Empa Quarterly

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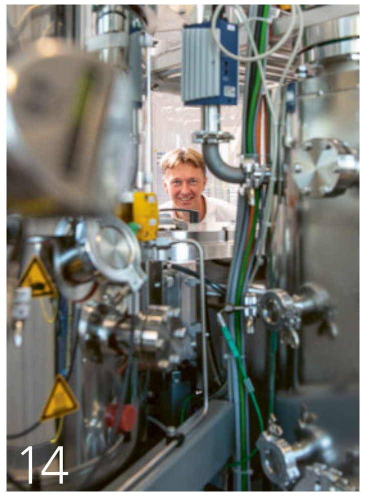
FOCUS: BATTERY RESEARCH

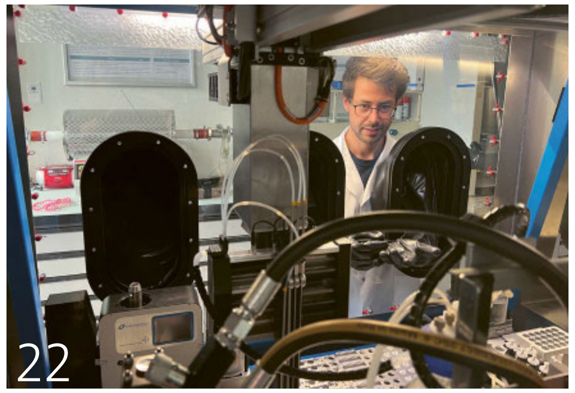
SUSTAINABLE STORAGE

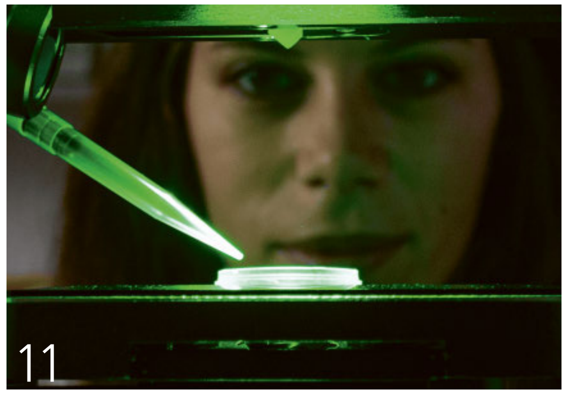
ARTIFICIAL INTELLIGENCE
SIMULATED RAIL NOISE
MINING THE ATMOSPHERE

[CONTENT]

[FOCUS: BATTERY RESEARCH]







Photos: MX3D and Joris Laarman Lab, Kyburz Switzerland AG, Marion Nitsch, Empa (2)

[COVER]

Good batteries are indispensable for the energy transition, and thus for a more sustainable world. Empa researchers are developing batteries for different applications, from electromobility to stationary energy storage. Another important research topic is the recycling of the batteries at the end of their useful lifespan.
Image: Adobe Stock

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HIGH TIME TO THINK BIG

Dear Readers,

There is no question that solutions for the energy transition and the climate crisis are Herculean tasks that require one attitude above all: Think big!

In other words: take a holistic stance and involve all stakeholders who can contribute to finding practicable solutions. This is exactly what we have set out to do at Empa, for instance in battery research, the focus of the current issue (from p. 14). Whether with our sister institutions within the ETH Domain, with industrial partners or in pan-European research consortia – interdisciplinary collaboration is always at the heart of our research activities.

Being able to store energy – in whatever form – is a central pillar of a sustainable energy system, since solar and wind energy are not always available in sufficient quantities when they are needed. That's why battery storage plays a crucial role on the road to net zero.

That is only half the story, though. Over the last 200 years, we have literally littered the Earth's atmosphere with CO_2 from fossil sources. And if you make a mess, you should clean it up afterwards – and maybe do something clever with it.

That – in a nutshell – is the idea behind our large-scale new research initiative Mining the Atmosphere. You can get a foretaste on p. 32 – in the next issue, we will present this ambitious project in more detail. Now that's one hell of a cliffhanger, don't you think?

Enjoy reading!
Your MICHAEL HAGMANN

THE BEAUTY OF IMPERFECTION

Crystal defects can drastically change the properties of functional materials such as "ferroelectrics". These materials have a polarity – comparable to magnets with a north and a south pole, but which can be reversed by applying an electric rather than a magnetic field. This property makes ferroelectrics suitable for use in data storage devices, for example in computers. However, optimizing them for technological applications requires a thorough understanding and precise control of possible defects. Researchers at Empa's Electron Microscopy Center are using state-of-the-art image analysis methods based on scanning transmission electron microscopy to study such "defects" in crystals at the atomic level. In this atomic resolution image, an ultrathin ferroelectric film (the layer of yellowish dots) shows a conspicuous arrangement of particles at the top edge. These atomic "pillars", arranged in pairs on top of each other, can negatively affect the ferroelectric property of the thin film.

Further information on the topic is available at:
www.empa.ch/web/s299

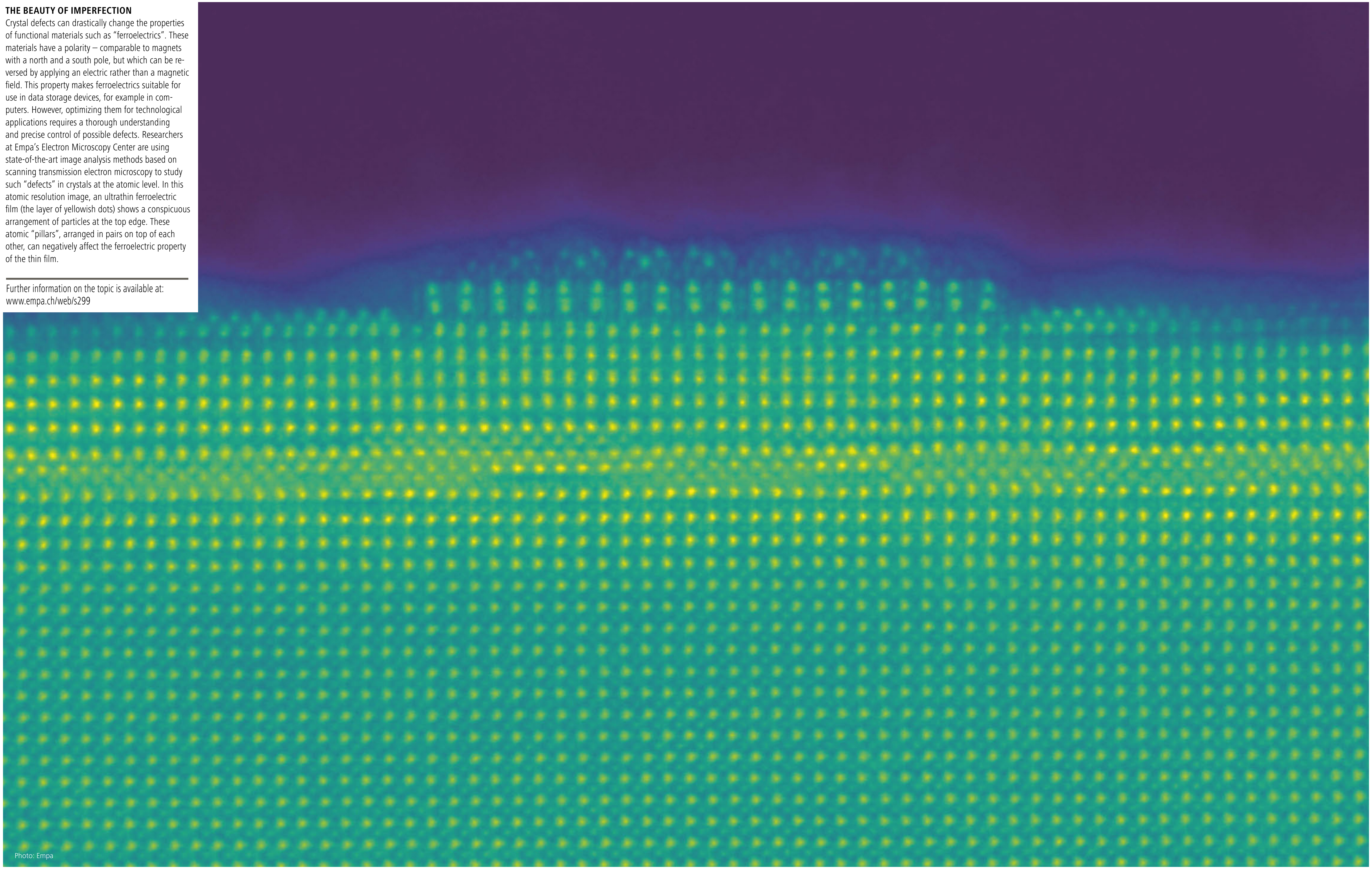


Photo: Empa

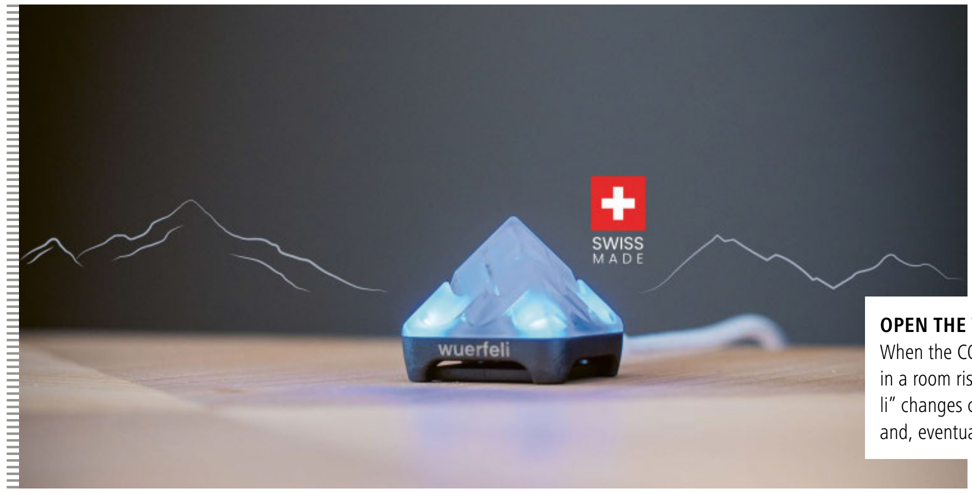
BRIGHT MINDS: REVOLUTIONIZING THE BATTERY MARKET

VIDEO SERIES
In the current episode of "Bright Minds", Empa researcher and spin-off co-founder Abdessalem Aribia talks about highlights and challenges.

Safer and longer-lasting lithium-ion batteries, which can also be manufactured much more sustainably, are soon expected to revolutionize the battery market. Developing such game-changing solutions is no walk in the park. Empa scientists take on that formidable task – and they deliver! High time to put the limelight on the faces behind the novel materials and technologies from our labs: The new video series "Bright Minds: Bold Ideas –Smart Materials" will give you insights about our researchers' journeys and their paths to discoveries all the way to the translation into practical applications. In the current episode, Empa researcher and spin-off co-founder Abdessalem Aribia highlights the challenges and successes in developing this promising battery technology.

www.empa.ch/bright-minds

A LIGHT SIGNAL FOR BETTER AIR



OPEN THE WINDOW
When the CO_2 concentration in a room rises, the "Wuerfeli" changes color to orange and, eventually, red.

