Empa Quarterly

Research & Innovation #62 | September 18

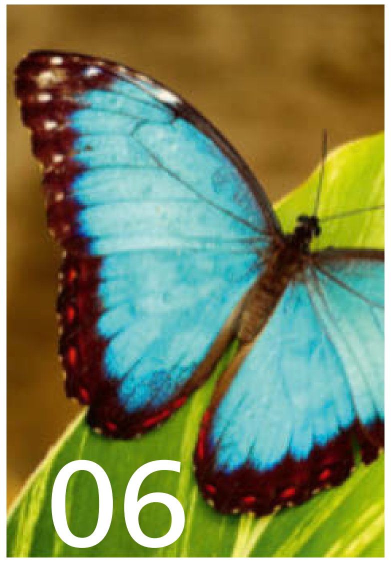
Strong ties with Romandy

Façades as solar power plants

Medication you can wear

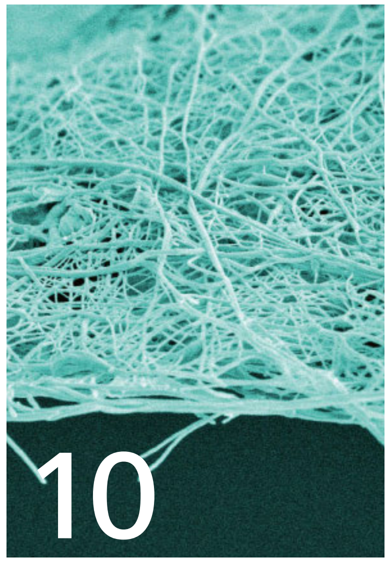
Next generation of watch springs

Empa
Materials Science and Technology



Focus

Strong ties with Romandy



Title page
The Swiss Tech Convention Center (STCC) is part of the École Polytechnique Fédérale de Lausanne (EPFL). The façade of the congress center is made of colored Grätzel solar cells named after their inventor, Michael Grätzel. The number and size of the cells constructed here is globally unique. The company Solaronix based in Aubonne, near Lausanne, holds the production patent for Grätzel cells and produces the façade panels. Solaronix is an industrial partner of both Empa and EPFL. ***Page 20 – 22.*** *Photo: Solaronix*

Imprint
Publisher Empa, Überlandstrasse 129, 8600 Dübendorf, Schweiz, www.empa.ch
Editorial & Layout Communications
Contact Phone +41 58 765 47 33
empaquarterly@empa.ch, www.empaquarterly.ch
Published quarterly
Advertisment Marketing rainer.klose@empa.ch
ISSN 2297-7414 *EmpaQuarterly (English ed)*

Empa Social Media

Swiss innovation: Connecting the dots

TEXT: Gian-Luca Bona / PICTURE: Empa

Switzerland is a small country. Nonetheless, in research and innovation we are playing in the "Champions League", as the renewed top ranking in the "Global Innovation Index" (GII) for 2018 impressively shows. For the eighth time in a row – a remarkable achievement for a country with the population of New York City.

Maybe we are not successful despite, but rather because of our small size. In about three hours you can reach almost every major Swiss city by public transport – and at the same time experience four languages and various cultures. Such proximity literally calls for inter-regional cooperation; the different languages and cultures should not hinder us, but on the contrary enrich and inspire us. It is precisely at the interfaces between different disciplines and cultures that oftentimes something very special emerges.

But despite our leading position, we must be clear about one thing: The international battle for the brightest minds will become much tougher in the future. Just a few indications: Countries like China and Singapore are investing heavily in research and innovation; Chinese research institutions are already the world´s largest patent applicants. And among the five most successful innovation clusters, two are in China, according to the GII. (For comparison: the Zurich region ranks 48th…)

What does this mean for Switzerland? Working even more closely together, sharing our excellent know-how, using our diversity as a strength, making better use of synergies – so that our research institutions and companies can continue to hold their own against global competition. We would do well to foster a culture of "open innovation" in Switzerland. In a team, you are always stronger than by yourself. And successful teams live from diversity and diversity.

The current issue of "EmpaQuarterly" is dedicated to this topic – with a very special focus: the numerous partnerships Empa maintains with research institutions and companies in the French-speaking part of Switzerland. We´re doing this for a good reason: Recently, NEST, our demonstration platform for sustainable building and energy technologies, opened its latest unit, "SolAce", which was developed under the leadership of EPFL researcher Jean-Louis Scartezzini (see p. 06).

Despite its three locations in the German-speaking part of the country, Empa is an institution for the whole of Switzerland: Empa has around 600 collaborations with organizations in the French-speaking region, and at around 60 locations (see maps on p. 18). These include research partners such as our sister institution, the EPFL – with which cooperation is most intensive, including joint professorships and numerous PhD students, as well as joint laboratories such as the "Laboratory of Materials for Renewable Energy" in Sion – but also countless industry partners, from start-ups and SMEs to global corporations such as the Swiss watch industry (see e.g. p. 14).

It is partnerships like these that ensure that Swiss research – and eventually our entire economy – will continue to be successful in future. Enjoy reading!

Empa CEO Gian-Luca Bona is keeping a close eye on partnerships with French-speaking Switzerland.

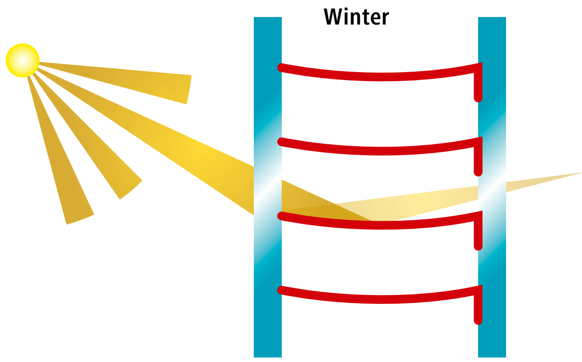
A façade in a class of its own

Anyone who spends most of their day indoors knows the importance of a comfortable atmosphere to work and live in. Researchers from EPFL's Solar Energy and Building Physics Laboratory are searching for ways to maximize the energy gain from a building's envelope while also optimizing interior comfort in an environmentally friendly way. They are demonstrating how this can be done with "SolAce", the latest unit in Empa's NEST research building.

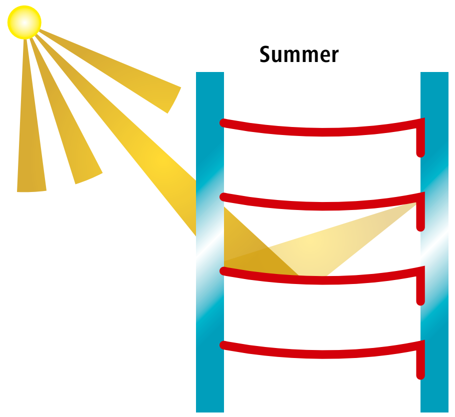
TEXT: Stephan Kälin, PICTURES: Roman Keller, GRAPHIC: Empa

Energy gain via the facade: The green-blue glazed photovoltaic modules and solar thermal collectors on the facade of «SolAce» are to produce more energy over the course of the year than the unit consumes.

>>



Inside the windows, between the panes of glass, sits invisible micro-structured glazing, which directs sunlight inwards in wintertime. To ensure an even illumination, the light is scattered towards the ceiling.



In the summertime, when the sun is higher in the sky, the same glazing ensures that the sun's rays are guided away from the windows and reflected outwards. This considerably reduces the extent, to which the rooms heat up.

The blue-green facade of the "SolAce" unit at NEST shimmers like a butterfly's wing in the sunlight. The latest addition to Empa and Eawag's research and innovation building in Dübendorf was officially opened on 24 September. The unit combines workspace and living space over almost 100 square meters and is integrated in NEST's south-facing side between the second and third platform of the typecase-like structure.

