanically coupled. This coupling leads to loss-free energy transport in the molecule. The system then relaxes through cooling, i.e. by releasing energy in the form of heat. The study demonstrates that quantum-mechanical effects can have a decisive influence on biologically relevant processes.



Energy transport in leaf green: Erika Keil and Prof. Jürgen Hauer show in their study that quantum-mechanical effects play a role in plant chlorophyll (obtained from frozen spinach).

Redox reactions form the basis of many fundamental processes of life. Without them, neither cellular respiration nor photosynthesis could take place. Understanding the fundamental principles of these reactions is therefore important for driving forward new technologies. Using an innovative method based on high pressures, a team led by LMU Munich chemist Prof. Ivana Ivanović-Burmazović and Prof. Dirk Guldi from FAU Erlangen-Nürnberg has managed for the first time to differentiate two related reaction mechanisms. Their tool: high pressure. In redox reactions, electrons are transferred between molecules. Because electrons have a negative charge, this can cause the charge of the reactants to change, which is energetically demanding. Nature has found an elegant solution to prevent this: the transfer of electrons is often coupled with the transfer of positively charged protons. This proton-coupled electron transfer (PCET), as it is known, does not produce any change in charge – the most efficient way for a redox reaction to occur.

There are two possible mechanisms here: either electrons and protons are transferred simultaneously (concerted), or the transfer occurs stepwise, meaning electrons and protons are transferred separately. “To be able to optimize these processes, we need to know the exact mechanisms,” says Ivanović-Burmazović. “Before now, however, there has been no direct method for differentiating the two alternatives with certainty. Our work set out to remedy this.” The researchers investigated the light-induced reaction of a photosensitive molecule in solution. Their analytical tool: high pressure – up to 1,200 atmospheres. “Our results show: measuring the effect of pressure on the reaction rate allows us to draw direct conclusions about the mechanisms,” says Ivanović-Burmazović. If the speed remains unchanged, it is a concerted reaction. If it changes, this indicates a gradual process. To their surprise, the researchers were able not only to determine the type of mechanism but also to influence the process: “By increasing the pressure, we managed to steer the reaction from a stepwise mechanism toward a concerted mechanism,” says Ivanović-Burmazović. The study provides new insights into fundamental processes of electron and proton motion and has great potential for applications in redox catalysis, solar fuel production, and energy storage.

High-pressure expert: Prof. Ivana Ivanović-Burmazović studies reaction rates using high-pressure techniques.

Honors & Awards 2024/2025

Prof. Bettina V. Lotsch (Max Planck Institute for Solid State Research) was awarded the Gottfried Wilhelm Leibniz Prize 2025 in recognition of her outstanding scientific contributions in solid-state chemistry. She also received the Remsen Award from the Maryland Section of the American Chemical Society (ACS), named after Ira Remsen, who championed the highest standards in chemical research and education.

Prof. Jennifer L.M. Rupp (TU Munich) was elected a member of the German National Academy of Sciences Leopoldina in 2024, joining the Engineering Sciences section in recognition of her outstanding expertise. Additionally, Rupp was appointed a Max Planck Fellow at the Fritz Haber Institute in Berlin for a five-year term, further strengthening ties with the Max Planck Society. She was also elected Vice President of the International Society for Solid State Ionics (ISSI) for 2024 and 2025 as well as President for 2026 and 2027. Moreover, Rupp received the Richard M. Fulrath Award from the American Ceramic Society for her exceptional and pioneering achievements in ceramic sciences and advanced materials research.

The German Chemical Society (GDCh) awarded **Prof. Roland A. Fischer** (TU Munich) the Wilhelm Klemm Prize 2025, honoring his groundbreaking contributions to metal-organic frameworks (MOFs) and his extensive engagement in research, teaching, and science policy.

Prof. Barbara A.J. Lechner received the Ernst Haage Prize from the Max Planck Institutes in Mülheim in November 2024.

Early-career researcher **Dr. Fuzhan Rahmanian**, a postdoctoral fellow in Prof. Jennifer Rupp’s group at TU Munich, was honored with the prestigious ZEISS Women Award 2024 in the Digital Research category.

On the pulse of cutting-edge research

Review: e-conversion Cluster Conference and CeNS Workshop in Venice

Exchanging knowledge, discussing research, and broadening horizons – the joint event of the e-conversion Cluster of Excellence and the Center for NanoScience (CeNS), held from September 23 – 26, 2024, provided an ideal platform for these objectives. It also brought together young researchers with experienced scientists from physics and chemistry, who offered insights into their current projects.