The "Wuerfeli" makes air quality visible. The small sensor measures the CO_2 concentration in indoor air and indicates by its color when it is time to ventilate. Moreover, the small pyramid measures parameters such as temperature, relative humidity and air pressure. The sensor was developed with the participation of Empa as part of a large-scale study on air quality in classrooms. The result is an effective and tested air measuring device, manufactured in Switzerland. The start-up QE GmbH, based in Technopark Graubünden, produces the "Wuerfeli", which is now available online.

www.wuerfeli.ch

Photos: Empa, Wuerfeli

Photos: BASF, zvg

FROM FICTION TO INNOVATION

PODCAST
Empa Director Tanja Zimmermann in the studio with Matthias Halusa, Country Manager Switzerland at BASF

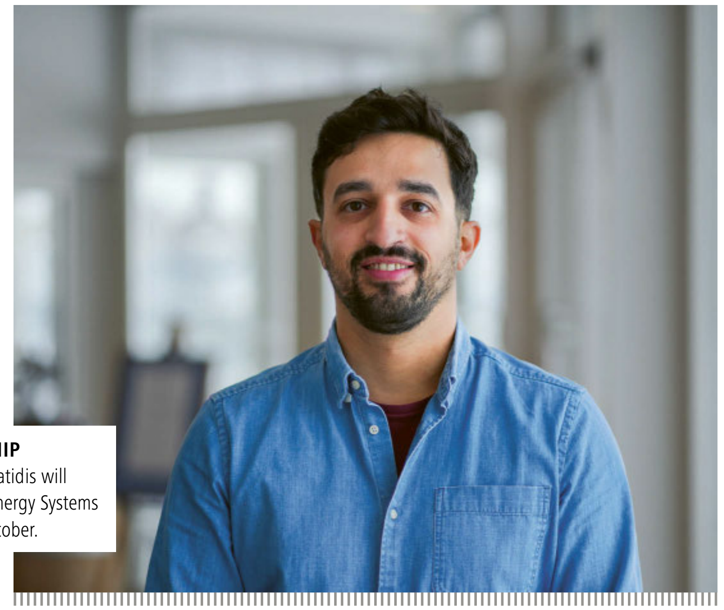
In BASF's "Schweizer Macher" podcast, Empa Director Tanja Zimmermann talks about her vision for Empa as a "beacon for new materials and technologies" and about inspiring ideas for a sustainable future. She also reveals how innovations are created at Empa, how much diversity contributes to this process, and what we can learn from science fiction. The episode (in German) is available on Spotify, Apple Podcasts and on the web.

in.basf.com/lwusxmk

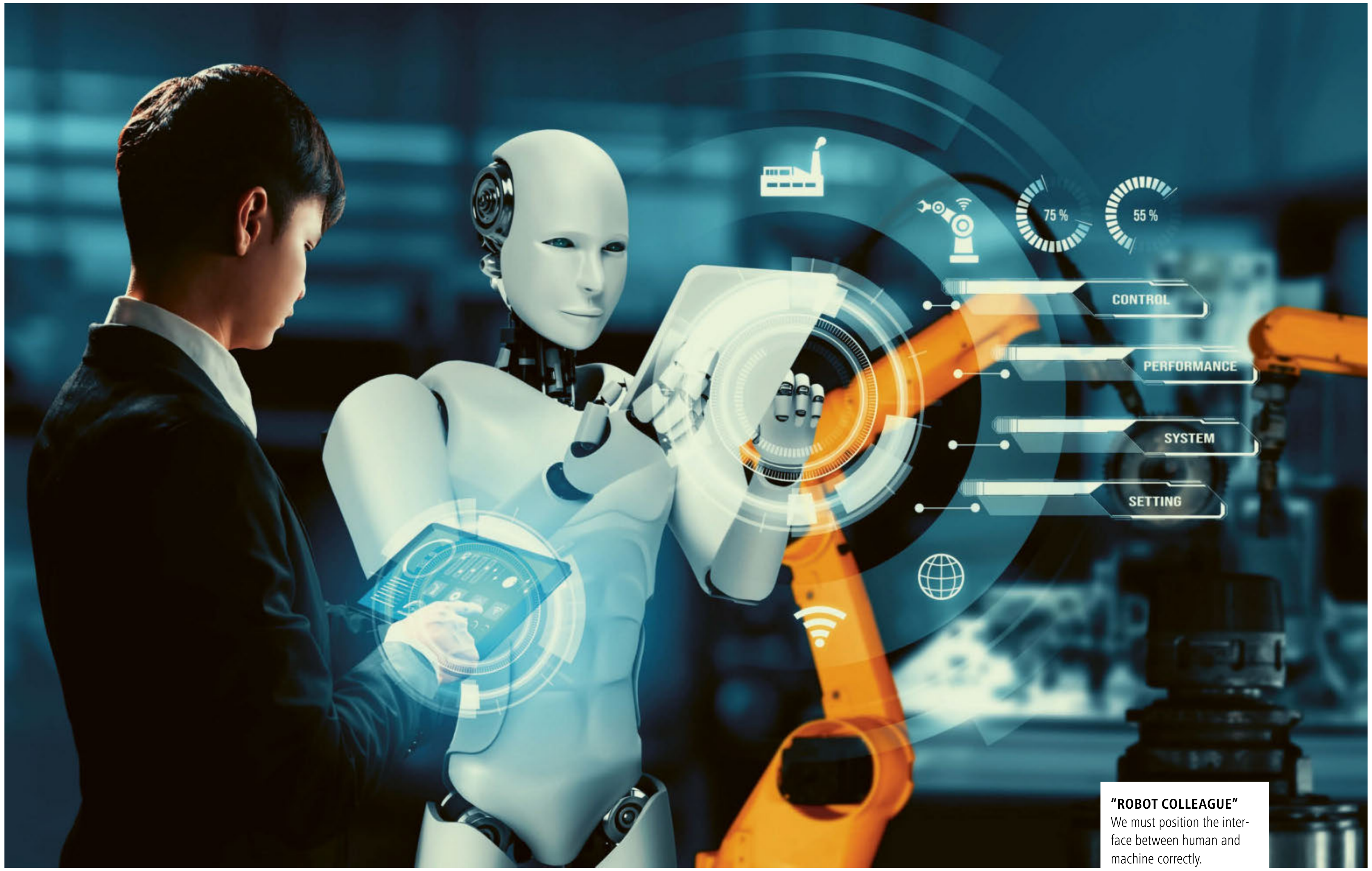
NEW HEAD OF THE URBAN ENERGY SYSTEMS LABORATORY

Starting in October, Georgios Mavromatidis will take over as head of the Urban Energy Systems lab. He will succeed Kristina Orehounig, who will be joining the Vienna University of Technology as a professor in the research area of building physics and building ecology. Currently a senior researcher at ETH Zurich, Mavromatidis has previously been a postdoc at the lab he is now to lead, doing research on multi-energy systems and building energy efficiency. He holds a doctorate in Energy Systems Modelling from ETH Zurich, an MSc in Sustainable Energy Futures from Imperial College London and a Diploma in Mechanical Engineering from Aristotle University of Thessaloniki.

www.empa.ch/web/s313



NEW LEADERSHIP
Georgios Mavromatidis will head the Urban Energy Systems Lab starting in October.



"ROBOT COLLEAGUE"
We must position the interface between human and machine correctly.

Photo: Adobe Stock

AI: ONCE A MERE TOOL – SOON A PARTNER ON EQUAL FOOTING?

Artificial intelligence – AI – is not just all over the media, but is also making its way into our work environments, from industrial manufacturing to research. But how can we best exploit potential synergies of man and machine, and what must we consider? Here are some thoughts from Pierangelo Gröning, until recently a member of Empa's Directorate.

Text: Pierangelo Gröning

Computers and the Internet are core technological pillars of our increasingly digitized society, enabling data to be accessed, processed and exchanged at speeds far beyond human capabilities. And when it comes to physical work in the real world, robots have revolutionized industrial manufacturing processes by performing these tasks faster, more reliably and with greater endurance and precision than is possible for us humans.

With the increasing spread of artificial intelligence (AI), these technologies are likely to evolve from mere aids and "vicarious agents" to (more or less) equal partners in human endeavors in the not too distant future. They will not only perform assigned tasks accurately and highly efficiently, as they have in the past, but they will also devise, suggest and, if necessary, perform them independently. Computers, robots and AI will thus become work colleagues, giving the term "human-machine interaction" a completely new quality.

In general, collaboration is particularly successful when both the strengths and weaknesses of the partners involved are known, all partners focus first and foremost on their strengths and apply them in a goal-oriented manner. This will equally apply to collaboration with "robot colleagues" or "AI colleagues"; indeed, it will be essential. A key factor is the correct positioning of the interface between human and machine, so that the synergy potential of the "team" is exploited to the fullest – and, above all, to the benefit of the human being!

The first widely known applications are robots in care and rehabilitation, chatbots for customer service, or the almost ubiquitous ChatGPT. The latter now enables everyone to access AI and, thanks to self-learning algorithms, provides plausible answers to (almost) any question on the basis of the data available on the Internet; it even generates entire texts (more or less meaningful depending on the problem at hand) by means of a few keywords, whether as a summary, in prose or as poetry, to name but a few.

In science and research, AI and the underlying machine learning algorithms have long been everyday tools. Whether it is to use AI, similar to digital route planners, to compile the reaction steps of complex (bio)chemical synthesis pathways from the starting substances to the final products, or to optimize process parameters in complex manufacturing processes such as 3D metal printing, to name just two areas of application from research at Empa.

For society as a whole, however, everyone agrees that dealing with AI and AI-based systems will be an enormous challenge. Social networks and the algorithms behind them, which follow their own business or "like" logic – with all the well-known side effects such as fake news, etc. – are a first small taste of this. The risk of job losses is another issue we have to face as a society.

THE KEY QUESTION: HOW CAN AI BE MADE SOCIALLY ACCEPTABLE?

Aware of this, governments, NGOs and other stakeholders are currently discussing measures and regulations on how AI can be made socially acceptable, to put it bluntly. On the other hand, the large US tech companies that offer and distribute AI and use it for their own commercial success promise to manage AI in a responsible manner. Will that be enough?

In order to establish a harmonious coexistence between humans and AI, it will be necessary to reflect on ▸

BUILDING BRIDGES
The goal is a harmonious collaboration and coexistence between humanity and AI.

the values and role of humans in a world with AI. Addressing very fundamental questions such as "Is an AI-generated painting art – or is it simply a composition of colors on canvas?" or "Can a novel written by AI be considered literature?" – in other words, what actually is creativity? – will perhaps help to use AI sensibly and for the benefit of mankind.

As far as industrial manufacturing is concerned, the EU Commission has already developed the vision "Industry 5.0 – Towards a Sustainable, Human-centric and Resilient Industry"[1] in 2020 and described it as follows: "Industry 5.0 profoundly restructures human tasks in the realm of manufacturing in ways that benefit the workers. They will be upskilled to shift from manual to cognitive labor, to provide value-added tasks in production and to work – with peace of mind – alongside an autonomous workforce."[2]

However, AI and AI-supported systems will also massively change the research and development landscape. On the one hand, AI will significantly shorten development cycles and – as a result – bring applied research and development even closer together, even to the point of merging in certain areas. In extreme cases, applied research could even become obsolete, because problem-solving-optimized AI will provide a suitable answer to every clearly defined question – in other words, a product. Commercial success is thus likely to become a central indicator for assessing the quality of this type of "research".

On the other hand, the primary product of research – data – is of outstanding importance. Because how does AI learn? How does it continue to develop? By constantly being fed with new – and above all reliable – data. Mind you: non-AI-generated data, so it needs input from outside! This should give additional impetus to the Open Data policy, the free access to research data. If this does not happen, or not to a sufficient extent, or only with "qualitatively inferior" data, AI will soon deliver the same thing over and over again, or – even worse – probably only nonsense.