"Through its facade, "SolAce" is to produce more energy than the unit needs over the course of the year, while at the same time providing the best possible comfort to the users". That's how Jean-Louis Scartezzini explains the objective of the project. The EPFL researcher is the Director of the Solar Energy and Building Physics Laboratory, and the idea for the latest NEST unit is his brainchild. To achieve this goal, the researchers combine several active and passive facade elements that feature technologies developed at the Lausanne-based lab. Some of those technologies are about to be commercialized by start-ups and collaborations with partners from industry, while others still have a way to go. "NEST gives us the unique opportunity to examine the various technologies in interaction with each other and in a real-life environment", says Scartezzini.

Electricity and hot water

The unit's positive energy balance is to be achieved by prducing solar electricity and hot water directly on the facade. Photovoltaic modules and solar thermal collectors with a novel type of colored nano-glazing will be used for this purpose. With the aim of promoting the integration of photovoltaic units in the building envelope by offering greater architectural scope through different colors, a team at EPFL has been researching coatings for coloration for almost 20 years. The research team, led by Andreas Schüler, was clear on the fact that the coating would need to cause as little energy loss as possible. There was no question of using absorbing color pigments. Instead, thin films of between 5 and 200 nanometers create what are referred to as 'interference color effects' on the interior of the glazing, not unlike those that appear on a soap bubble or on the wings of a butterfly for example. "Because the nano-coating is very transparent, there are virtually no absorption effects and just very minor energy losses", explains Schüler. This technology has now been patented and is currently being brought to market by the spin-off "SwissINSO", with the blue-green version being used in NEST.

How to monitor wellbeing?

Besides office space for four people, "SolAce" also offers a living area for two. To keep the promise of optimum comfort, the researchers are attempting to recreate the users' individual perception by using innovative optical sensors. The prototype sensors measure lighting conditions and glare from a user's perspective, for instance a person working at a computer. This on-the-fly monitoring is used to control electric lighting and sun shading in the best possible way. It means that if a certain glare value is exceeded, the curved venetian blinds start directing the rays of light entering the building to the ceiling. Circadian lighting is also intended to boost the working performance of the "SolAce" inhabitants, but also to support them during recovery phases. Circadian lighting simulates the sunlight over the course of the day, thus promoting our natural sleep-wake rhythm.

Micro-structured glazing

Likewise, innovative window panes are to contribute to a cozy atmosphere for living and working – and above all else to lower energy consumption for heating in winter and for ventilation in summer. Invisible to the human eye a micro-structured glazing in a polymer film on the interior of the glass directs wintertime light to the ceiling of the unit for even illumination, thus allowing the interior to heat up naturally. In summer, the same glazing ensures that the sun's rays are guided away from the windows and hence the rooms don't heat up that much. This new type of glazing was developed at EPFL by Andreas Schüler and his team. The researchers used a precision laser from Empa in Thun to manufacture the first prototypes. Now the team is working with BASF / Switzerland to develop an industrial manufacturing process. As soon as the first window panes are available, they are to be installed in the "SolAce" facade. Researchers from EPFL's Laboratory of Integrated Performance in Design will then measure the visual comfort of the new panes in situ. Until then, reference panes will be used that will provide benchmark figures.

Proving everyday use

As is customary for NEST, the "SolAce" unit will be used and lived in on a real-life basis. During the first phase, it is primarily EPFL researchers who will use the rooms and monitor the systems and technologies and adjust them to ambient conditions. "Once this is done we will use the unit for our guests to work and to live in", says NEST Innovation Manager Rico Marchesi. He is delighted about the new addition to the research and innovation building and is convinced that "SolAce" can make a valuable contribution to the future design of building envelopes. "Thanks to the color glazing shown here, aesthetic concerns about the use of photovoltaic modules on the facade are clearly no longer valid", he is convinced.

For Jean-Louis Scartezzini, the project is already a great success: "Again and again, the close cooperation between researchers and partners from industry, but also amongst the industry partners themselves, led to surprising ideas and a valuable exchange of knowledge." The architect of the unit, Fabrice Macherel from Lutz Architectes in Fribourg, also found the collaboration between the realms of research and business to be hugely enriching: "Striking the balance between theory and practice was not always easy, but we learned a lot of new things and we can use this knowledge in future projects." To put it more briefly: technology transfer in its purest form. //

ACADEMIC PARTNERS

Jean-Louis Scartezzini, EPFL

INDUSTRY PARTNERS

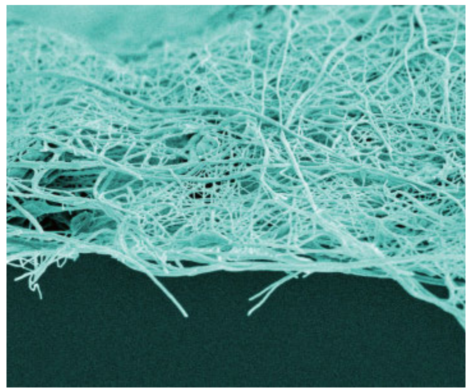
Lutz Architectes, 1762 Givisiez
Regent Lighting, 4018 Basel
Solstis SA, 1004 Lausanne
SwissINSO, 1004 Lausanne
TZ menuiserie SA, 3960 Sierre
Geberit, 8645 Jona
V-ZUG AG, 6302 Zug
ABB Schweiz AG, 5405 Baden
Griesser AG, 8355 Aadorf
Duscholux AG, 3604 Thun

Inside «SolAce», the lighting changes gently throughout the day and supports the human biorhythm. An innovative sensor system and seasonally dynamic window glasses create a pleasant living and working climate.

Lifting the mask

Laughter is the best medicine, says medical research. But how are patients supposed to feel like smiling if the faces of the nursing staff and even their beloved ones are covered with masks? Researchers from Empa and EPFL are currently developing a novel face mask, which offers an unobstructed view of the wearer's facial expressions.

TEXT: Andrea Six / PICTURES: istockphoto.com; Empa



A face mask often stands in the way of human contact between nursing staff and patients. Empa researchers are working on transparent protective membranes made of finely spun fibers. This renders the facial expressions visible again..

A surgical mask covers the majority of the face. Researchers from Empa and EPFL are now devising a novel solution that enables medical staff to communicate with patients despite the mask.

Anyone who has to go to hospital for treatment will already not be in the best of spirits. The situation is even more unsettling for small children or the elderly, who, overwhelmed with pain and medical procedures, just need to get well. After all, how is someone in a mask supposed to read a comforting story to a small child? And how is an enfeebled patient supposed to grasp what the masked individual plans on doing with the needle in his hand? It would be easier to deal with patients if the lips and facial expressions were visible through the mask. With this in mind, researchers from Empa in St. Gallen and EPFL's EssentialTech program are currently developing the Hello Mask with an integrated transparent filter film.

"A conventional face mask is composed of several layers of relatively thick fibers," says Empa researcher Giuseppino Fortunato. And although the individual fibers of the white or green masks might well be see-through, their diameter and processing cause the incident light to scatter to such an extent that the mask turns opaque. The woven fibers of the Hello Mask, on the other hand, should leave a transparent surface that offers an unobstructed view of the lips, also enabling the wearer to communicate non-verbally with the patient via facial expressions.

For the see-through film to also filter out pathogens from the wearer's breath, however, it may only contain very tiny pores. This protects patients with a weakened immune system against infections, for instance. By the same token, the mask should also keep out germs: Nursing staff and the loved ones of people suffering from highly contagious diseases like Ebola covet a more humane contact with the patients, without jeopardizing their own health. The Hello Mask should bring more humanity to how highly contagious diseases are handled.

"Using a technique referred to as electrospinning, we can produce such fine membranes with a pore size of around 100 nanometers," explains Fortunato. The challenge in producing one of these masks, however, is to enable sufficient air to flow through the close-meshed material of the mask. The materials researchers are currently analyzing which kinds of polymer fibers can be used to produce a film with maximum respiratory activity.