“We were able to attract an impressive line-up of top experts from around the world, covering a wide range of topics that are highly relevant to our researchers,” explains Prof. Frédéric Laquai (LMU Munich), who served on the program committee. The conference location – the island of San Servolo in Venice’s lagoon – could hardly have been more attractive. Around 140 participants arrived by vaporetto at the historic buildings of the former monastery buildings, now housing the Venice International University (VIU). “The impressive conference venue and the perfectly organized workshop left a lasting impression on me,” adds Laquai.

Achieving more together

Some were already familiar with the conference venue, as it hosted the first e-conversion conference in fall 2022. “It felt a bit like coming home, for several reasons,” says Prof. Bettina Lotsch (MPG). “The e-conversion community emerged from the Munich nanoscience community, and it was wonderful to see the researchers reconnect and exchange ideas!” The Center for NanoScience (CeNS) was founded in 1998 at LMU Munich as one of the world’s first nanoscience networks. Some e-conversion researchers are also CeNS members, enabling an incredibly diverse program.

A conference with many facets

The four-day conference featured presentations as varied as the e-conversion and CeNS research fields. The conference covered the latest advancements in materials science and physical chemistry, including innovative methods for carbon dioxide capture and conversion through sunlight, simulations of electrochemical systems, as well as charge transport in polymer materials. The conference also highlighted groundbreaking developments in catalysis research, such as programmable catalysts. A particular focus was on new materials like perovskite crystals, which promise significant progress in solar cell technologies. “The quality of the presentations was truly impressive,” emphasizes Prof. Ian Sharp (TU Munich), who was also responsible for the conference program. “They provided not only foundational introductions to their respective fields but also inspirational scientific advances. The complementary breadth stimulated many productive discussions and highlighted potential synergies that emerge from interdisciplinary research, which is a core theme of e-conversion’s approach to research.”

Valuable impulses and points of connection

The presentations by international speakers also covered the latest advances in nanophotonics and quantum research, including concepts for light-based energy storage and AI-supported

Focus on research: For Prof. Bettina Lotsch (left, 3rd from left), the conference provided an ideal platform for exchanging ideas, thanks to its diverse program. Young researchers such as Nina Miller (top r.) presented their research results in poster sessions. The start-up Qlibri (center r.) was also present at the conference.

quantum simulations of (bio)molecules. There were also talks on innovative methods for designing protein materials and the use of DNA origami. In addition to the expert presentations, young researchers held Poster Flash Talks. Two poster sessions allowed young scientists to discuss their projects with the attending experts. “The active participation of doctoral candidates through flash talks, poster presentations, and discussions was especially important for generating the lively, intellectually stimulating atmosphere of the conference,” explains Sharp. Overall, the conference offered many opportunities for scientific exchange, networking, and personal conversations. “For me, the conference was a highly enjoyable experience. I also received very positive feedback from the students,” says Prof. Christopher Stein (TU Munich), a program committee member. “The level of the presentations was simply incredible, so you can truly say that the location attracted a fantastic, diverse set of speakers. I was very pleased to see so many discussions between the participants and the speakers. I hope we can offer this event again soon,” Stein summarizes his impressions.

We are looking forward to the next Cluster Conference in September 2025. The e-conversion community will then meet in Tutzing to discuss the latest research highlights – and will bring at least as much energy as this year to continue the work of the Cluster of Excellence starting in 2026!

Top-class presentations and inspiring discussions: the joint e-conversion and CeNS conference in Venice offered researchers a wide range of topics and many opportunities to exchange ideas, accompanied by perfect weather and against a stunning backdrop.

Networking. Discussing. Learning.

Review: e-conversion's Industry Day e-Connect

Expert presentations, start-up talks, poster sessions, and discussions: The e-Connect event provided an inspiring atmosphere for all participants and demonstrated that strong partnerships drive the energy transition.

Review of e-Connect 2025: research meets business

What does it take for a scientific idea to evolve into a market-ready technology? How do successful start-ups operate, and what makes industry partnerships effective? These and other questions were explored during the Industry Day *e-Connect*, which was organized by e-conversion on March 27, 2025 at the Galileo Conference Center on the Garching Research Campus. Around 90 participants from research and industry, the start-up community, and the tech transfer ecosystem came together at the event, impressively demonstrating how application-driven fundamental research at universities and entrepreneurial thinking in industry can go hand in hand. Through expert and start-up talks, poster sessions, and open discussions it became clear that this platform is exactly what is needed to make the energy transition successful. To kick off the event, Cluster Speaker Prof. Achim Hartschuh (LMU Munich) provided a concise overview of e-conversion 1.0 and the Excellence Cluster's goal of understanding the fundamental processes of energy conversion at the molecular level. The unique research infrastructure provided by Munich's university landscape significantly supports this mission.