Finally, to achieve real progress, new and inventive breakthrough science is still direly needed. Despite the immense possibilities that AI opens up for research, the basis for achieving scientific quantum leaps or opening up new scientific horizons will continue to be curiosity, perseverance and intuition. And above all, a pronounced culture of failure, because you only learn from mistakes, from failure – whereas AI is primarily designed to avoid mistakes. These virtues must be preserved at all costs; they must not be allowed to fall victim to the lure of quick success made possible by AI. ■

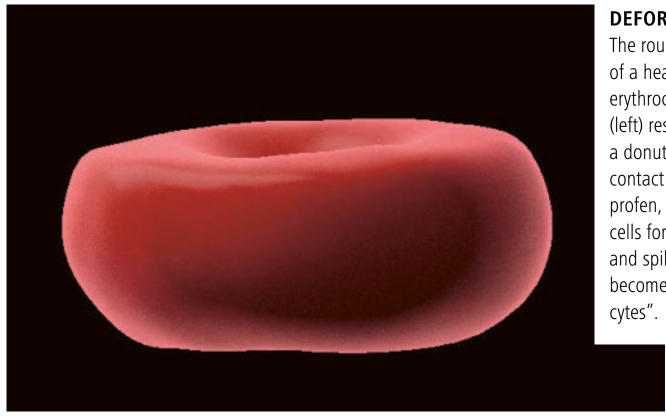
[1] ISBN 978-92-76-25308-2
[2] F. Longo et al. Appl. Sci. 10 (2020) 4182

Photo: MX3D and Joris Laarman Lab

OUT OF SHAPE

Empa researchers have observed living red blood cells transforming into spiky "echinocytes" in real time when treated with high concentrations of ibuprofen using holotomographic microscopy and displayed them in 3D renderings. They recently published their findings in the scientific journal "ACS Nanoscience Au".

Text: Andrea Six



DEFORMED
The round shape of a healthy erythrocyte (left) resembles a donut. After contact with ibuprofen, the blood cells form bumps and spikes and become "echinocytes".

Images: Empa

Blood is indeed "a juice of rarest quality." What the poet and natural scientist Goethe already suspected can now actually be visualized using innovative imaging techniques. One of these special features is the cell that occurs most frequently in the bloodstream: the erythrocyte. Trillions of these red blood cells make their way through the human body every minute. The fact that they do not always take on a round shape enables them to squeeze through the narrowest blood vessels to supply the most remote corners of our body with oxygen.

However, some changes in the shape of erythrocytes are also typical of special changes in the environment: so-called echinocytes with spiny extensions similar to a sea urchin occur, for instance, in the case of burns, liver damage, or after contact with certain drugs. Empa researchers have now observed the transformation of red blood cells into echinocytes using digital holotomographic microscopy.

Talia Bergaglio and Peter Nirmalraj from Empa's Transport at Nanoscale Interfaces laboratory in Dübendorf provoked the deformation of living red blood cells by adding the drug ibuprofen. They were able to show the transformation of roundish donuts into echinocytes in real time thanks to holotomographic microscopy. This innovative technique works similarly to computed tomography (CT), where imaging takes place via laser technology instead of X-rays. Digital holotomographic microscopy is therefore particularly suitable for biological samples such as blood cells, as it enables high-resolution, non-contact and marker-free images to be taken, which can then be reconstructed as three-dimensional representations.

Red blood cells are ideal model cells for this purpose, as they can be easily identified even in whole blood and given their morphology is sensitive to chemical and physical environment, during the course of their existence; they are ultimately (almost) empty membrane shells. "Therefore, the interactions of a variety of drug molecules with the cell membrane can be studied particularly well on red blood cells using our bio-imaging technique," says Empa researcher Nirmalraj. ■

Further information and videos on the topic is available at: www.empa.ch/web/s405

MAPPING THE MENISCUS

Knee operations on the meniscus cartilage are a frequent procedure on a particularly complex part of the human body. Empa researchers want to provide an improved basis for clinicians in order to reduce the risks of the operation. Using 3D models based on micro-computed tomography analyses in the laboratory, they are mapping the blood vessel network of the meniscus on a nanometer scale.

Text: Andrea Six

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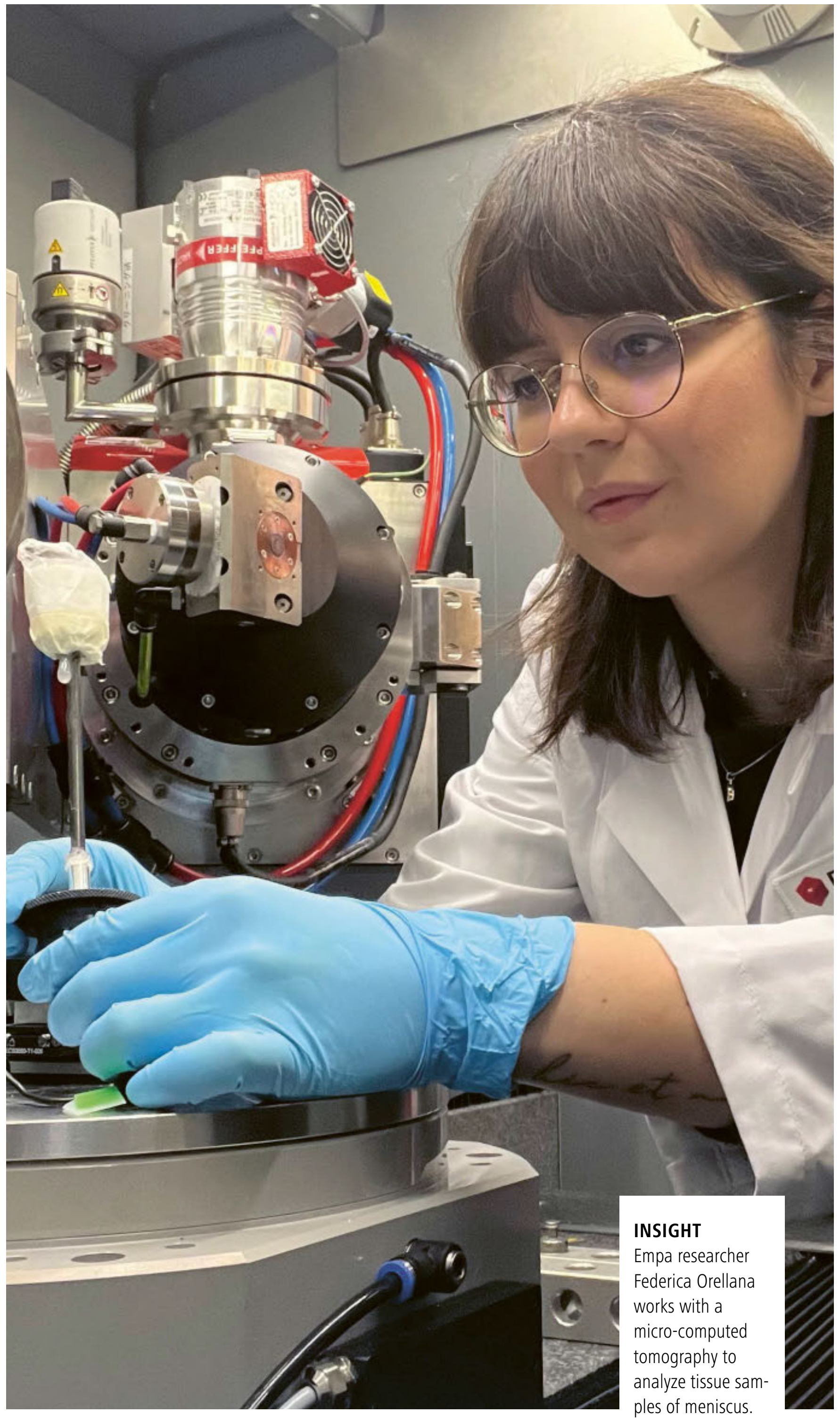
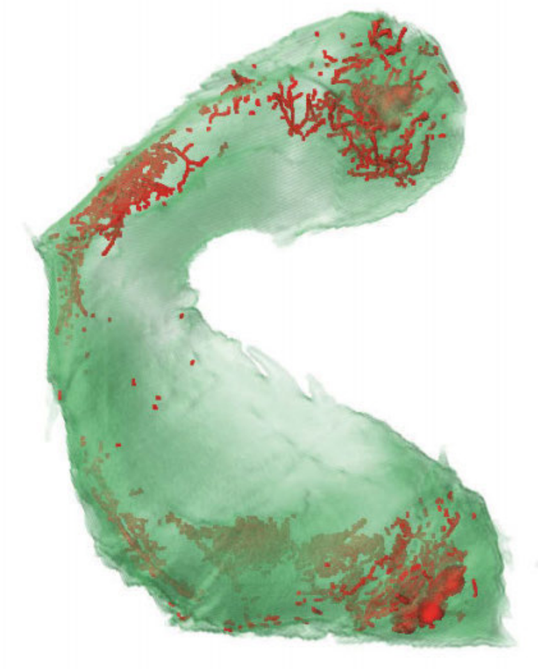
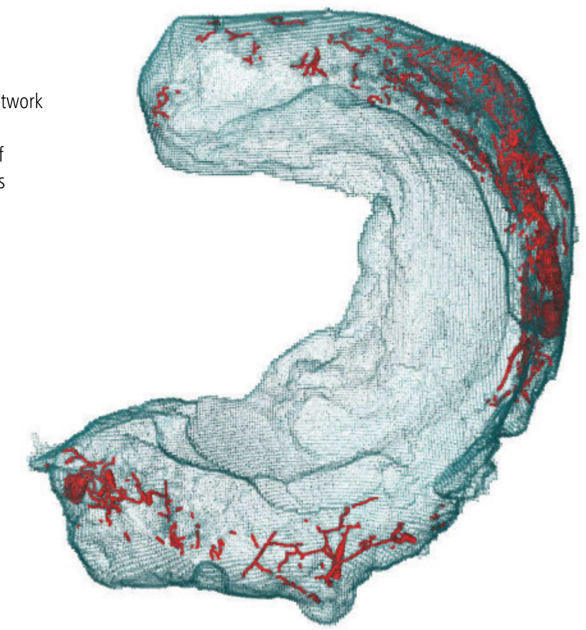
The knee joint is an extremely complex biomechanical evolutionary achievement. Anyone who has suffered an injury there knows the painful tests of patience during diagnosis and therapy. A non-trivial player in the anatomical orchestra of the compound joint is the meniscus cartilage. Empa researchers are now creating a "3D map" of the precious cartilage.



INSIGHT
Empa researcher Federica Orellana works with a micro-computed tomography to analyze tissue samples of meniscus.

Photo: Empa





INTRICATE
The meniscus and its network of blood vessels in a 3D rendering. The course of the blood vessels (red) is clearly visible.

Graphics: Empa

As a crescent-shaped sliding cushion, the meniscus absorbs shocks and enables smooth movement between the upper and lower leg. However, the two menisci per knee are susceptible to wear and injury. For example, about one in three knees in the population age 40 and older exhibits significant meniscus wear, and about 15 percent of all knee joint accidents involve the meniscus. According to the accident insurance company Suva, these accidents alone cause annual health care costs of over 650 million Swiss francs in Switzerland.

If a surgical procedure is to be performed on the knee, the meniscus is generally not a favorable candidate because the so-called fibrocartilagineous tissue is only supplied with blood in certain sections. Precise knowledge of this valuable vascular plexus is helpful to improve healing chances. Until now, however, information has been based on two-dimensional images of tissue sections. This means that valuable data is lost, for example on the deformability of the tissue or the interconnectedness of the vessels.