Back in 2016, the team received the Challenge Debiopharm-Inartis Award. The project, which is also funded by the Gebert Rüf Foundation and the Staub Kaiser Foundation, is due to run until 2019. EPFL's EssentialTech program will refine the product to prepare the Hello Mask for industrial production as swiftly as possible. //

ACADEMIC PARTNERS
Klaus Schönenberger, EPFL

Medicals to wear

Drug-releasing textiles could, for instance, be used to treat skin wounds. Empa researchers are currently developing polymer fibers that can be equipped with drugs. The smart fibers recognize the need for therapy all by themselves and dose the active ingredients with precision and accuracy.

TEXT: Andrea Six

For the "Self Care Materials" project, fibers are produced from biodegradable polymers using various processes. "The targeted use of the fiber determines which manufacturing process is best," explains Empa researcher and project coordinator René Rossi. Delicate, light membranes with a large surface are formed during so-called electrospinning. If robust fibers are required, e.g. for protective clothing, it is better to draw the melted ingredients. In the end, all processes produce novel fibers, the nano-architecture of which is made up of several layers and components. "The properties of these new materials are currently being investigated with test substances," says Rossi. In the finished product, for example, antibiotics or painkillers are to be integrated into the fibers.

In order to ensure that the dosage of the active substances is precisely as needed, the researchers have devised a tricky control mechanism: Some polymers are degradable by the body under certain conditions. This property can be used specifically. Rossi: "In response to a stimulus from the body, the fibers should release their drugs into the environment at a calculated degradation rate." Such an irritation can be the altered pH value of a skin wound, which indicates that the tissue damage must be treated. As a so-called self-care material, the fibers in the form of a plaster or garment thus support the diagnosis and treatment of diseases.

"The use of self-care fibers is conceivable for an enormous number of applications," says Rossi. In addition to chemical signals from the body, however, stimuli can also be used that are deliberately set from the outside to control the release of medication by the fibers. Textiles or dressings that release a remedy under slight pressure or a stimulus of light can contribute to the quality of life of patients and at the same time relieve the burden on health care staff.

The system can also be used for preventive measures. The idea behind it: Where active substances can be released, substances are also able to penetrate the fiber in the opposite direction. "Thus, the fibers can act as sensors and, for instance, measure the sugar level in the blood," explains Rossi. In the case of premature babies, the sugar balance is particularly likely to be out of balance. With the help of such sensors, blood sugar can be monitored painlessly through the tender skin without the babies having to suffer from a prickly blood sample.

For the CCMX project, the team of Empa and EPFL scientists is conducting joint research into the further development of smart medical fibers until 2020. 20 companies have so far been won as industrial partners, including Syngenta and – as the latest addition – Nanosurf from Liestal. The industry association Swiss Textiles and the research initiative of the Swiss textile manufacturers Subitex are also involved in the project. //

ACADEMIC PARTNERS
Fabien Sorin, EPFL

What does graphene do in our lungs?

Graphene has been hailed as the material of the future. As yet, however, little is known about whether and how graphene affects our health if it gets into the body. A team of researchers from Empa and the Adolphe Merkle Institute (AMI) in Fribourg have now conducted the first studies on a three-dimensional lung model to examine the behavior of graphene and graphene-like materials once they have been inhaled.

TEXT: Cornelia Zogg / PICTURE: Agefotostock

Tensile, tear-proof, highly elastic and electrically conductive: Graphene has a startling array of extraordinary properties, which enable revolutionary applications in a vast range of fields. It is not by chance that the EU launched the Graphene Flagship project, which enjoys one billion Euros in funding and is the largest European research initiative. As part of this enormous project, Empa also brings its expertise to the table, since potential health aspects and the impact on the human organism also play a key role within the scope of this pan-European graphene research.

These activities have now spawned an additional project funded by the Swiss National Science Foundation (SNSF), which was recently launched at Empa and AMI. It involves using a cellular 3D lung model, with the aid of which the researchers hope to find out what impact graphene and graphene-like materials might have on the human lung under conditions that are as realistic as possible. No mean feat: After all, not all graphene is the same. Depending on the production method and processing, a vast range of forms and quality spectra of the material emerges, which in turn can trigger different responses in the lung.

Three-dimensional cell cultures "inhale" particles

The research team headed by Peter Wick, Tina Bürki and Jing Wang from Empa and Barbara Rothen-Rutishauser and Barbara Drasler from AMI recently published their first results in the journal Carbon. Thanks to the 3D lung model, the researchers have succeeded in simulating the actual conditions at the blood-air barrier and the impact of graphene on the lung tissue as realistically as possible – without any tests on animals or humans. It is a cell model representing the lung alveoli. Conventional in vitro tests work with cell cultures from just one cell type – the newly established lung model, on the other hand, bears three different cell types, which simulate the conditions inside the lung, namely alveolar epithelial cells and two kinds of immune cells – macrophages and dendritic cells.

Another factor that has virtually been ignored in in vitro tests thus far is the contact with airborne graphene particles. Usually, cells are cultivated in a nutrient solution in a petri dish and exposed to materials, such as graphene, in this form. In reality, however, i.e. at the lung barrier, it is an entirely different story. "The human organism typically comes into contact with graphene particles via respiration," explains Tina Bürki from Empa's Particles-Biology Interactions lab.

In other words, the particles are inhaled and touch the lung tissue directly. The new lung model is designed in such a way that the cells sit on a porous filter membrane at the air-liquid interface and the researchers spray graphene particles on the lung cells with the aid of a nebulizer in order to simulate the process in the body as closely as possible. The three-dimensional cell culture thus effectively "breathes in" graphene dust.

No acute damage discovered

These tests with the 3D lung model have now yielded the first results. The researchers were able to prove that no acute damage is caused to the lung if lung epithelial cells come into contact with graphene oxide (GO) or graphene nanoplatelets (GNP). This includes responses such as sudden cell death, oxidative stress or inflammation.

In order to also trace chronic changes in the body, the SNSF project is set to run for three years; long-term studies using the lung model are next on the agenda. Besides pure graphene particles, Wick and his team also expose the lung cells to rubbed graphene particles made of composite materials, which are classically used to reinforce polymers.

Jing Wang from Empa's Advanced Analytical Technologies lab is also involved. In order to estimate the number of graphene particles humans are exposed to as realistically as possible, Wang is studying and quantifying the abrasion of composite materials. Based on this data, the team exposes the 3D lung model to realistic conditions and is able to make predictions regarding the long-term toxicity of graphene and graphene-like materials. //

The "Graphene Flagship"

With a budget of one billion Euros, the "Graphene Flagship" represents a new form of joint, coordinated research on an unprecedented scale, forming Europe's biggest ever research initiative. The Graphene Flagship is tasked with bringing together researchers from universities, research institutes and industry with the goal of bringing innovative graphene applications to the market in the space of 10 years. The consortium comprises more than 150 academic and industrial research groups in 23 countries. In addition, the project has a growing number of associate members.

Further information: http://graphene-flagship.eu

ACADEMIC PARTNERS

Barbara Rothen-Rutishauser, Adolphe Merkle Institut (AMI)

Next generation of watch springs

What happens when something keeps getting smaller and smaller? This is the type of question Empa researcher Johann Michler and his team are investigating. As a by-product of their research completely novel watch springs could soon be used in Swiss timepieces.

TEXT: Rainer Klose / PICTURES: A.Lange & Söhne, Empa

The balance wheel is the beating heart of every mechanical watch mechanism. The delicate springs are usually made of cast, forged Nivarox alloy. At Empa a new generation of balance springs is produced with means of electroplating.

Applied research is not always initiated by industry – but oftentimes it yields results that can swiftly be implemented by companies. A prime example can be seen on the Empa campus in Thun: Tiny watch springs are on display at the Laboratory for Mechanics of Materials and Nanostructures. These springs – the beating heart of every mechanical clock – are not your usual components. They are not made of the famous Nivarox wires, but rather deposited electrically – or, rather, electrochemically – in the desired form from a cold, aqueous saline solution.

By now, the production in the Empa lab has outgrown the first pilot tests. On a regular basis the electroplated springs are delivered to the R&D department at a major Swiss watchmaker, where they are fitted in prototype watch mechanisms. The watches run. However, there is still work to do on their accuracy and long-term stability.