Vision for e-conversion 2.0

Prof. Jennifer Rupp (TU Munich), who is set to take over as the next speaker of the cluster, gave an outlook on its future. She highlighted the global challenges of increasing energy demand and the urgent need for energy to be storable, sustainable, and widely available. According to Rupp, this calls for nothing less than a Green Energy Tech revolution. She emphasized that many materials we use today were developed over 50 years ago, and the next generation of energy materials must be researched now. The e-conversion Cluster of Excellence offers a strong platform for this, creating new concepts such as solar batteries and optoionics, and presenting radically new approaches to battery technology. In Rupp's view, deep tech start-up development is a key part of the success formula, building bridges between research and the market. Supporting initiatives like the battery start-up incubator at TU Munich also plays an important role.

Successful start-ups and industry partnerships

Chiara Turrina from TUM Venture Labs presented the extensive support network available to founders. The initiative, a collaboration between TU Munich and UnternehmerTUM, offers a comprehensive ecosystem with modern infrastructure and twelve specialized venture labs. It also serves as a launchpad for deep tech and life science entrepreneurship, from the initial idea to market entry. In brief start-up talks, founders Dr. Andreas Weis (Qkera), Christoph Gruber (iNSyT), and Prof. Dominik Bucher (Quantum Diamonds) shared their entrepreneurial journeys, challenges, and achievements, offering authentic overviews of their start-ups. Industry representatives also

www.e-conversion.de

provided valuable insights into their strategies and opportunities for collaboration. Dr. Simon Anniés (PULSETRAIN) discussed multilevel batteries and challenges along the battery value chain – from first-life to second-life use and technical components such as MOSFETs. Dr. Johanna Poschenrieder (Wacker Chemie AG) highlighted strategic connections in electrochemistry and shared experiences from working with start-ups. Dr. Daniel Böhm and Dr. Julius Hornung (Freudenberg ePower Systems) presented novel manufacturing methods for electrodes and catalysts – from ink to MEGA production. Dr. Raphael Tautz (Tautz & Schuhmacher Patentanwälte PartGmbB) addressed the economic importance of intellectual property for research, start-ups, and funding – a topic that is often underestimated but crucial. Patricia Hornstein (TUM School of Management) spoke on the importance of sustainable leadership. Andrea Capogrosso introduced the H2 Real Lab in Burghausen, outlining the challenges of transitioning to green hydrogen.

Inspiration and impulses

There were numerous opportunities for networking and scientific exchange during the poster session as well as over coffee and meals in a relaxed setting. With much positive feedback, new contacts, and many ideas for future collaborations, the event demonstrated e-conversion's success as a platform linking basic research with industrial application, and how essential close cooperation between science, industry, and entrepreneurial innovators is for advancing the energy transition.

Research impulses for quantum sensors and microscopy

Research means discovering new paths – and turning initially unconventional ideas into practice. To achieve this, scientists need time away from routine work as well as financial support. The **Hans Fischer Senior Fellowship** of TU Munich is designed to support exactly such endeavors. It is aimed at outstanding international researchers who want to collaborate with a research group at TU Munich or LMU Munich on a joint project. Among other benefits, fellows receive a three-year fellowship that includes at least nine months at the Munich partner institution. The Hans Fischer Senior Fellowship is part of the broad fellowship program offered by the TUM Institute for Advanced Study (IAS). In late 2024, the research groups led by Prof. Dominik Bucher (TU Munich) and Prof. Jennifer Rupp (TU Munich) assumed their roles as hosts for two Hans Fischer Senior Fellows:

Prof. Sossina Haile from Northwestern University, USA, conducts research on fuel cells, batteries, thermochemical hydrogen production, and other energy conversion systems. Her group studies ion transport mechanisms and electrochemical reaction pathways to achieve high efficiency in energy technologies. The collaboration with e-conversion researchers centers on the development of novel methods in the field of quantum sensing to detect ion motion.

Prof. Dennis Valbjørn Christensen from the Technical University of Denmark is a renowned expert in materials science and applied physics. His research group characterizes novel oxide materials and devices using scanning magnetometry. Together with the e-conversion teams, he focuses on advancing magnetic quantum microscopy to better visualize dynamic nanoscale processes.

Escape from Carbonia

Cracking the escape room with future energy

Creative energy pays off: with the communication concept *Escape from Carbonia*, the e-conversion Cluster, together with TU Munich, was selected as one of ten finalists in the 2025 University Competition organized by *Wissenschaft im Dialog*, among nearly 120 entries submitted under the theme of the Science Year *Energy of the Future*.