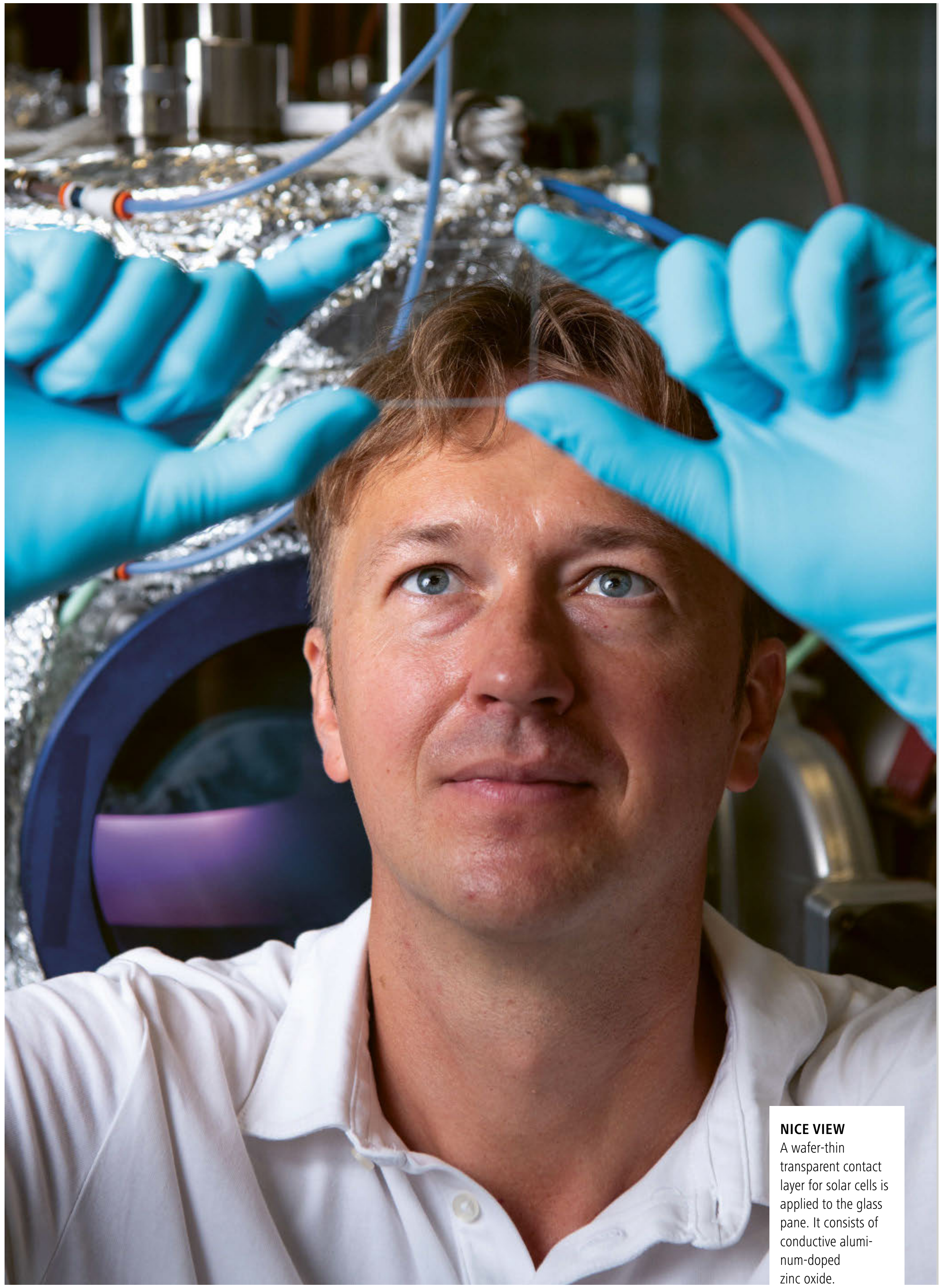
"We want to create a three-dimensional 'map' through the meniscus with high precision," explains Federica Orellana from Empa's Center for X-ray Analytics in Dübendorf. According to the biophysicist, this could optimize treatment and enable tailored therapies in the sense of personalized medicine.

With this project, funded by the Swiss National Science Foundation (SNSF), Federica Orellana and principal investigator of the project, Annapaola Parrilli, are striving for a level of accuracy that cannot be achieved with equipment in hospitals. Compared to the millimeter resolution of clinical computer tomography, the micro- and nano-computer tomographs in Empa's laboratories can even go below the micrometer limit. From these radiological images, the researchers create mathematical models that can be used to record and map the density, structure, biomechanical deformability and vascular network of cartilage in space.

Together with clinical partners at the Istituto Ortopedico Rizzoli in Bologna, the Cantonal Hospital Winterthur, and the University of Zurich, the researchers are currently working with a large number of laboratory samples in order to build up as meaningful a data base as possible. Initial computer simulations already show the branching veins in the meniscus with promising precision. The micro-CT images convey the structural complexity of the meniscal tissue and, in the mathematical modeling, also allow further information such as the porosity or how strongly the blood vessels are tortuous.

Federica Orellana is currently working on a 3D atlas of healthy meniscus tissue samples. In a next step, CT images of all kinds of injuries and wear and tear will be integrated into the models. Patients could thus receive essential information on the self-healing potential of the tissue directly during an examination, and the strategies for individual treatment could be optimized. The biophysicist emphasizes that the 3D map can be used for accident patients as well as for wear and tear processes in old age. ■

Further information on the topic is available at: www.empa.ch/web/s499



NICE VIEW
A wafer-thin transparent contact layer for solar cells is applied to the glass pane. It consists of conductive aluminum-doped zinc oxide.

Photo: Marion Nitsch

THIN LAYERS, HIGH GOALS

Yaroslav Romanyuk has been working at Empa for around 15 years on complex thin-film technologies for solar cells, printed circuits, novel solid-state batteries and other applications. Since the beginning of July, he is heading the Laboratory for Thin Films and Photovoltaics and is pursuing ambitious goals with his team – from innovative materials to founding a start-up and using artificial intelligence for future experiments.

Text: Norbert Raabe

He could have lived in Germany, in the US, in Poland perhaps, or at home in Ukraine. But then Yaroslav Romanyuk had his postcard moment. In 2002, he traveled to Lausanne for an interview for a doctorate at EPFL: from Luzk in Ukraine by bus via Poland to Zurich; from there on the train to Lausanne, into the tunnel behind Puidoux – and out into the enchanting vista over the vineyards to Lac Léman. That picturesque place, of which the vernacular says that the German-speaking Swiss tear their return tickets and throw them out of the window.

And so it became Switzerland. Romanyuk's Empa career began in Zurich in 2008, when he moved to Empa from Zurich's Technopark with the now retired lab head Ayodhya Tiwari and his solar cell research group. The chemist shares valuable experience and successes with his former boss, such as several world records in the efficiency of flexible thin-film solar cells, a dozen successful jointly supervised doctoral theses and much more. "Together, we have opened up new fields of research we would never have dreamt of in the beginning!" says Romanyuk.

That's how it should continue: big goals with thin films and novel combinations of materials that have fascinated him since he started doing research. For instance, as a postdoc at the University of California at Berkeley, where he worked on semiconductors made of gallium nitride and similar combinations, doped with rare earths – for light emissions, i.e. optical applications or future lasers. In the end, though, it didn't work. "The obstacles were stronger than me … unfortunately," Romanyuk admits bluntly, "It was a really ambitious idea, though. And I really wanted to try something new at that time."

THE JOY OF WORKING WITH TALENTS

But the proof of the pudding is in the eating. This holds true also for his current research fields. In addition to very targeted projects with his collaborators, such as novel solid-state batteries produced by physical vapor deposition, or printed electronics using digital printing processes, some results also came about unexpectedly, for example transparent security films for invisible "locks". Not everything can be planned, Romanyuk says: "Some discoveries just happen; suddenly and surprisingly, when teams work together with a lot of enthusiasm."

He has mentored and nurtured many talents, with great pleasure, more than 40 diploma and doctoral theses. And numerous graduates, the new lab head recalls, are now working in leading positions at renowned high-tech companies throughout Switzerland. "That's the best part", he says, "watching them develop and get better and better!" Not under pressure, no, because creativity can't thrive that way – but with a large advance of trust, patience and the knowledge that even failures often lead to important progress in the end.

BATTERY STACKS AS A HOPE

Yaroslav Romanyuk is also proud of his co-workers Moritz Futscher and Abdessalem Aribia, who recently founded the start-up company BTRY (pronounced "battery") – with the aim of developing a lithium-ion solid-state battery to market maturity that takes advantage of the rapid charge transport in thin-film batteries. "The problem with this technology is that such batteries only have a small capacity," explains Romanyuk. "Our idea is: We stack at least ten individual cells on top of each other and get powerful batteries that can be charged and discharged in an extremely short time." What's more, such elements are more robust than current products and safer because they are not flammable (see graphic).

YAROSLAV ROMANYUK

CAREER: The scientist studied chemistry at the Volyn National University in Luzk, Ukraine, and graduated summa cum laude with a master's degree in 2002. He then completed his doctorate at EPFL, followed by a two-year research stay at the University of California in Berkeley, which was financed by the Swiss National Science Foundation (SNSF). Romanyuk has been working at Empa since 2008; from 2012, as a group leader, he deputized for the lab head and was responsible for the chemical safety of the laboratory. He also coordinated the "Bike to work" campaign at Empa for more than ten years.

Admittedly, many steps are still needed to develop this technology, which has already been patented, to the point where it is ready for practical use. The specialists are currently working on a lab-scale prototype and are already looking for investors for further development, which could one day also be worthwhile in applications for sophisticated technologies such as aviation. Although, due to the complex manufacturing process, the cost of such batteries will be significantly higher than that of current products, Romanyuk still sees great potential. "For an iWatch, we calculated that our battery would increase the final price tag by about five percent," he explains, "but for a charging time of less than a minute, that could very well be attractive to consumers, couldn't it?"

Diverse technologies, exciting projects, ambitious goals: This means a lot of coordination, lots of mails and contacts, always new research proposals – more management than before and a rigorous workload, also physically. He already acquired the necessary stamina for his very first job in research: a 10-percent stint in the third year of his studies at the Volyn National University in Ukraine.

"My job was to control a furnace for semiconductor crystals at night and set the temperature correctly," Romanyuk recounts, "this meant: waking up every hour, all night long, alone in this huge building!" Conditions that would be unthinkable today – thanks to modern equipment, such as in Empa's Coating Competence Center (see infobox), where thin layers, for example for contacts of thin-film solar cells or batteries, are produced around the clock every day. This is also a cost factor due to the time and energy required.

DIGITAL TWINS AS HELPERS

In the future, this work will become ever more efficient: "We will use machine learning and artificial intelligence," says Romanyuk. One example? Developing digital twins of batteries or solar cells before they are actually manufactured. Such virtual models could be used to predict material properties – and that, in turn, could reduce the number of production cycles needed in a vacuum, thus saving time and energy. "Today, it can take up to a week to manufacture a batch of thin-film batteries," Romanyuk explains. "At Empa, we're the record holders in vacuum, so to speak."