Only a few years ago, Empa had to rely on partners to take care of certain process steps. Meanwhile, the knowhow for the entire production process is pooled in Michler's lab. Laetitia Philippe, who oversees the production of the springs, explains the production steps. The base material is a silicon wafer like the ones used to produce computer chips and solar cells. This wafer is initially coated with a conductive gold layer and, later on, a thin layer of light-sensitive paint. The shape of the spring is then projected onto it and the illuminated parts of the paint are etched out. Now the desired metallic alloy can be electroplated onto the conductive gold base.

As Philippe knows only too well, this crucial step in the process is tricky. "We need a good swirl in the galvanic bath, the right temperature, some organic additives and a current at just the right strength and – if it's alternating current – in the right form." Eventually, the goal is to dissolve the springs out of the galvanic mold. Initially, the researchers use a light microscope to check whether the spring molds are filled correctly with metal. Then the top side of the mold is fine-polished to ensure all springs are of a defined thickness; the result is verified via X-ray fluorescence analysis. Finally, the paint is removed with an oxygen plasma, the silicon wafer etched away using a strong alkaline solution and the gold coating dissolved. The remaining springs then need to go into a special washing machine for a few hours to remove any ridges and protruding metal remnants. These flawless springs then go into the watch lab for prototype production.

A by-product of research

For the researchers at Empa, however, this kind of prototype production is only one aspect of their scientific work. "Our goal is certainly not to compete with suppliers in the watch industry," says Michler. "At Empa, we are mainly interested in the process of miniaturization itself." Michler's team studies the mechanical properties of the tiny parts with minuscule stamps and needles. After all, the properties of materials change if we build tiny parts: Ductile metals become harder; brittle ceramics, on the other hand, become ductile with very small component sizes.

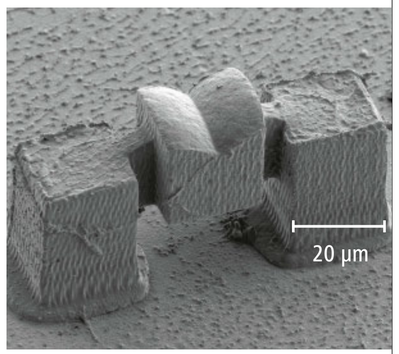
"The prerequisite for any examination, however, is that we are able to produce the objects we are interested in based on defined criteria," explains the Empa researcher. Thus, Michler's team not only strives to master one single process step, but also keep a grip on the quality of the entire process chain. "Some process steps are closely intertwined," says Michler. "If we change one parameter, such as the geometry of the electroplating molds or the composition of the alloy, we usually have to adjust the preceding and subsequent steps, too. We want to understand these connections and the effects of miniaturization in every aspect." //

INDUSTRY PARTNERS

Various companies in the Swiss watch industry

Additive manufacturing in 3D

Besides two-dimensional structures, the researchers in Thun have already made progress in the production of 3D structures – also with the aid of electroplating. The required molds are not produced by illuminating layers of paint on silicon wafers, but rather via what is known as two-photon polymerization. This involves emitting a laser beam in a container with a special liquid plastic precursor. In the focal point of the beam, the liquid polymerizes and solidifies. The Empa team succeeded in making delicate structures and electroplating them with a nickel boron coating. In strength tests, these metallized structures exhibited much more stability than the raw polymer scaffold. Meanwhile, the researchers have also managed to produce bridges and columns made of solid nickel that are merely a few micrometers in size. Stress tests reveal how the nickel alloys behave in these dimensions. "We are already able to make such structures with a nice regularity and in a replicable manner," says Laetitia Philippe. "We have taken a major step forward on the road towards micromechanics made of electroplated components." In the not too distant future, these components might permit clock mechanisms with particularly fine mechanical complications.



Sparking ideas

TEXT: Rémy Nideröst / PICTURE: iStockfotos.com

A fine-tuned laser welds more effectively

Using laser technology Empa scientists optimized a technique to weld the electronics of implantable pacemakers and defibrillators into a titanium case. The medtech company Medtronic is now using the method worldwide to produce these devices.

In Tolochenaz (Canton of Vaud) the US medtech company Medtronic produces one out of five heart pacemakers available on the global market and one out of four defibrillators. The electronics of these implantable devices are housed in titanium cases, which thus far were welded hermetically with a solid state flash laser. However, the lasers are high-maintenance and often the source of irregularities. Moreover, they require water cooling and take up a lot of space.

A new type of laser launched in 2015 by US company IPG Photonics came to the rescue: This fiber laser is cooled energy-efficiently using air instead of water, requires less maintenance, works more consistently and is more compact. Initial tests conducted by Medtronic, however, revealed that the weld seams now have black edges that look a lot like soot – extremely problematic for implants. Therefore, Medtronic's Sébastian Favre approached Empa materials specialists Patrik Hoffmann and Marc Leparoux at the Thun site, who initiated a project to optimize the new laser for usage with titanium. The project was funded by Innosuisse, the former Commission for Technology and Innovation (CTI).

In order to simulate production processes at Medtronic, Empa built its own "plant" to precisely analyze the behavior of the laser in a controlled environment. The results revealed that an interaction with the titanium vapor interferes with the process: The black edge on the seams turned out to be titanium nanoparticles. In follow-up experiments, the Empa researchers demonstrated that the black edge disappears if the laser is operated at a different wavelength. Laser manufacturer IPG Photonics subsequently built a fiber laser tailored towards the Empa researchers' specifications and offered it for further tests. As these experiments confirmed, adjusting the laser frequency indeed solved the problem.

Meanwhile, Empa, Medtronic and IPG Photonics jointly hold a patent for the optimized fiber laser. Medtronic benefits from improved production processes for its implants – at considerably lower costs. And Switzerland could confirm its status as a leading technology hub within the globally operating US multinational. After all, the special lasers "made in Switzerland" are now being used at Medtronic factories in Puerto Rico, Singapore and the US.

INDUSTRY PARTNERS

Medtronic Internat. Trading Sàrl, 1131 Tolochenaz

Troubleshooters for laser technology

Sometimes, metal-working companies can reach the limits of their routine skills. For instance, when it comes to welding highly reflective metals such as copper, aluminum, gold or silver with lasers or polishing surfaces with lasers. This is where Empa researchers come in. Thanks to their expertise, they are able to help.

Unitechnologies SA, based in Gals between Lake Biel and Lake Neuchatel, works in precision automation. One of its products is a laser polishing platform to process small metal parts such as the ones used to make nozzles or valves. Unfortunately, for a long time the company was unable to broaden the platform's scope to laser-polish larger surfaces, such as 3D polishing for injection molds or sterile valves. This only changed in 2017 when the company started working with Empa in Thun on the advice of an Innosuisse expert. In no time, the cooperation yielded impressive results. Meanwhile, the Unitechnologies specialists have also mastered polishing large surfaces – for all key commercial materials.

Cooperating with Empa has also paid off for another Swiss company, Coherent Switzerland, which develops and produces laser sources and heads for laser machines. These are primarily used to make high-quality weld joints in car manufacturing and mechanical engineering. Thanks to a close collaboration with Empa, new technologies have continually been incorporated since 2014, including an intelligent sensor system, which monitors and optimizes the laser process opto-electronically, and an innovative wobble tool head for particularly challenging laser applications. The latter can now be used to weld various micro-patterns such as eights, spirals and ellipses with a high frequency and in different sizes and angles.

INDUSTRY PARTNERS

Unitechnologies SA, 3238 Gals
Coherent Switzerland, 3123 Belp

Soldering beats casting

Marrying the good sliding properties of bronze with the lightness and stability of titanium is a much-coveted solution for many high-tech slide bearings. However, titanium and bronze cannot be combined via casting. Empa's experts came to the rescue.