Endowed with 10,000 euros in prize money, the joint project has already taken shape and debuted at the Kunstarealfest in Munich. With *Escape from Carbonia*, a team of students, doctoral researchers, and staff from science management and communication at TU Munich bring energy research to the streets: the interactive escape room game offers a playful way to engage with research on renewable energy. Visitors to Munich's street festivals, such as the Kunstarealfest, can look forward to tricky, fun-to-solve puzzles about innovative technologies, hands-on experiments, and physics and chemistry models. Along the way, they learn more about e-conversion's cutting-edge research for a climate-neutral future and gain insights into the current work.

Science communication with aha moments

The game focuses especially on technologies needed for artificial photosynthesis. The escape room has a clear goal: to convey the potential of sustainable energy sources and demonstrate that there are many ways to contribute to the energy transition. But fun is essential, according to Lukas Rau, who studies energy markets and renewable energy at TU Munich: "Good science communication creates aha moments – especially through personal experiences and fun. When I heard about the University Competition on the Science Year *Energy of the Future* through the TUM Sustainability Office, I immediately wanted to be part of this."

Escaping the carbon trap: How can artificial photosynthesis be implemented? How can the fictitious planet Carbonia be saved? This is the mission facing the players of the escape game (top). At the end of the game they decide by using a sticky dot (left): stay on Carbonia or take the technology back to Earth.

Escape room as a creativity engine

The aim is to create a reusable format that can be used not only at festivals but also on the campus. The entire team has been hard at work in the e-conversion student lab over the past few months. “This competition is a veritable creativity engine,” says Kolja Kröger from TUM’s Public Engagement Team, who initiated and energized the project. “It’s a new, playful outreach format that brings science to the streets – and a win for everyone because it builds skills in public engagement, especially for the students and early-career researchers involved.” The project centers on learning by doing, gaining new experiences, and building something together, agree Silke Mayerl-Kink, responsible for school programs, events, and diversity at e-conversion, and Dr. Caroline Zörlein, e-conversion's Public Outreach Manager. The winning teams of the University Competition are supported by *Wissenschaft im Dialog* through training and events, receiving valuable input in science communication, social media, storytelling, and event planning.

Follow updates regularly on Instagram, LinkedIn, and at:
www.hochschulwettbewerb.net/2025/escape-from-carbonia

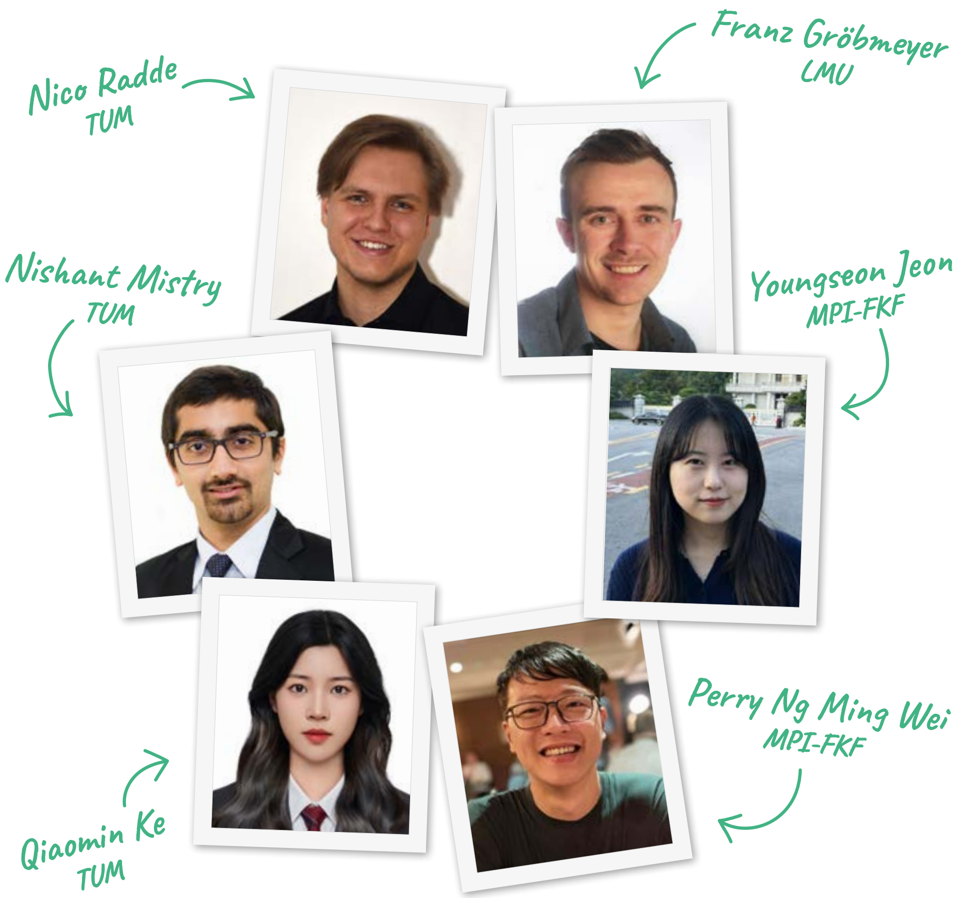
Festival premiere at the Kunstarealfest: Visitor groups puzzle over the electrolysis game setup, decipher the light code, and solve molecular puzzles. With 3D-printed nanostructures and voice messages from the fictitious Dr. Violetta Photon, players learn more about artificial photosynthesis (top), semiconductors, and catalysts.