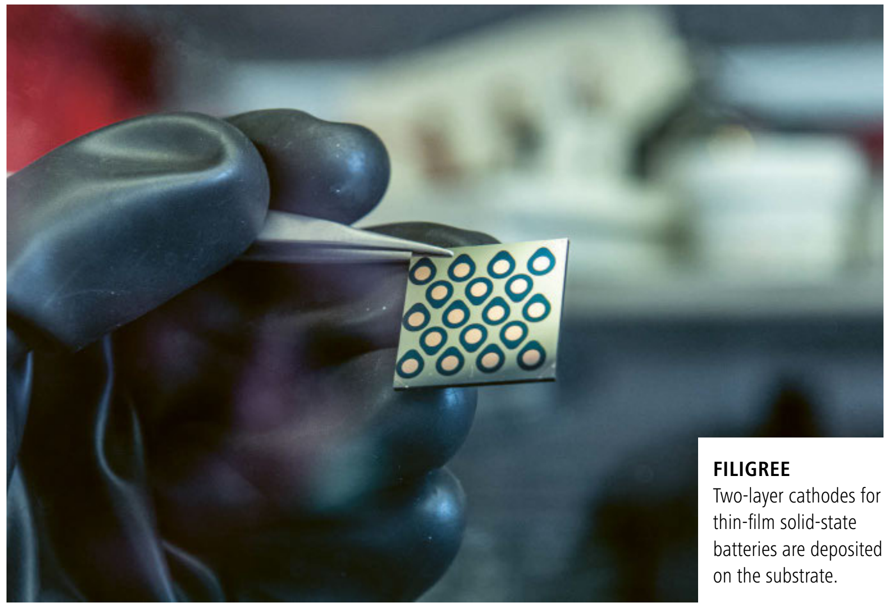
EMPA'S COATING COMPETENCE CENTER

Closing the gap between laboratory research and industrial production for coatings: That is the goal of Empa's Coating Competence Center (CCC for short), which went into operation in 2016. A wide range of technologies are available there for the production of printed electronics, solar cells, thin-film batteries and other elements. These include state-of-the-art 3D printers for additive manufacturing (AM) and equipment for curing layers on substrates with light pulses from xenon flash lamps. Of great importance is so-called magnetron sputtering. In this process, a plasma is generated in vacuum chambers using the noble gas argon, which dislodges atoms from a target, which are then deposited in a targeted manner on the desired substrate. Such layers typically reach a thickness between 10 nanometers and 10 micrometers. With its diverse capabilities, the CCC is structured as a private-public partnership. The idea is for the partners involved to work together along the value chain from science to industry to develop new technologies and find creative solutions.

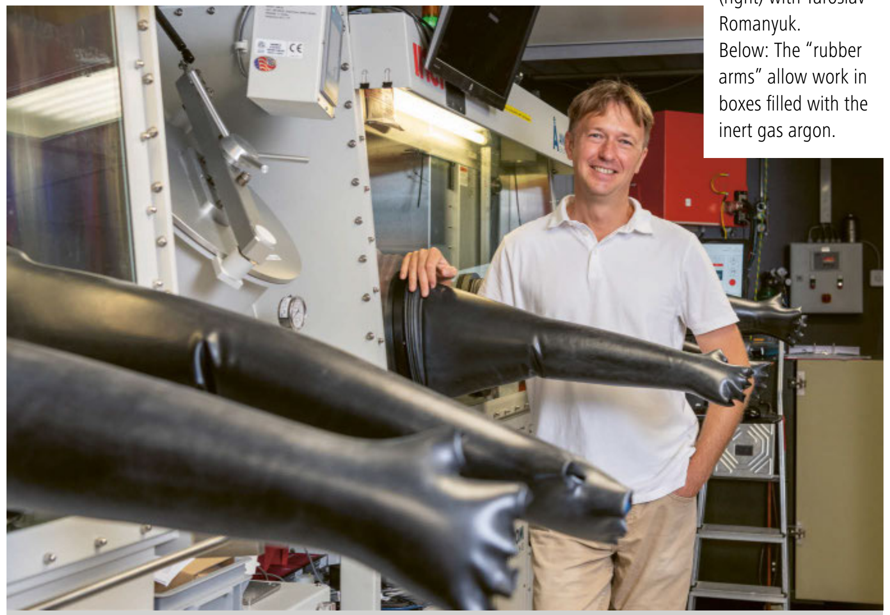
His compensation? Fresh air! Swimming, running, or riding his bike six kilometers to work. And at the nature conservation association at home in Fällanden: Bird watching and counting, building stork nests and nesting boxes, also with his two sons, Marco and Taras, 3 and 14 years old. Romanyuk shows the younger one in a happy photo in the garden – but shortly after the snapshot he reached into a wasp nest and was punished with a sting. "That's when daddy wasn't paying attention for a second," says the chemist with a smile: a prick, painful, yes, but no drama – and a first experience in the matter of great curiosity aka the spirit of research. ■

"Watching young talents develop and improve is the best!"

Further information on the topic is available at:
www.empa.ch/web/s207



FILIGREE
Two-layer cathodes for thin-film solid-state batteries are deposited on the substrate.



TECHNICAL DISCOURSE
Middle: Doctoral student Joel Casella (right) with Yaroslav Romanyuk.
Below: The "rubber arms" allow work in boxes filled with the inert gas argon.

Photos: Marion Nitsch

WHAT'S INSIDE THE BATTERY OF THE FUTURE?

The Empa research group led by Maksym Kovalenko is researching innovative materials for the batteries of tomorrow. Whether it's fast-charging electric cars or low-cost stationary storage, there's a promising material or a novel manufacturing process for every application.

Text: Anna Ettlin

UNDER PRESSURE
Kostiantyn Kravchyk studies whether the unwanted growth of dendrites can be reduced with pressure. The work on the novel batteries is carried out in a protective atmosphere.

Photo: Empa

What are the hallmarks of a good battery? Is it its capacity? How fast it charges? Or its price? The answer depends on where the battery is used, says Empa researcher Kostiantyn Kravchyk. In the Functional Inorganic Materials Group, led by Maksym Kovalenko and part of Empa's Laboratory for Thin Films and Photovoltaics, the scientist is developing new materials to make tomorrow's batteries more powerful and faster – or more cost-effective. Two areas of application for rechargeable batteries are crucial for the transition to renewable energy. One is electromobility; the other is so-called stationary storage, which stores electricity from renewable energy sources such as wind and sun. Batteries for electric cars must be compact and lightweight, have a high capacity and charge as quickly as possible. Stationary batteries may take up more space, but they are only cost-effective if they are as cheap as possible.

NO SIMPLE TASK

In essence, every battery consists of a cathode, an anode and an electrolyte. In conventional lithium-ion batteries, the anode is made of graphite, and the cathode material is a mixed oxide of lithium and other metals, such as lithium cobalt(III) oxide. The electrolytes are used as transmitters of lithium ions from the cathode to the anode and back, depending on whether the cell is being charged or discharged.

When it comes to batteries for electromobility, a high energy density is required. "With an anode made of pure metallic lithium instead of graphite, we could store many times more energy in a cell of the same size," says Kravchyk. However, the lithium is not stripped and deposited evenly when the cell is charged and discharged. This results in the formation of so-called dendrites: branched structures of metallic lithium that can short-circuit the battery.

One way to slow down the growth of dendrites is to use solid electrolytes. In so-called solid-state batteries, instead of a liquid, a solid layer of material conducts the lithium ions from the cathode to the anode and back.

The requirements for the electrolyte material are high. "People talk about charging batteries within ten to fifteen minutes," Kravchyk explains. "That requires a very high current density, at which dendrites form even in solid-state batteries." Current density is the ratio of the current to the area through which it flows. A further issue is that the uneven stripping and deposition of lithium creates voids at the boundary between the electrode and the solid electrolyte, reducing the available contact area and further increasing the current density.

ONE MATERIAL, TWO LAYERS

As part of the Fraunhofer ICON (International Cooperation and Networking) funding program, Kravchyk and other Empa researchers have now refined a promising solid electrolyte. The material, lithium lanthanum zirconium oxide, or LLZO for short, has high ionic conductivity and chemical stability – ideal properties for use in batteries.

"We have made a bilayer LLZO membrane consisting of a dense and a porous layer," says Kravchyk. If lithium is stored in the pores, a very large contact area is created between the lithium and the electrolyte, and the current density remains low. The dense layer ensures that no dendrites can grow to the other electrode and cause a short circuit. The researchers have also thought about cost-effectiveness: They have developed a simple, inexpensive and scalable process to produce the bilayer membranes.

INEXPENSIVE IRON INSTEAD OF COSTLY COBALT

The researchers took a very different approach in a project involving stationary storage of renewable energy. "The most important metric for stationary storage is the price," Kravchyk explains. The lithium-ion batteries used for stationary storage today are comparatively expensive. "That's why most of stationary storage needs are still met by pump storage hydropower technology, even though it has a very low energy density compared to batteries," the researcher continues.

One of the biggest cost drivers for stationary lithium-ion batteries are the materials used to manufacture them. In addition to lithium, cobalt and nickel are needed for the cathode. The search for better cathode materials quickly led the researchers to one of the most common elements in the Earth's crust: iron.

For their cathode, the researchers combined the inexpensive metal with fluoride in the form of iron(III) hydroxyfluoride. "Previous approaches to making a battery based on iron fluorides relied on chemical conversion," Kravchyk explains. This involves converting iron ions into metallic iron. "This process is not very stable," the researcher states. "Ideally, the ions simply move from one pole to the other without undergoing major structural transformations."

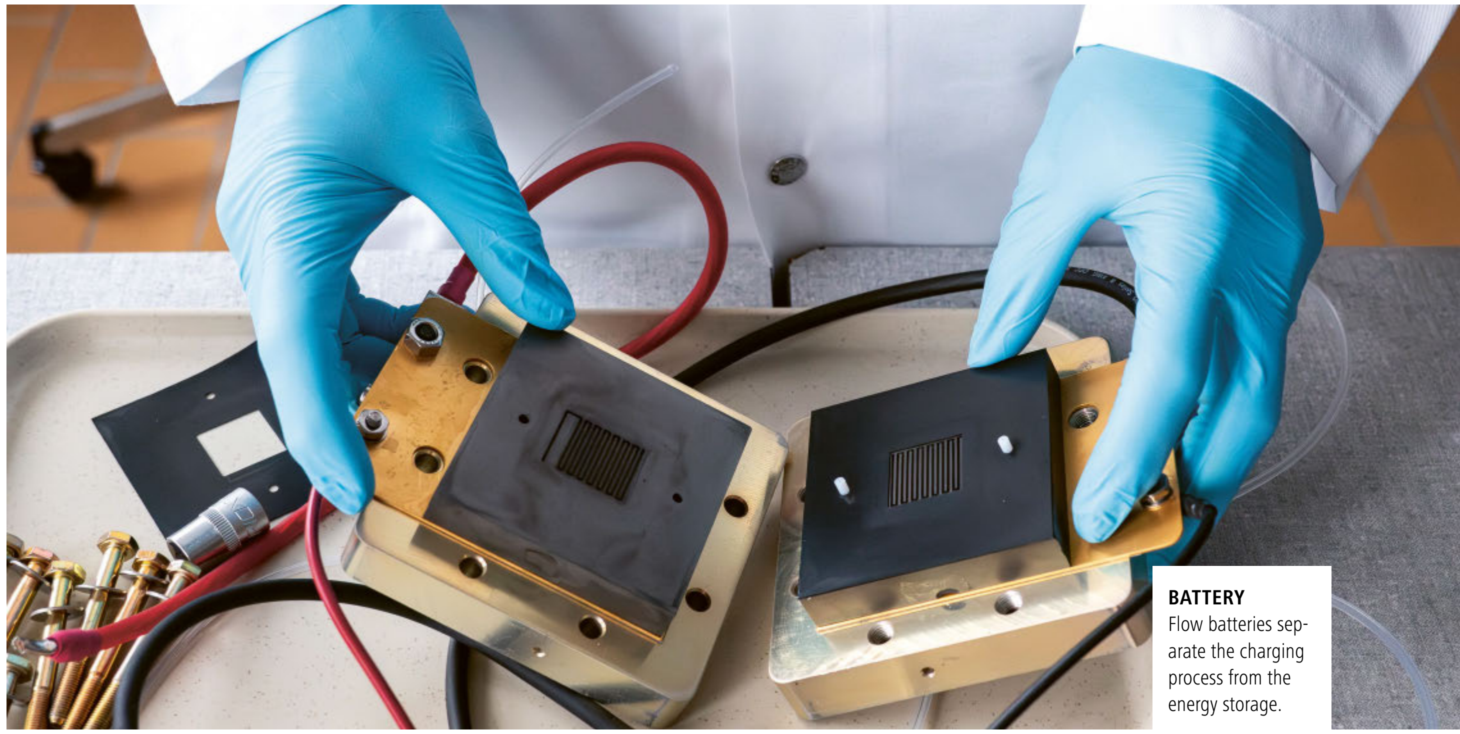
A challenge for the researchers, since fluorides have poor conductivity, both for electrons and for lithium ions. But Kravchyk's team has the solution: Using a simple and inexpensive process, they have given their iron(III) hydroxyfluoride a particular crystalline structure. This so-called pyrochlore structure contains channels inside it that conduct lithium ions.