Components for the aviation industry need to meet considerably more stringent requirements than, say, car parts. Low temperatures, UV radiation and extreme acceleration are just some of the challenges that the materials face. Moreover, a clear reduction in weight is supposed to reduce fuel consumption. Empa is just the partner for such high-tech innovations in the field of materials science.

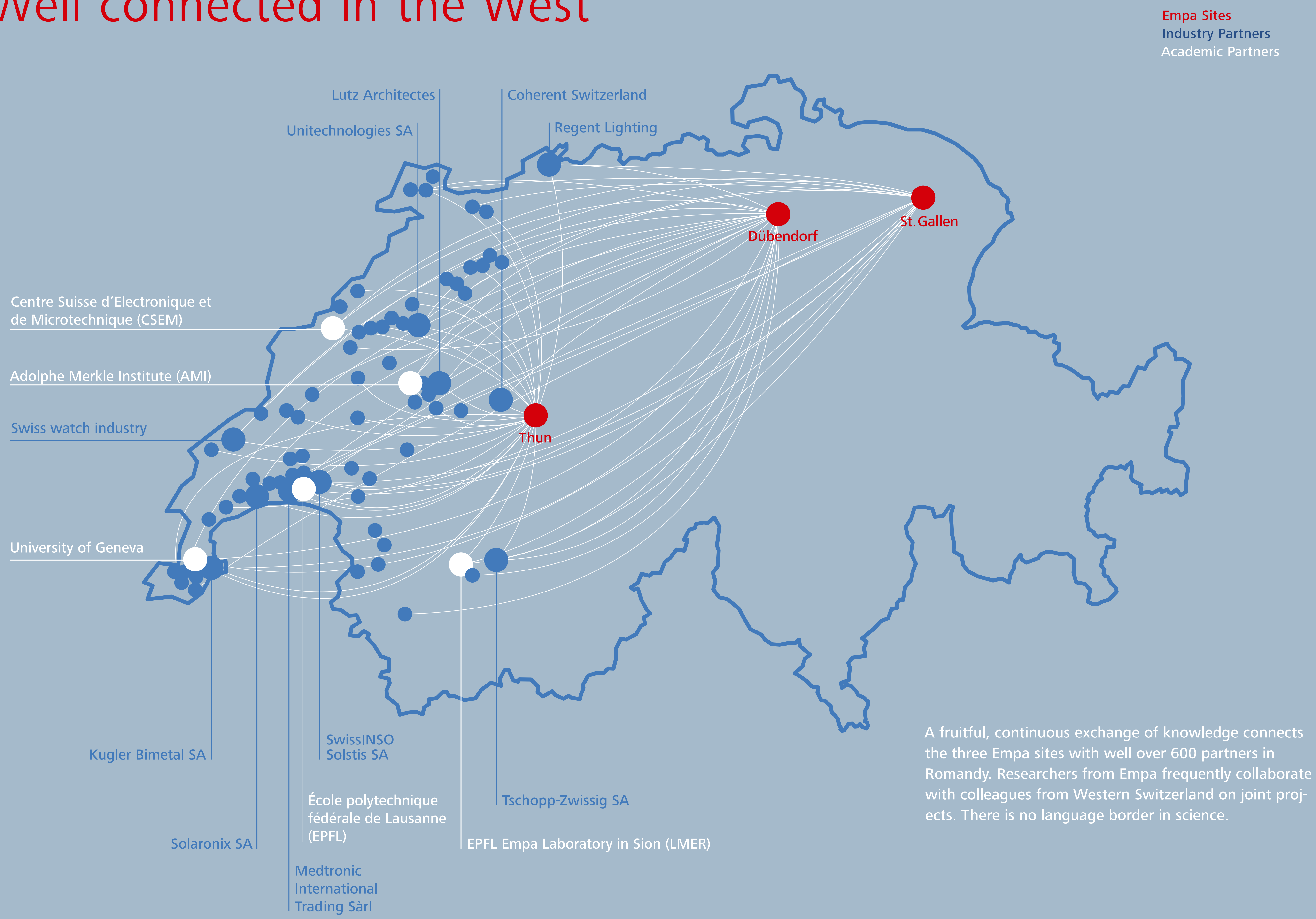
Kugler Bimetal, a company based in the Geneva area, is a global leader in bimetal cast bronze. The goal of a joint project between the company and Empa was to develop a soldering technique for particularly low-friction bearings made of high-strength bimetals that are as light as possible. The project was funded by Innosuisse (formerly the Commission for Technology and Innovation; CTI). The 100 million-dollar question they had to address: Is it possible to solve friction problems by marrying the good slide properties of bronze and the excellent mechanical properties of a lightweight titanium alloy? The production of such bronze-titanium bearings using a casting process, however, is virtually impossible on account of the high thermal stresses – caused by the different expansion coefficients of the two materials – and the brittle reaction layer formed simultaneously.

One promising approach, developed by Empa researchers from the Joining Technologies and Corrosion lab together with experts from Kugler Bimetal, is a soldering concept tailored to the materials' properties. Once the Empa researchers had studied the interactions between the materials and the resulting interfaces systematically, they were able to develop a soldering and coating method that enabled the production of high-quality compounds made of titanium and bronze. If this technique can be scaled up to industrial levels, this could be a breakthrough for joining bearings in the aviation industry.