Network for young researchers

The current Student Board of e-conversion

The new Student Board of the e-conversion Graduate Program (the official representative body for its doctoral students) began its work in November 2024 and successfully organized a Winter Retreat in Bayrischzell in March 2025. Another such meeting is planned for the coming winter. In addition, the Student Board is planning events such as workshops and summer gatherings. In order to promote scientific exchange beyond e-conversion, joint events with researchers at LMU Munich and TU Munich are planned in light of the extension and launch of several new Clusters of Excellence.

More information on the program and conditions of participation at:
www.e-conversion.de/about-e-conversion/graduate-program



Harvesting more solar power

Prof. Peter Müller-Buschbaum

The future of energy is renewable. The optimum mix of solar, wind, and hydroelectric power is still uncertain today. But one thing is sure: it must be possible to convert these forms of energy into each other. As this process involves high losses, the interface between materials is critical. This is precisely where e-conversion scientists step in, investigating conversion processes with the aim of making them more efficient. We spoke to one of them: Prof. Peter Müller-Buschbaum and his team at TU Munich are focusing on energy materials for solar cells, among other things, and are convinced that with suitable materials, the sun could enable households to become energy self-sufficient.

What research topics does your research group focus on?

We research functional materials, particularly in the energy sector, and focus on batteries and thermoelectrics – the latter can convert heat into electricity. But above all, we investigate solar cells. I have long been fascinated by them, especially by the further development of organic, perovskite, and quantum dot solar cells. I see great potential for these new types of solar cells and their wide range of future applications.

Why can't silicon solar cells keep up in this respect?

It is often misunderstood that the aim is not to replace the classic solar cells used in rooftop solar panels. Instead, we aim to develop further solar cell applications that are not possible with rigid silicon modules. These new devices can be semi-transparent, for example, so that windows can be fitted with them. This gives glass facades an additional function by producing electricity, which could make high-rise buildings energy self-sufficient. The new solar cell types also score points for their high flexibility and low weight, making them attractive as photoactive fibers for clothing or photoactive paints for cars. There are still so many possibilities for harvesting solar energy. So far, we are only using a fraction of them.

How does the light yield of the new solar cell types compare with those based on silicon?

Silicon solar cells need a blue sky and full sunlight. If it is cloudy, they do not yield any electricity. The new types can compensate for this because they still work very well when the light intensity is low. In addition, they absorb solar energy even better than silicon due to their semiconducting properties. Very thin layers of just 100 nanometers are often sufficient for these high-tech materials.

A thinner layer thickness is, of course, economically attractive. Can the new energy materials keep up economically regarding their manufacturing processes?

They do indeed have the potential to become really cheap. That is why we are also working to ensure that they will be used in a wide range of applications in the future. The materials needed for organic, perovskite, and quantum dot solar cells can be produced using wet chemical processes. The starting materials are often available in large quantities and are inexpensive. In addition, smaller amounts of substances are required, and processing usually does not require complex clean rooms. Another advantage is that the materials can be printed in layers on carrier substances. This makes the new solar cells very interesting for industrial production.

Is printing solar cells comparable to printing paper?

Partly, yes. Basic printing techniques such as inkjet and screen printing can also be used for solar cells. The roll-to-roll printing process is particularly interesting because it allows very large areas to be printed in a very short time. However, photovoltaic inks are required, and the printing process is physically very complex. I am investigating this in detail with my team. The active layers consist of complex structures built up through the self-organization of the molecular building blocks. The optimal nanoarchitecture is required to efficiently generate, separate, and transport charge carriers. This is exactly where our research comes in: we fabricate the solar cells ourselves and use special scattering experiments to observe in real time how the layers and structures form during the printing process. This allows us to determine how different components, additives, or solvents influence film formation and self-organization. And, of course, we also measure the structures themselves and the performance of the finished solar cell.