"We were able to achieve comparable performance at a much lower price with our battery," Kravchyk says. "We are totally surprised that hardly anyone has explored to develop the low-cost synthesis of this promising material until now." ■

Further information on the topic is available at: www.empa.ch/web/s207

RESEARCHER
David Reber's goal is to develop a better kind of flow battery.

Photo: Empa



BATTERY
Flow batteries separate the charging process from the energy storage.

Photo: Empa

THIS IS A BATTERY

Non-toxic and scalable water-based flow batteries would be a good solution for storing renewable energy in urban areas – if it weren't for their very low energy density. Empa researcher David Reber wants to remedy the situation with clever materials design.

Text: Anna Ettlin

Two colored liquids bubbling through tubes: Is this what the battery of the future looks like? Empa researcher David Reber has set out to answer this question over the next four years with the support of an Ambizione grant from the Swiss National Science Foundation (SNSF).

So-called redox flow batteries have been known since the 1970s. Unlike conventional lithium-ion batteries, they store energy not in solid electrodes but in tanks containing liquid electrolyte solutions. The charging and discharging process does not take place in the tanks themselves; the electrolytes are pumped through an electrochemical cell instead.

Liquid batteries are impractical for cell phones, laptops or cars. But they are very promising for stationary storage solutions. Since the energy is stored outside the actual cell, flow batteries can benefit from a simple and targeted scaling. A larger electrochemical cell makes the battery charge and discharge faster, larger electrolyte tanks allow it to store more energy.

"As we use more renewable energy, we will need energy storage on a large scale – even in urban areas," Reber says. Another point for flow batteries: If water-based electrolytes are used, they are basically non-flammable, unlike conventional lithium-ion batteries.

OUTSOURCED ENERGY DENSITY

Nevertheless, the technology has not yet caught on. Reber knows the main problem: "Flow batteries have an energy density around ten times lower than batteries made of solid storage materials," he explains. The more storage material can be dissolved in the electrolyte, the higher the energy density of a flow battery. "However, high concentrations thicken the solution, and you need a lot more energy to pump it through the cell," the researcher says.

Reber now wants to solve precisely this problem in his work in Empa's Materials for Energy Conversion laboratory – with an unusual approach. While most projects on flow batteries focus on better solubility of the storage materials, he wants to completely decouple energy storage from the electrolyte solution. "My vision is to develop a hybrid of sorts of a flow battery and a lithium-ion battery," he says. To do this, Reber wants to add solid storage materials, such as those used in cell phone batteries, to the flow battery's tank. "If the dissolved material and the solid storage material are precisely matched, they can transfer energy between each other," Reber elaborates. "This allows the scalability of flow batteries to be combined with the high energy density of batteries with solid storage materials."

WANTED: SUITABLE MATERIALS

But first, the researcher needs to find suitable pairs of materials that enable the energy exchange while also remaining stable over an extended period of time. "Ideally, a redox flow battery should be able to operate for about 20 years," he says.

Whether a pair of materials fits together depends on what is known as the redox potential of the substances: at what voltage they donate or accept electrons. "I already have several possible pairs in mind," Reber says. And if a promising pair doesn't quite match, its redox potentials can be manipulated with certain chemical tweaks. One of Reber's ideas is to use a chelate as the dissolved storage material: a multi-armed organic molecule that "wraps" around a metal ion. Depending on how many arms the organic molecule – the ligand – has, the redox potential changes. Reber already conducted research on chelate-based redox flow batteries during his postdoctoral period at the University of Colorado Boulder, for which he will receive the prestigious Battery Division Postdoc Award at the annual meeting of the Electrochemical Society in Gothenburg in October.

At the end of his Ambizione funding period of four years, Reber hopes to have a well-functioning battery with additional solid storage. "If this approach works, the potential applications are very diverse," he says. For example, compact flow batteries with a flexible form factor would be much easier to integrate in urban areas. "All it would take would be pumps and a few pipes," the researcher adds. ■

Further information on the topic is available at: www.empa.ch/web/s501

A SPRINGBOARD FOR BATTERY RESEARCH

Empa researchers want to accelerate the development of urgently needed new energy storage systems with the help of the Aurora battery robot. The Aurora project is part of the European research initiative Battery2030+, which was recently awarded over 150 million euros in funding by the EU. In addition, the project is part of the ETH Board's "Open Research Data" initiative, which promotes digitization and free access to research data.

Text: Andrea Six

The world urgently needs new types of energy storage. Developing completely new concepts for batteries and exploring their potential is currently a lengthy process, as Corsin Battaglia, head of Empa's Materials for Energy Conversion laboratory in Dübendorf and professor at ETH Zurich, emphasizes: "Our goal is to accelerate this process," he says. This acceleration is currently manifesting itself in the form of the Aurora robot platform, which is to take over the fully automated and, in the future, autonomous material selection, assembly and analysis of battery cells in the laboratory. As part of the European Materials Acceleration Platform, which is being set up within the European Battery2030+ project BIG-MAP, the aim is to achieve a roughly tenfold acceleration of current development processes.

For internationally competitive battery research and development, time-consuming and error-prone steps in the innovation process are now being automated using Aurora. The robotic platform is currently being further developed in the Empa laboratories together with the company Chemspeed Technologies AG. Empa researcher Enea Svaluto-Ferro is implementing the work steps and "training" Aurora. "While the robot weighs, doses and assembles the individual cell components with constant precision, initiates and completes charging cycles precisely and performs other repetitive steps, researchers can use the generated data to drive the innovation process forward," says Svaluto-Ferro.

In future, however, Aurora will also learn to work autonomously. Using machine learning, the Aurora AI could thus create mathematical models and decide which experiments should be carried out in the next step and which materials and components are particularly promising candidates for the desired battery application. This is because the search is currently underway worldwide for new battery materials that are inexpensive, readily available and do not entail any technical disadvantages.

EU INVESTS 150 MILLION IN SUSTAINABLE BATTERIES

Battery 2030+ is a pioneering European research initiative making strides to develop the batteries of the future. Their focus is on green, high-performing, and long-lasting batteries instrumental in the transition to a carbon-neutral society. Under Horizon Europe, the EU's research program, over €150 million funding has been awarded to cutting-edge projects coordinated by Battery 2030+. This signifies a renewed confidence in Battery 2030+ with the goal to make Europe the world leader in the development and production of green batteries.

Since the platform can be used independently of materials, battery chemistry and generation, it could therefore be used not only to improve lithium-ion batteries, but also to develop alternative sodium-ion batteries or batteries with a self-healing mechanism in the future, Svaluto-Ferro said." "With the chemistry-agnostic Aurora, we can also bring prototypes from our labs, such as salt water batteries or solid-state batteries, to market more efficiently and quickly," says lab head Corsin Battaglia.

Aurora is not alone in this effort. The robotic platform is embedded in the ETH Board's Open Research Data initiative, which aims to promote digitization in research and make data freely available to the scientific community. One of the tools used is AiiDA, an open source workflow management system developed as part of the National Center of Competence in Research MARVEL. For the communication between the Aurora AI and the AiiDA platform, Empa researchers are currently developing the appropriate software in collaboration with researchers at EPFL and PSI. This makes Aurora the first robot platform to be coupled to the existing AiiDA system. Data will finally be transferred to the data management system openBIS, which is being developed at ETH Zurich.

For battery research, this means that the numerous process steps during battery cell development and manufacturing can be efficiently monitored and evaluated, and data can be traced back to its source at any time. "This will allow innovation processes to be further accelerated and provide Industry 4.0 with a comprehensive digitalization strategy in the field of research and development," says Empa researcher Corsin Battaglia. ■

Photo: Empa

UNDER A PROTECTIVE ATMOSPHERE
In the glove box, Enea Svaluto-Ferro controls the process steps.

Further information on the topic is available at:
www.empa.ch/web/s501/research

(UN)WANTED: HEAVY METALS

Although strict limits exist, older types of batteries can still contain too many hazardous ingredients such as mercury, cadmium and lead. The Federal Office for the Environment (FOEN) has therefore launched a control campaign. Empa has laid the foundations for this with a novel tailor-made method for analyzing heavy metals.

Text: Rémy Nideröst

RISK
Older types of batteries can contain too many heavy metals.

Photo: Empa

Our lives would be inconceivable without batteries as energy storage devices. They are practically everywhere and are used as starter batteries in cars, in industrial equipment, but also in everyday objects such as toys, watches, radios, laptops, phones, flashlights, hearing aids, and so on. The demand for batteries – including rechargeable batteries – is huge. And because of the high demand for raw materials used in electricity storage devices, they are already becoming scarce in some cases and thus more expensive. Therefore, intensive research is being conducted to replace scarce or even rare materials with more common ones.

What's more, some ingredients of certain batteries such as cadmium or lead are harmful to human health or even toxic. Here, too, science is looking for unproblematic substitutes. And indeed, there are promising new approaches to further improve the sustainability of batteries.

WHAT'S INSIDE A BATTERY?

Although many widely used battery types – such as lithium-ion batteries – are already available on the market without heavy metals, there are still old battery types with heavy metals. In Switzerland, a wide variety of battery models are sold – mainly by major distributors. They differ, for example, in the materials used to manufacture them. Many are based on zinc-manganese or lithium ions, neither of which contains heavy metals. Both in Switzerland and in the EU, the trade and sale of batteries containing mercury (chemical: Hg) or cadmium (Cd) are severely restricted. There is a limit value for mercury in batteries of 5 mg/kg and of 20 mg/kg for cadmium. For a lead content of more than 40 mg/kg, a corresponding declaration on the battery or on the packaging is mandatory.

But what is the point of regulations if it is not possible to check whether they are being complied with? Until recently, there was hardly any way to check compliance in Switzerland; there was simply no reliable and recognized method for precisely determining the various elements being used in batteries.

INCREASED KNOWLEDGE ABOUT BATTERIES

A team from Empa's Advanced Analytical Technologies lab led by chemist Renato Figi was therefore commissioned by the FOEN to develop a method for analyzing the heavy metals mercury, lead and cadmium in various types of batteries. A task that turned out to be not that simple. This is because, unlike many objects that can simply be crushed to analyze their chemical contents in solution by various spectrometric methods, batteries cannot simply be shredded. Even attempting to open a power storage device can be quite dangerous. Again and again, there are accidents in which batteries have exploded during such manipulations.