INDUSTRY PARTNERS

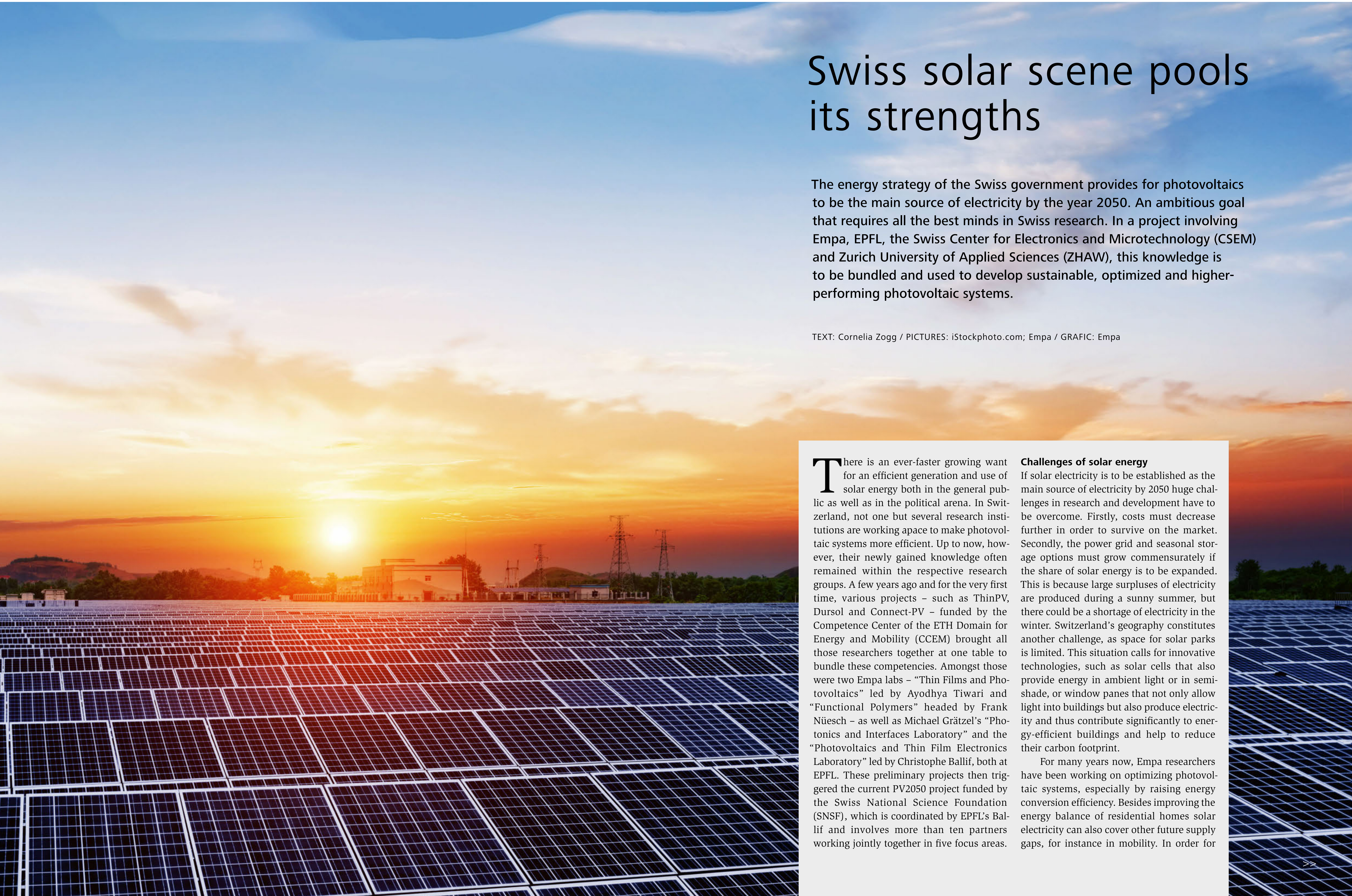
Lutz Kugler Bimetal SA, 1219 Lignon

Well connected in the West



A fruitful, continuous exchange of knowledge connects the three Empa sites with well over 600 partners in Romandy. Researchers from Empa frequently collaborate with colleagues from Western Switzerland on joint projects. There is no language border in science.

GRAPHICS: Empa



Swiss solar scene pools its strengths

The energy strategy of the Swiss government provides for photovoltaics to be the main source of electricity by the year 2050. An ambitious goal that requires all the best minds in Swiss research. In a project involving Empa, EPFL, the Swiss Center for Electronics and Microtechnology (CSEM) and Zurich University of Applied Sciences (ZHAW), this knowledge is to be bundled and used to develop sustainable, optimized and higher-performing photovoltaic systems.

TEXT: Cornelia Zogg / PICTURES: iStockphoto.com; Empa / GRAFIC: Empa

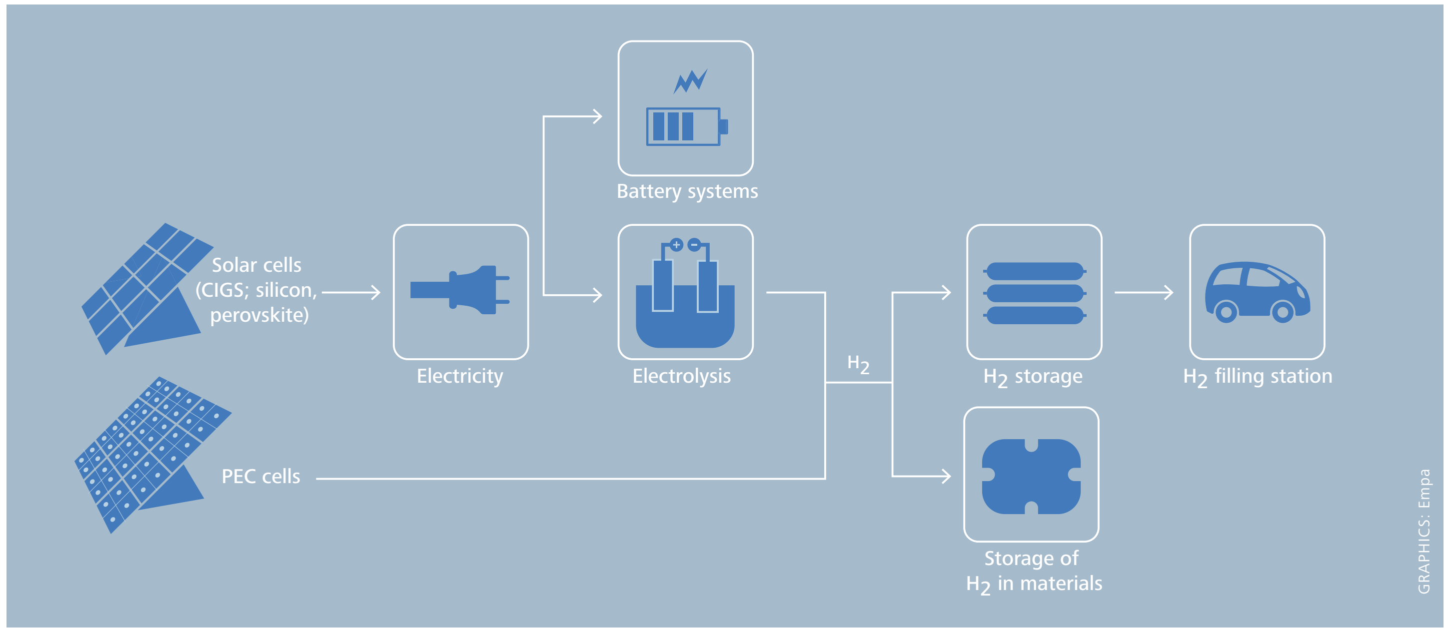
There is an ever-faster growing want for an efficient generation and use of solar energy both in the general public as well as in the political arena. In Switzerland, not one but several research institutions are working apace to make photovoltaic systems more efficient. Up to now, however, their newly gained knowledge often remained within the respective research groups. A few years ago and for the very first time, various projects – such as ThinPV, Dursol and Connect-PV – funded by the Competence Center of the ETH Domain for Energy and Mobility (CCEM) brought all those researchers together at one table to bundle these competencies. Amongst those were two Empa labs – "Thin Films and Photovoltaics" led by Ayodhya Tiwari and "Functional Polymers" headed by Frank Nüesch – as well as Michael Grätzel's "Photonics and Interfaces Laboratory" and the "Photovoltaics and Thin Film Electronics Laboratory" led by Christophe Ballif, both at EPFL. These preliminary projects then triggered the current PV2050 project funded by the Swiss National Science Foundation (SNSF), which is coordinated by EPFL's Ballif and involves more than ten partners working jointly together in five focus areas.

Challenges of solar energy

If solar electricity is to be established as the main source of electricity by 2050 huge challenges in research and development have to be overcome. Firstly, costs must decrease further in order to survive on the market. Secondly, the power grid and seasonal storage options must grow commensurately if the share of solar energy is to be expanded. This is because large surpluses of electricity are produced during a sunny summer, but there could be a shortage of electricity in the winter. Switzerland's geography constitutes another challenge, as space for solar parks is limited. This situation calls for innovative technologies, such as solar cells that also provide energy in ambient light or in semi-shade, or window panes that not only allow light into buildings but also produce electricity and thus contribute significantly to energy-efficient buildings and help to reduce their carbon footprint.

For many years now, Empa researchers have been working on optimizing photovoltaic systems, especially by raising energy conversion efficiency. Besides improving the energy balance of residential homes solar electricity can also cover other future supply gaps, for instance in mobility. In order for

>>



In future, fuels will have to be obtained from solar power. Long-distance trips that are so difficult to achieve with battery-powered vehicles will be possible with hydrogen cars. Hydrogen can be produced from sunlight in a variety of ways. Empa is conducting research to develop all the components displayed in the graphics.

Coating seven times faster

Empa conducts basic research to boost the efficiency of solar cells. But Empa wouldn't be Empa if it didn't develop promising approaches further. One of them is a collaboration with Solaronix, a company in Aubonne on Lake Geneva, funded by the Federal Office of Energy (SFOE).

Empa developed a process for solar cell coatings suitable for industry, which is supposedly seven times faster than existing methods. Until now, Solaronix has been using screen-printing methods to coat its solar cells. Although there are already solar cells that, to a certain extent, are produced using the slit die technique, this often only affects one sub-step. "We managed to produce all layers with the slit die method and at industrial speed," explains Frank Nüesch, Head of the Laboratory for Functional Polymers at Empa.