Can organic solar cells or perovskite solar cells keep up in terms of efficiency and operating life?

Absolutely. You only need to take a look at the diagram from the National Renewable Energy Laboratory, which is well-known among energy researchers. Perovskite solar cells have almost caught up with silicon solar cells in terms of cell efficiency, for example, and organic solar cells are on the cusp of reaching 20 percent. One weak point of the new solar cell types is still their relatively short lifetime. That is why we want to better understand the aging process and determine why the materials become unstable at a molecular level over time. Unfortunately, it is often the record-breaking solar cells that do not last very long. Therefore, our findings are very helpful in designing a more stable molecule or improving the film formation process. Temperature profiles, drying times and the selection of solvents play a decisive role here.

Are there other aspects that play a role for you?

We are also trying to establish more environmentally friendly components for the solar cell manufacturing process, such as green solvents. This involves challenges because surface tensions and evaporation rates change. But we have already managed to adapt other process parameters so that more environmentally friendly solvents also work. This is a crucial aspect for industrial production. What is important and motivating for me and my team is that we have a big goal – the broad application of solar cells. Compared to mountain climbing, it is the summit we want to reach. No one would stop ten meters below the summit and let others take the final steps. We keep the entire value chain in mind.

This is also evident from your overarching commitment. How are you networked when it comes to energy?

I founded the TUM Solar Keylab for solar energy research more than ten years ago, which I also head. It is integrated into the so-called Soltech network, which includes four other key labs at LMU Munich and the universities in Erlangen, Würzburg, and Bayreuth. The idea behind it is that research is not carried out in competition but in collaboration. In the third funding period, the focus is now on solar water splitting. I am also involved in the Renewable Energy Network (NRG) at TU Munich's Institute of Integrated Materials, Energy and Process Engineering (MEP). This network brings together experts from a much broader context – engineers, architects, and electrical engineers. These interdisciplinary meetings broaden the perspective enormously, which is particularly inspiring for young researchers and offers exciting starting points for joint projects. The circle is even larger on the TUM Sustainability Board, where I represent the natural sciences and energy aspects. The board also includes medical scientists, social scientists, and political scientists, and the range of issues and projects is very broad. The sustainable transformation of our society must be considered holistically.

Back to the solar cell: Where do you see perovskite, organic, and quantum dot solar cells in the future?

The latter is something of a *rising star*. Quantum dots are a new class of fluorescent nanocrystals that can efficiently emit brilliant colors. The particle size is used to adjust the absorption properties in a unique way and almost the entire spectral range is accessible. For example, we have combined them with triboelectric components, which convert kinetic energy into electrical energy. The idea is that the solar cell harvests solar energy during the day and wind energy can be used at night when the component is bent by the wind, for example. In this way, two energy generation modes could be combined. As already indicated at the beginning, the sun could make every household energy self-sufficient if we capture it everywhere: with windows designed as solar cells, photovoltaic wall paints, indoor photovoltaics or photovoltaic clothing. All these applications require new materials, which we are researching at full speed.

Thank you very much for the interesting interview. We wish you all the best and every success in your research at TU Munich and the e-conversion Cluster of Excellence!

Brief profile

Peter Müller-Buschbaum studied physics at the University of Kiel, where he received his doctorate in 1996. He then worked as a scientist at the MPI for Polymer Research and at the European Synchrotron Radiation Facility in Grenoble, among other institutions. He completed his habilitation in 2002 and headed the Chair of Functional Material at TU Munich, before he was appointed full professor in 2018. From 2018 – 2023, he was Scientific Director of the Research Neutron Source and the Heinz Maier Leibnitz Zentrum. Since 2024, he has served as Deputy Editor of the ACS Applied Materials & Interfaces journal and as member of the TUM Sustainability Board.

Materials in space: Prof. Peter Müller-Buschbaum (right; left: Lennart K. Reb) and his team have already sent solar cells into space for testing and evaluated them from a materials science perspective – with promising results.

Decoding energy conversion with light

Prof. Frédéric Laquai

Using ultrashort light pulses, Prof. Frédéric Laquai and his team are closely tracking the behavior of electric charges. The reason is that when photons (particles of light) strike semiconductors, they trigger highly complex photophysical processes and at best generate usable charges. The physical chemist studies the processes in solar cells and identifies where energy losses occur. Through his spectroscopic experiments, he aims to identify more efficient materials for energy conversion. Laquai joined LMU Munich in August 2024, where he is involved in research, teaching, and the management team of the newly approved e-conversion 2.0 Cluster of Excellence.