Claudia Schreiner did not want to expose herself to this risk in the Empa laboratory. She therefore turned to an Empa colleague, a specialist in the field of battery safety. Marcel Held from Empa's Transport at Nanoscale Interfaces lab advised her first and foremost to carefully discharge all batteries to be examined. Only then should one dare to look at the "inner life" of a battery.

But not all batteries are created equal. There are countless different designs. Even if one battery looks like a twin to another from the outside, the construction inside can differ significantly!

And something else became apparent during the project: Potentially hazardous substances are not always found where one would expect them to be. They can also be found in the seemingly harmless sheathing.

A LONG AND WINDING ROAD TO AN INNOVATIVE METHOD

But the painstaking work in the laboratory paid off: Empa's innovative method can now reliably determine the ingredients of common batteries even in minute amounts. For analysis, the batteries must first be discharged and then separated. The various components of the different battery types are sorted and then dissolved by boiling under pressure using an acid mixture. In this way, the heavy metals dissolve and can be determined spectroscopically.

The method now allows it to monitor compliance with existing regulations. It is being used as part of a broad campaign by the FOEN. To ensure that the random samples of the different battery types provide as representative a picture as possible, around 80 different batteries will be selected over the course of the year and then analyzed at Empa. The cantonal laboratory in Zurich is in charge of the campaign; results are expected in 2024. ■

INNER WORKINGS
Small button cells are analyzed as a whole, while larger batteries are disassembled.

Photo: Empa

Further information on the topic is available at: www.empa.ch/web/s502

PILOT PROJECT The facility separates end-of-life batteries into their components.

Photo: Kyburz Switzerland AG

BATTERY-GO-ROUND

Empa and Kyburz Switzerland AG are looking for ways to recycle end-of-life lithium-ion batteries in an efficient and resource-saving way. A specially developed experimental facility breaks down the old batteries into their components so that materials can be recovered as clean as possible.

Text: Anna Ettlin

Everyone is familiar with this phenomenon from their cell phone or laptop: Over time, the capacity of the battery decreases, so that you have to reach for the charger more and more often. The same is true of the much larger batteries in electric vehicles. Although manufacturers can now guarantee a service life of eight to ten years for lithium-ion batteries, sooner or later they too will have to be recycled.

In a project supported by the Swiss Federal Office of Energy (SFOE), the Swiss electric vehicle manufacturer Kyburz Switzerland AG and Empa have set themselves the goal of recycling discarded batteries from electric vehicles. To this end, Kyburz, with the support of Empa researchers, developed a special recycling plant that disassembles old batteries into their components.

Before a battery ends up in the recycling facility, however, it can be given a second, sometimes even a third, life. After its first use in the yellow electric three-wheeled scooters that Kyburz manufactures for Swiss Post AG, it can, for instance, be fitted into second-life vehicles powered by batteries that have already been used. If the battery's capacity continues to decline, even that doesn't have to be the end. Batteries with reduced capacity could be installed in stationary applications for storing solar energy, for example. This "multi-life" concept should significantly reduce the demand for primary raw materials in the future.

PRECISE SEPARATION

If the capacity of the battery is no longer sufficient for any further use, it is finally sent to the recycling facility. "In the type of battery we are currently recycling, the cathode, separator and anode are installed in several layers in a plastic casing," explains Empa researcher Andrin Büchel from the Technology and Society laboratory. By cleverly unrolling the separator, the cathodes and the anodes – metal foils coated with particles which allow lithium ions to be stored – are sorted into two separate containers.

The next step is the recovery of the electrode materials. The cathode, an aluminum foil coated with lithium iron phosphate particles, is placed in a water bath where the particles detach from the foil and, after decanting and drying, are recovered as powder. Exactly the same procedure is followed with the anode, which consists of a copper foil coated with graphite particles. In this case, however, a homogeneous suspension is formed, which means that an extra step in a centrifuge is necessary to separate the particles.

"At the end of the recycling process, we get back the casing, the separator, the aluminum and copper foils, and the electrode materials, all cleanly separated," Büchel says. This type of recycling process is called direct recycling. "In direct recycling, the battery is only disassembled as much as necessary to preserve the functional properties of the materials. This allows us to minimize the number of steps required, including for further processing," Büchel says.

ACCURATE ANALYSIS

But the work is not done with the recovery of the materials. Before they can be used again in a new battery, they have to be regenerated. This is precisely what Büchel is currently working on across various Empa labs with his colleague Edouard Quérel. In the battery lab of the Materials for Energy Conversion laboratory, they have already uncovered the mechanism behind the aging of the cathode material. "The lithium iron phosphate has a crystalline structure that releases and reabsorbs lithium ions during each charge and discharge cycle," Büchel explains. "This structure is preserved, but the amount of active lithium ions decreases over time." Currently, the researchers are aiming to "refresh" the cathode material by selectively adding lithium. The ultimate goal: to build the most powerful new batteries possible from recycled materials and thus close the loop.

In conventional recycling processes, batteries are shredded and the materials are separated using thermal and wet chemical processes. Direct recycling is said to be more resource-efficient in comparison, using less energy and no chemicals. However, the process developed by Kyburz and Empa is currently only suitable for the specific design and cell chemistry of batteries such as those used in Kyburz vehicles. "We are currently investigating whether and how this process can be adapted to other battery cell types as part of the Innosuisse project CircuBAT, involving 24 partners from industry as well as 11 research partners," says Büchel. ■

> "In direct recycling, the battery is only disassembled as much as necessary."

Further information on the topic is available at: www.empa.ch/web/s506

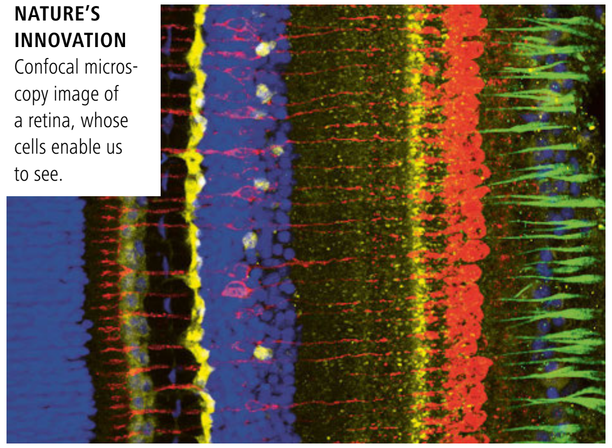
SHOWING FORESIGHT

As an innovative developer of surgical tools, Heinz A. Oertli founded the company "Oertli Instrumente" at a young age. He knows from own experience how great ideas flourish on a small scale and grow into sustainable start-ups. Now Heinz A. Oertli is supporting innovative projects at Empa with a fund of his very name as part of Empa's "Zukunftsfonds".

Text: Andrea Six

He has never been short of ideas – Heinz A. Oertli started his own business at the age of 24 as an instrument maker for ophthalmic surgery, along with a wealth of ideas. Thanks to his sought-after innovations, the original one-man business quickly grew into a quality factory in the Rhine Valley of St. Gallen with currently around 220 employees, although he handed it over to other hands around 30 years ago. The latest idea of the inventor, who is now over 90 years old, came to him some time ago during a visit to Empa in St. Gallen: Research at the innovation hotbed Empa, especially in the field of instrument development, could be promoted with private funds.

The common ground between the former instrument maker and Empa's materials scientists goes beyond the spirit of innovation: Oertli was fascinated by innovative materials and technologies right from the start of his entrepreneurial activity. As a pioneer in his field, he was looking for new materials for stainless, anti-magnetic precision instruments for eye surgery. He found what he was looking for in the watch industry, which places similar demands on its tools. Heinz A. Oertli is now promoting this inventive spirit, which is peculiar to him, with a fund of his very name as part of the "Zukunftsfonds", the fundraising endeavor of Empa.



NATURE'S INNOVATION
Confocal microscopy image of a retina, whose cells enable us to see.

Photo: PC Koch, M Hess; J Neurosci Res 89:1316 (2011); doi:10.1002/jnr.22651

PRESSURE SENSOR FOR SELF-HEALING

Now the "Heinz A. Oertli Fonds," established in 2022, is supporting the first two projects. One of them deals with new therapeutic options for glaucoma. The goal is to enable the eye to treat itself without medical assistance. In people suffering from glaucoma, the nerve cells in the retina die over time – leading to blindness. In a large proportion of those affected, increased internal pressure in the eye poses a risk for the development of glaucoma. Empa researchers led by Yashoda Chandorkar and Markus Rottmar from the Biointerfaces lab in St. Gallen, together with the Department of Ophthalmology at the Animal Hospital in Zurich, are now developing a self-regulating system consisting of a tiny, highly sensitive sensor that measures the eye pressure and normalizes the pressure of the chamber fluid in the eye via a valve made of a biocompatible hydrogel.

SOLDERING INSTEAD OF SEWING

The second project aims to protect the highly sensitive eye tissue during operations thanks to a laser-based adhesive procedure. Until now, the use of needle and thread has been common practice for interventions on the lens in cataract or corneal surgeries. Lasers are also currently being used for a welding process at rather high temperatures. Inge Herrmann, professor at ETH Zurich and head of the Nanoparticle Systems Engineering group at Empa in St. Gallen, is working with her team to develop a minimally invasive laser soldering process that can be used to close wounds on the eye efficiently and gently. The biological soldering material with so-called nanoabsorbers is intended to improve the mechanical properties in the tissue, accelerate healing and reduce scarring. Thanks to the support of the "Heinz A. Oertli Fonds", the project can now start in cooperation with the Cantonal Hospital St. Gallen and the University Hospital Zurich. ■

Further information on the topic is available at:
www.empa.ch/web/s404 / www.empa.ch/web/s403

A PLATFORM TO STUDY RAILROAD NOISE

At Empa, acoustics experts have been investigating for years how noise is generated by passenger and cargo trains – and which technical and structural measures are particularly effective to prevent or at least reduce it. Their findings have now been incorporated into the SILVARSTAR project resulting in a simulation tool for rail noise that can help in practice.

Text: Norbert Raabe

RATING RAILROAD NOISE
The monitor shows what the user sees in 3D virtual reality – with the realistic rail noise exactly where she stands.

Photo: Empa

It is often a nuisance for residents living near railroad lines – and such a multi-faceted challenge for experts that there should be more than one word for "railroad noise". Sounds from steel wheels on rough or smoother rails, braking sounds at different frequencies, engine noise, aerodynamic noise…– all of it muffled or influenced by noise barriers, embankments, the nature of the ground beneath the tracks, and by the environment in which the sound waves propagate.

Empa researchers led by Reto Pieren from the Laboratory for Acoustics / Noise Control know from practical and theoretical experience just how complex these acoustic consequences of rail traffic are. For years, they have been exploring the phenomenon with measurements, simulations, validations: Findings that led to the two-year EU project SILVARSTAR with many partners (see infobox). Pieren presented the results at the "forum acusticum" conference in Turin: an acoustic simulation of various types of railroad noise – audible and tangible with the help of virtual reality.

INTERNATIONAL PROJECT WITH EU FUNDING

The European research project SILVARSTAR, which ran for a good two years, was funded by Europe's Rail as part of the EU's Horizon 2020 program. In addition to Empa, the project consortium included industrial and academic partners from five European countries: Vibratec (France, coordination), Wölfel Engineering (Germany), the University of Southampton (England), KU Leuven and Union des Industries Ferroviaires Européennes (UNIFE; both from Belgium). In addition to the simulation of railroad noise, the project also developed models for the vibrations of the subsurface caused by train traffic.