The Empa researchers have also made considerable progress in producing individual layers of the solar cells: Whereas every layer has had to be fired individually until now, they managed to fire all the cell layers at once in a single step. Two patent applications have already been filed; another project with Solaronix is in the pipeline. After all, the aim now is to expedite the upscaling to an industrial level with a view to transferring the process to industrial partners.

this to happen, electricity needs to be converted into hydrogen – for example by means of electrolysis – which could then be used in fuel cell vehicles. This form of energy use called Power-to-gas is already being tested in "move", Empa's demonstrator for future mobility on the Dübendorf campus.

Progress is also being made in novel ways of storing solar electricity – here too for example in the form of hydrogen (see inset to the right) or using new types of batteries (see page 30). The more electricity can be obtained from solar cells, the more diverse will be the possibilities for optimizing Switzerland's power grid to allow the ambitious targets for 2050 to be reached.

Interfaces – inconspicuous but key

Within the PV2050 project, in a sub-project coordinated by Empa researcher Frank Nüesch, the partners are developing new materials and interfaces for ultra-high efficiency PV systems. "The interfaces are particularly important here", explains Nüesch. They help to separate positive and negative charge carriers and prevent them from recombining again. This is the only efficient means of generating electricity from sunlight. Intermediate layers made of special oxides can also increase the efficiency of crystalline silicon solar cells.

An exchange of knowledge and experience is at the core of the collaboration between the individual researcher groups. "Every solar cell technology needs interfaces", says Nüesch, "but all of them use a different approach." It's a pot full of ideas, as he adds. Out of this came the idea as part of the PV2050 project to "exchange" the different approaches, meaning to clarify whether technologies that work for one type of solar cell could also be used for a different type of cell.

Promising tandem solar cells

While Nüesch's team is focusing on research into interfaces, the "Thin Films and Photovoltaics" lab under the leadership of Ayodhya Tiwari and Stephan Bücheler is also involved in two other focus topics, again in close cooperation with the EPFL groups of Michael Grätzel and Christophe Ballif as well as with CSEM researchers. The objective is tandem cells – cells that combine different PV technologies in one cell in order to achieve a higher efficiency.

In these tandem cells, the visible light is first absorbed by a transparent layer and converted into electricity. However, part of the light, in the near infrared range, penetrates the uppermost layer and is collected by another thin film solar cell that lies underneath. This method considerably increases the electricity yield, as a larger portion of the solar spectrum can be used.

"We use traditional silicon cells for this, but we also work with thin film solar cells made from CIGS in combination with transparent perovskite cells", says Bücheler. This research is part of the Nano-Tera initiative, which particularly promotes the development of such tandem cells. The team led by Tiwari and Bücheler has already succeeded in demonstrating the concept of the efficiency-enhancing perovskite CIGS tandem solar cell.

Bundled know-how

The second interdisciplinary project that the two Empa researchers and their EPFL colleagues are involved in is being carried out with a research team from Zurich University of Applied Sciences (ZHAW) led by Matthias Schmid; it focuses on computer simulations of solar cell systems. If they succeed in "simulating" these systems on a computer, it will be easier to identify material combinations for future, promising research projects. This would speed up the pace of solar cell research tremendously.

Further research topics include, among others, the optical integration of solar cells into the Swiss landscape, because the public will only accept alternative energies if their generation can be integrated more or less seamlessly into the environment. Bundling these various projects within the PV2050 consortium should make a key contribution to realizing the Swiss government's energy strategy. High-efficiency PV modules that are more affordable and space-saving than at present could ease Switzerland's energy supply – thanks to an interdisciplinary collaboration by all Swiss research institutions and the merging of expertise from all over the country. //

ACADEMIC PARTNERS

Alain Christophe Ballif, EPFL
Michael Grätzel, EPFL
Christophe Moser, EPFL
Julien Bailat, CSEM

INDUSTRY PARTNERS

Solaronix SA, 1170 Aubonne
GRZ Technologies, 1951 Sion

From solar power to hydrogen

Hydrogen is playing an increasingly important role in the debate on alternative energies. However, it is not trivial to produce. Photoelectrolysis (aka photoelectrochemistry or PEC) constitutes a highly promising approach here: Thanks to what are known as PEC cells, not "only" is solar energy converted into electricity, it is also "refined" directly into hydrogen, rendering electrolytic water splitting superfluous. Within the scope of the SHINE project, Empa researcher Artur Braun teamed up with Christophe Moser from EPFL and Julien Bailat from the Centre Suisse d'Electronique et de Microtechnique (CSEM) in Neuchatel to develop a device that is capable of mimicking photosynthesis in plants without relying on rare metals. The idea is for hydrogen to be produced basically "in one step" using cheap and readily available materials ("Earth-abundant materials"). This reduces costs and increases the efficiency of the electrochemical reactions.

Andreas Züttel, head of the LMER in Sion

The next step – once the hydrogen has been produced – is to store it. The joint Empa-EPFL Materials for Renewable Energy lab in Sion, headed by Andreas Züttel, collaborates with national and international partners to find possibilities of storing hydrogen in solid materials such as metal hydrides, carbon nanotubes or borohydrides. This method could replace the often bulky pressurized gas cylinders – hydrogen storage with new geometries would thus be possible. In order to expedite the commercialization of the technique, Züttel founded the spin-off GRZ Technologies in 2017, which develops and realizes hydrogen-based energy storage systems.

The conversion and particularly the (long-term) storage of solar power in the form of hydrogen is a key element of a sustainable energy supply, for instance for mobility. A fleet of hydrogen vehicles is already in operation at "move", the demonstration platform for sustainable mobility on the Empa campus in Dübendorf; the photovoltaics systems on both the façade and the roof of the demonstrator supply the power needed for water electrolysis. In other words, "move" exemplifies how the mobility of the future might work without any fossil energy throughout the entire "chain".

A brace for historical steel bridges

Empa scientists are saving iron bridges from the 19th century from collapse. Carbon fiber plasters are strengthening the crumbling structures. A railway bridge in Switzerland and a road bridge in Australia have already been reinforced successfully. Many historical bridges could follow. "Partners in crime" are specialists for steel fatigue at EPFL.

TEXT: Rainer Klose / PICTURES: Empa

Maintaining, not discarding – not only true for art nouveau villas, pre-war sports cars or Hammond organs from the 1950s, 'maintaining, not scrapping' is also a good idea for old railway or road bridges. These industrial monuments, often conceived and calculated by steel construction engineers from the 19th century, are rusting away quietly or creaking audibly under the weight of modern Intercity trains and heavy trucks.

The good news is: They can be saved. A supporting brace made of CFRP (carbon fiber-reinforced polymers), reversibly affixed to the bridge and in line with monument protection regulations, strengthens the resistance of the old structures, making them safe and helping them to survive day-to-day wear and tear better and for longer.

Gentle method for old structures

Masoud Motavalli and Elyas Ghafoori have already braced two old bridges using this "gentle" method: the Münchenstein railway bridge near Basel, built in 1892, and the Diamond Creek road bridge in Australia, built in 1896. If their system achieves a global breakthrough, there would be plenty of work to do: Roughly 30% of all bridges in Europe are more than 100 years old. The situation is similar in the US, Australia and Japan. Road authorities and railway companies are on a global hunt for methods to keep these structures viable. And it's possible that Empa holds the key. Empa's research partner is Alain Nussbaumer. At EPFL, he carries out research into the fatigue and fracture mechanics of steel structures. Nussbaumer also supervises the dissertations under way at Empa as part of these research projects.

CFRP is often the material of choice for reinforcing structures. It is rust-resistant and doesn't display any material fatigue. It's also light and doesn't burden the structure with extra weight in the same way that steel reinforcement would. Under its previous CEO, Urs Meier, Empa gathered lots of experience in the 1990s with CFRP reinforcements of concrete and wood constructions.