What initially led you to study chemistry, and how did you come to focus on your current research area, which deals primarily with semiconductor materials?

I was already very interested in the natural sciences at school. I had dedicated teachers who enabled me to participate in the *Jugend forscht* youth research competition in the late 1990s. The project I submitted focused on organic light-emitting diodes (OLEDs) and won first prize at national level. I was fascinated by the idea of using organic molecules in electronics, which was a very new field back then. During my chemistry studies in Oldenburg and later in Marburg, I specifically looked for ways to continue working in this area. For my diploma thesis, I studied OLEDs and used time-resolved photoluminescence spectroscopy. I deepened this focus during my PhD at the Max Planck Institute for Polymer Research. That laid the foundation for my current research.

What role did your time at the Cavendish Laboratory at the University of Cambridge and the MPI for Polymer Research in Mainz play?

My two-year postdoc stay in Cambridge starting in 2006 was crucial to my scientific development and my future career. During that time, I focused intensively on femtosecond laser spectroscopy, which allows the detailed investigation of ultrafast electronic processes. I learned how to apply this technique and broadened my perspective on time-resolved phenomena. Equipped with this new knowledge, I returned to the MPI in Mainz to establish and lead an independent junior research group for seven years. We worked extensively on charge transport and energy transfer in organic semiconducting materials. Later, other material systems such as hybrid (organic-inorganic) perovskites were added to our research.

You then moved to Saudi Arabia. Tell us about your time at the King Abdullah University of Science and Technology (KAUST).

That's right. In 2015, I joined KAUST as Associate Professor of Materials Science, and later I was promoted to Professor of Applied Physics and became Director of the KAUST Solar Center. I spent more than nine years in Saudi Arabia. At KAUST, I was engaged in research and teaching, while I was also heavily involved in managing the Solar Center. I led a sizeable research group consisting of Master and PhD students as well as postdocs and research scientists, and directed the research center comprising ten research groups.

How did your return to Germany and your move to LMU Munich come about?

That was related to the succession of Prof. Thomas Bein in Physical Chemistry at the Department of Chemistry. I applied for the position because LMU Munich seemed like a very attractive and exciting option, not least because of the e-conversion Cluster of Excellence. In the summer of 2024, I took over the W3 professorship for Physical Chemistry and Spectroscopy of Energy Materials at LMU Munich, and my colleagues invited me to join the future speaker team of e-conversion 2.0.

What are your group's current research priorities?

A main goal of our research is to better understand why energy materials aren't as efficienct as theoretically possible. We examine the processes – the conversion of photons into charges – in every detail, including charge separation, transport, and extraction. At every stage, losses occur that we aim to understand and ideally reduce.

What are the biggest challenges in the lab right now?

You could say time, or rather, the different timescales on which energy conversion processes occur. Processes like generating excited states through light absorption followed by charge separation often happen in less than 100 femtoseconds up to a few picoseconds. Charge extraction takes place over nanoseconds to microseconds. Then there are degradation processes that unfold over much longer periods, from minutes to days or even longer. To cover this wide range experimentally, we need a variety of time-resolved spectroscopic methods. This requires advanced experimental setups where we delay light pulses against each other on optical tables to carry out the measurements. Many of our experimental setups are at least partly self-constructed, allowing us to go beyond what commercial systems can offer.

What is the overarching goal of your research, and which materials are currently in focus?

We aim to uncover structure–property relationships and derive design rules for developing new materials. To do so, we study not only thin films of semiconducting materials but also complete and functional solar cell devices that we fabricate ourselves. By comparing, for example, absorption spectra in the ground and excited state, we can decode how charge generation occurs in the materials. Our findings then help synthetic chemists to design and synthesize new compounds that convert light into electrical energy more efficiently. The energy landscape of the material plays a key role in this. We want to translate our characterization results into general rules for material development. Much of our current work focuses on novel semiconductor materials, both organic and hybrid types, such as perovskites, particularly aiming to reduce or eliminate lead content. We are also investigating materials that could be useful for photocatalytic water splitting, CO_2 reduction, and solar batteries. e-conversion 2.0 offers very promising collaborative opportunities in these areas. After just under a year in Munich, several exciting projects are already underway.