Such tools for "auralisation" exist sporadically as prototypes in research, but they are not yet available in the practice of planning and noise control. The system SILVARSTAR aims to change that – thanks to the combined knowledge of numerous experts. While the Empa team, which was leading the simulation project, incorporated its acoustic expertise from numerous projects, experts from the University of Southampton and the Zurich-based company Bandara VR GmbH contributed valuable know-how to develop a user-friendly system. Among other things, the widely used Unity software for professional game developers served as the basis for this.

MANY FACTORS, EVEN MORE VARIATIONS

The ultimate goal was a tool that even laypersons could use. For example, transport politicians who want to assess the impact of a future railroad line. How they experience such virtual drive-bys is exemplified by a video of drive-bys, which can be found on Empa's SILVARSTAR website: For a single line, several scenarios can be compared, for example with train types ranging from cargo trains to a regional train to an ICE, with high or low noise barriers, specific wheel and damping types that also have an audible impact on railroad noise, and many other factors. And because the environment also plays a role, users can decide between "city" or "countryside" or even select a ground-level or elevated position, such as on a balcony.

Behind these possibilities are complex algorithms in a physics-based computational model that does not generate acoustic signals from archived sound files, but calculates and generates them all individually – for hundreds of noise sources and influencing factors, depending on the complexity of the scenario. This also presented challenges for the Empa team. The large variety of influences enables realistic simulations. But at the same time, it required the mesh of algorithms to be sensibly reduced to the essentials – also with the necessary computing time in mind: A modern PC needs up to three hours for a 500-meter long cargo train to pass by so that its noise emissions can be made audible under various conditions.

POSITIVE REACTIONS AT THE DEMONSTRATIONS

But the effort is worth it, as the validation of the system showed. The graphs of the synthesized noise curves are very close to measured real-world values and are even partly congruent. Subjective impressions were provided by demonstrations at transport technology trade fairs such as last year's InnoTrans in Berlin: Visitors attested to the simulation's high credibility and showed great interest in using the virtual "rail noise game".

For those interested, the tools, including a license agreement for non-commercial purposes, can be downloaded from Empa's SILVARSTAR website. "The first uses of the simulation are already starting," says Empa researcher Pieren, "we are very satisfied with the results and expect numerous applications in the future." ■

Further information on the topic is available at: www.empa.ch/web/s509

OUT OF THIN AIR

To prevent irreversible and damaging changes to the Earth's climate system, we need to remove excess (man-made) CO_2 from the atmosphere. This is the goal of a large-scale research initiative at Empa: Mining the Atmosphere.

Text: Michael Hagmann

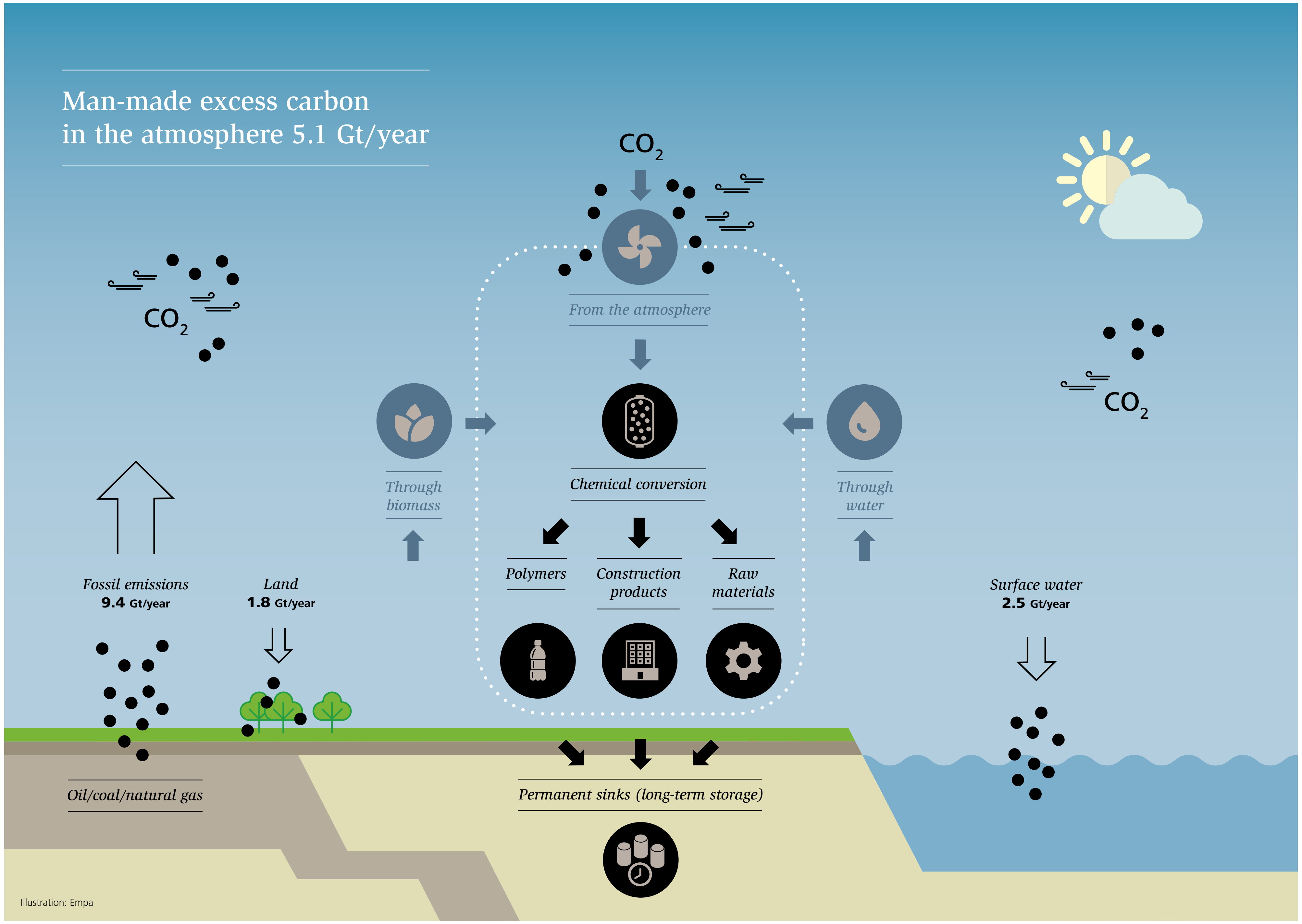


Illustration: Empa

"WISSEN2GO"

CO_2 EINFANGEN, VERWERTEN UND SPEICHERN, UM NETTO-NULL ZU ERREICHEN

Wednesday, 25 October 2023
Empa Academy and online via Zoom, in German

Fossil fuels are simply ... brilliant: easy to handle, with a high energy density, versatile, available in large quantities, hence cheap. They are the foundation of our technological progress and prosperity over the last 200 years. But there's quite a price tag that comes with it: The Earth is heading for climate collapse. Every year, we pump around 9.4 billion tons of carbon (in the form of CO_2) into the atmosphere. Natural processes, especially via vegetation and the oceans, partially compensate for this gigantic output. The bottom line, however, is an excess of around 5.1 billion tons of atmospheric carbon – every year. Since 1988, the CO_2 concentration in the atmosphere has been above 350 ppm (parts per million), which is considered the limit for climate stability. If this is exceeded for a longer period of time, the Earth's climate system is in danger of collapsing – with potentially irreversible consequences.

Business as usual is therefore not an option, and even net zero can only be an interim goal. What is needed is a holistic approach that can be both technically implemented and financed. Which brings us to Mining the Atmosphere. In contrast to simply capturing CO_2 and storing it in the ground – the necessary first step – the "mining" approach goes much further: The goal is to develop a completely new global economic model and the associated industrial sector that converts CO_2 as the raw material of the future into valuable materials to replace conventional building materials and petrochemicals. This approach calls for a change of perspective: Where raw materials were previously mined underground, the focus is now shifting to the atmospheric "mine". At the same time, this affects society as a whole, which is changing from a CO_2-emitting society to a CO_2-binding society, via the energy transition heading for net zero over the next 20 years.

That's the idea – the implementation of which is a century-long task for which countless players from research and industry will have to work together. The challenge is to remove an estimated 400 billion tons of carbon (around 1,500 billion tons of CO_2) from the atmosphere. And that is just the beginning. Then it's a matter of converting this carbon into value-adding materials, polymers, construction materials, etc. The construction sector, in particular, has a key role to play here, as concrete and other building materials could bind an enormous amount of atmospheric carbon due to their mass. After being recycled several times, the carbon-containing materials could eventually be deposited as a final carbon sink at the end of their service life. ■

Read more about this topic in the December issue of Empa Quarterly.

MINING THE ATMOSPHERE: BUILDING IN A MORE SUSTAINABLE WAY

CO_2 SINK
An insulating material made from plant-based raw materials could permanently bind CO_2.

Will we build with CO_2 in the future? The "RFA Built Environment" seminar on 7 November will showcase a wide range of Empa research activities revolving around the concept of "Mining the Atmosphere", i.e. extracting excess CO_2 from the atmosphere and using it as a sustainable resource for the construction industry, for instance. The free event is aimed at stakeholders, practitioners and researchers from the construction, building and infrastructure, energy, environment and sustainability sectors.

Register by 30 October at: www.empa-akademie.ch/rfa

LET'S TALK ABOUT PLASTICS

The panel discussion "Plastic: Success – at what price?" will take place on Thursday, 26 October, in the Kursaal Engelberg. At the event, organized by Academia Engelberg, Empa researchers Bernd Nowack and Claudia Som from the Technology and Society laboratory will speak about the environmental impact of plastics and what we can do about it. The event is open to the public and free of charge.

Registration by 15 October at: academia-engelberg.ch

PLASTIC WASTE
A panel discussion with Empa experts focuses on the environmental impact of plastics.

Photos: Jannis Wernery/Empa; Adobe Stock

Photos: Empa

ECONOMY AND SUSTAINABILITY GO HAND IN HAND

EXPERTISE
Empa Director Tanja Zimmermann (top right) and head of laboratory Mirko Kovac were among the speakers at the Symposium.

The Swiss Green Economy Symposium was held in Winterthur in early September. The 3-day conference on business and sustainability in Switzerland focused on the topic of "Creating more impact together" and used specific examples to show how cooperation between business, politics, science and NGOs contributes to greater prosperity, protection of the environment and more sustainable coexistence. Empa was a scientific partner at the event. Among the 250 speakers were Empa Director Tanja Zimmermann and Mirko Kovac, head of Empa's Sustainability Robotics lab. Numerous other Empa scientists participated in various innovation forums.

sges.ch

EVENTS
(IN GERMAN AND ENGLISH)

24. – 25. OKTOBER 2023
Konferenz: Precision Photonic Systems '23
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/precision-photonic
OST Campus Buchs, St. Gallen

25. OKTOBER 2023
Wissen2go: CO_2 einfangen, verwerten und speichern, um Netto-Null zu erreichen
Zielpublikum: Öffentlichkeit
www.empa.ch/web/w2go/netto-null
Empa, Dübendorf

07. NOVEMBER 2023
Seminar RFA Built Environment: Mining the Atmosphere
Zielpublikum: Wissenschaft und Wirtschaft
www.empa-akademie.ch/rfa
Empa, Dübendorf

16. NOVEMBER 2023
Kurs: Metallische Gläser
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/metallglas
Empa, Dübendorf

16. NOVEMBER 2023
Technology Briefing: Switzerland's Climate Neutrality 2050: The Journey through Energy Storage Technologies
Zielpublikum: Industrie und Wirtschaft
www.empa.ch/web/tb/energy-storage
EPFL Auditorium, Neuchâtel

Details and further events at: www.empa-akademie.ch

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THE PLACE WHERE INNOVATION STARTS.

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