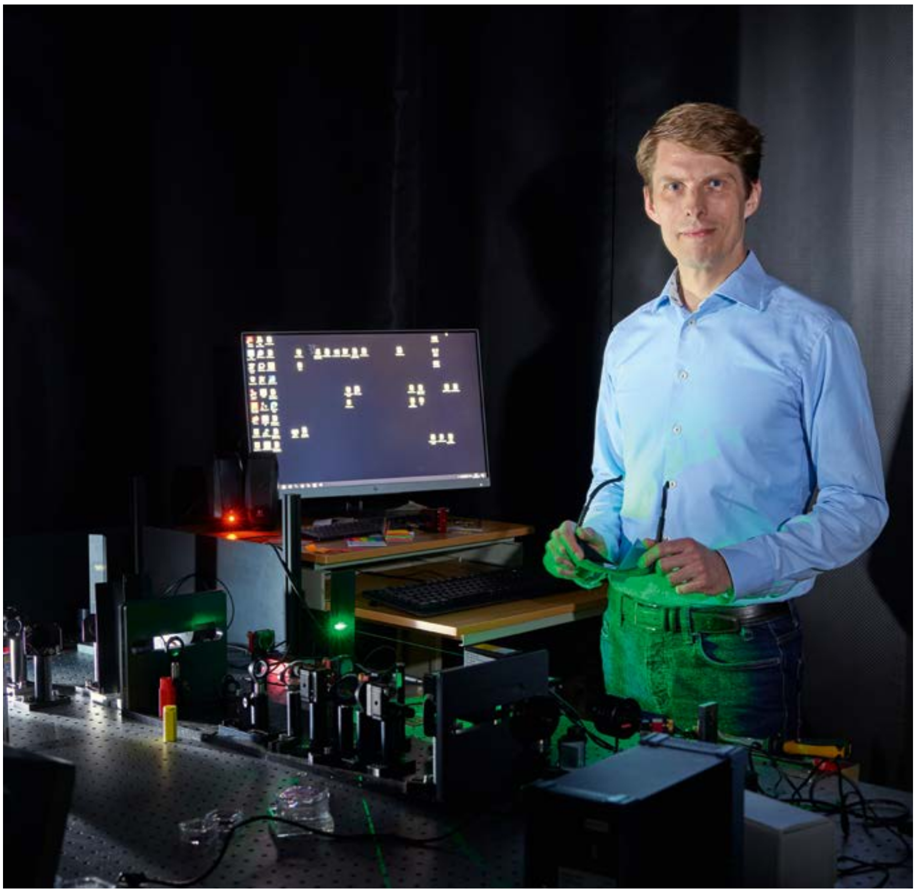
What motivates you personally, and how do you recharge and find new energy?

I'm driven by fundamental research itself: understanding what previously was not understood or observing something entirely new for the first time. That's what keeps me going and truly inspires me. I'm also passionate about providing young people with excellent scientific training, both my team members and our university students. For me, sport is an important way of relaxing and clearing my mind. In Saudi Arabia, I often went jogging, even in 30°C heat, carrying a water bottle. Here, I regularly hop on my indoor bike. I started flying sports planes about twelve years ago, but I haven't had much time for that lately. And, of course, my two elementary school-aged sons also keep me on my toes every single day.

Thank you very much for the interesting interview. We wish you all the best and every success in your research at LMU Munich and the e-conversion Cluster of Excellence!

Brief profile

Frédéric Laquai studied chemistry from 1999 – 2003 at the Universities of Oldenburg, Cambridge (UK), and Marburg. He earned his doctorate in 2006 at the University of Mainz and then worked as a postdoc at the University of Cambridge (UK). From 2008 – 2015, Laquai headed an independent junior research group at the Max Planck Institute for Polymer Research in Mainz. From 2015 – 2024, he conducted research at the King Abdullah University of Science and Technology (KAUST), where he also served as Director of the KAUST Solar Center. Since April 2024, he has held the W3 professorship in Physical Chemistry and Spectroscopy of Energy Materials at the LMU Munich's Department of Chemistry.



Tracking photons: Using ultrashort light pulses, Frédéric Laquai investigates the conversion of photons into charges and the subsequent processes involved in charge generation and transport. His goal is to uncover structure–property relationships and to drive the development of new and promising materials.

Outlook

Save the dates

Escape from Carbonia

October 11 – 17, 2025 | *Science Communication Lab, Deutsches Museum München*
November 7 – 9, 2025 | *Spielwiesn, Augsburg*

On several dates, we invite you to take a closer look at the escape room developed by e-conversion and TU Munich (see page 22) – under the motto *Escape the carbon trap! How can artificial photosynthesis be implemented?*
More information: www.hochschulwettbewerb.net/2025/escape-from-carbonia

e-conversion Cluster Conference 2026

October 5 – 9, 2026
San Servolo, Venice International University, Italy

The annual Cluster Conference is all about connecting cluster members with top researchers from around the world. It's the perfect chance to network, broaden horizons, and discuss research – make sure you save the date now!

For more information and future events visit: www.e-conversion.de/events.

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