An anchor instead of glue

Unlike wood or concrete, however, where the CFRP reinforcement can simply be glued on, it is considerably more complicated to affix it to old steel girders. Often the bridge girders are rusty or covered with thick layers of paint. Sometimes rivets in the steel girders prevent the CFRP plasters from being stuck on smoothly. Ghafoori gets around these problems by affixing the plates to the bridge using anchors rather than sticking the CFRP directly to the bridge. This means there is no need for smooth sanding large surface areas. An additional bonus: The bridge doesn't need to be closed to traffic while mounting the CFRP strips. Likewise, the bridge doesn't need to be wrapped in film – something that's often necessary with old bridges that span rivers to prevent paint splinters containing heavy metals from falling in the water.

Diamond Creek Bridge near Melbourne was reinforced with CFRP strips in 2018 and, once the work was complete, its durability was tested with a 42-ton truck.

The anchors that Ghafoori uses to attach his CFRP plasters are not that easy to recreate. "It's important that the carbon fibers do not break when attaching the CFRP", says Ghafoori. He has been experimenting with this technique at Empa for more than ten years and uses the heavy hydraulic presses in the construction hall for his experiments. "It wasn't easy at first", the researcher recounts. "When I was testing the first anchors in a tensile test for my Master's thesis in 2009, they fell off overnight. That didn't exactly earn me the respect of my colleagues. I was even banned from visiting the lab for a few days, as my work was considered too dangerous."

In the meantime the anchoring system developed at Empa is protected by patent and has long since overcome its teething problems: Münchenstein Bridge has been reinforced with the pre-stressed CFRP plasters in 2015. Several dozen passenger and goods trains rumble across the historical steel construction every day. A long-term monitoring system comprising a wireless sensor network measures the load and movements of the bridge parts and delivers the data to Empa in real time.

Prepared for all occasions

News about the project, which also provided the topic for Ghafoori's PhD thesis, spread quickly in expert circles. As a result, a very similar bridge in Australia was reinforced using the CFRP system in January 2018: the 122-year Diamond Creek Bridge near Mel-

>>

bourne. “We’ve learned a lot since Münchenstein”, says Ghafoori. For example, the researchers were able to improve the shape of the anchors and make the entire construction flatter. That’s important, because many bridges have trucks driving underneath them. If the brace were to project too far downwards, high trailers in particular could collide with the new technology.

Münchenstein Bridge near Basel was reinforced with CFRP strips back in 2015. Several intercity trains per hour and several goods trains per day roll over the 126-year-old bridge.

The team has also incorporated temperature fluctuations between summer and winter in the calculation: The measurements on Münchenstein Bridge had shown that the CFRP reinforcement on the bridge is much more effective on hot summer days than in winter. The reason is that summer heat causes the steel bridge to expand, but the length of the CFRP reinforcement remains virtually the same. This means that the bridge is held together more tightly by its supporting brace in summer than in winter.

Diamond Creek Bridge also has sensors and will provide load data online to Empa for at least a year and a half. To see if the reinforcement has an effect, the researchers sent a 42-ton truck over the bridge before and after attaching the CFRP strips. “The initial data has shown that the forces acting on the bridge are reduced by half”, says Ghafoori. “As a conservative estimate, this could mean that the remaining life of the bridge is doubled.”

Bridges made future-proof

Nowadays Ghafoori and Motavalli are getting more and more visits from abroad. The French institute of science and technology for transport, development and networks (IFSTTAR), the French center for mobility (CEREMA) and a Chinese delegation have all announced their intention to come, while a US delegation has already visited Empa. The method can be used anywhere in the world without a great deal of effort. “For Australia, we preassembled the clips with the CFRP strips and tested them here at Empa. Then we simply sent them to the construction site by parcel post”, says Ghafoori. “We just had to fly out there later and assemble everything in situ.”

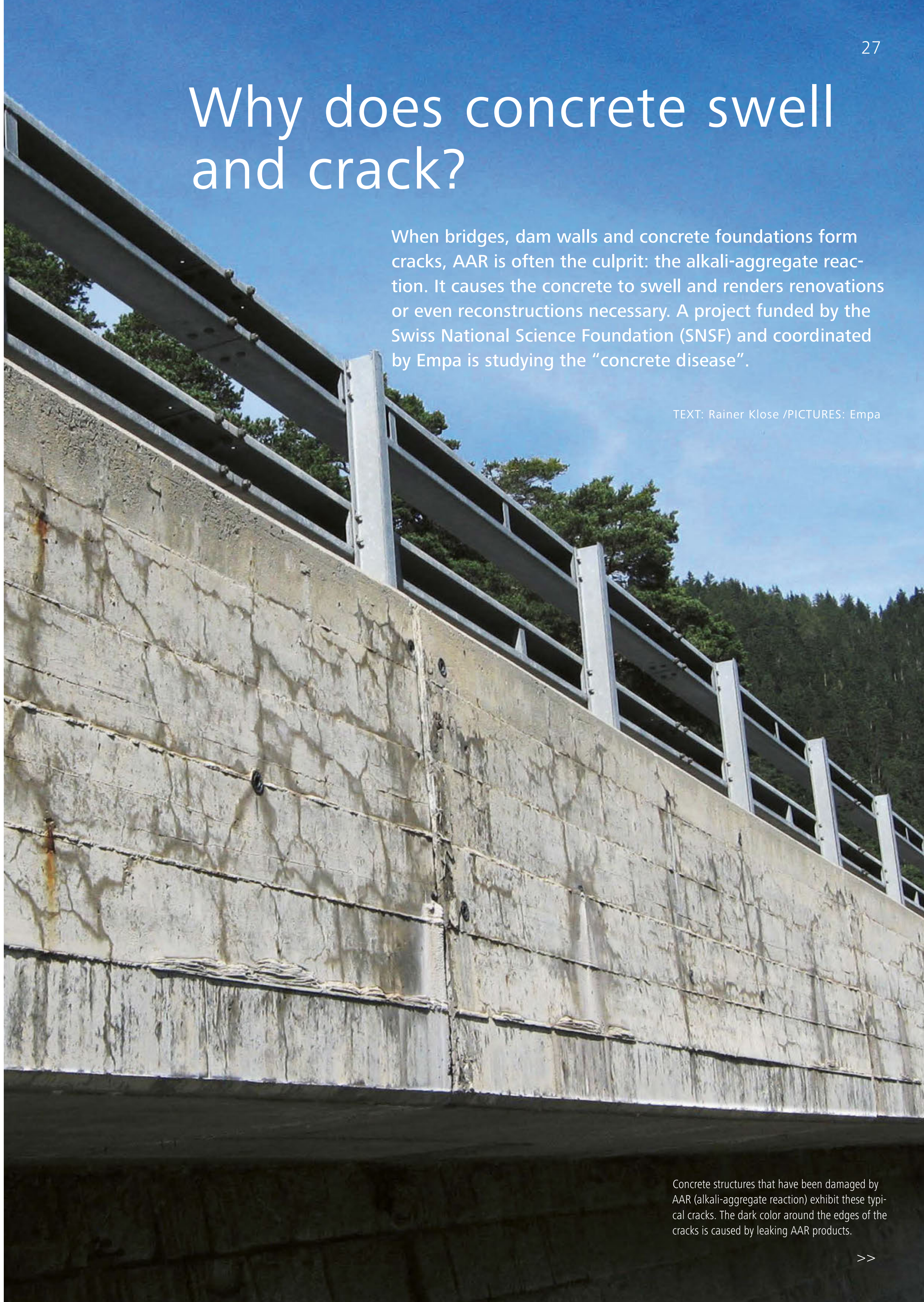
Of course the researchers want to advance their knowledge even further. Having already reinforced straight steel girders, the aim now is to also reinforce the X-shaped connectors between the girders. The points where welded seams and connecting joints meet are especially prone to rust and this is also where fatigue cracks appear that can make the bridge unstable. A newly developed CFRP strip system could soon solve this problem. This type of support could make many steel bridges from the 19th century future-proof – allowing them to significantly outlive their younger reinforced concrete counterparts. //

ACADEMIC PARTNERS

Alain Nussbaumer, EPFL

INDUSTRY PARTNERS

S&P Clever Reinforcement Company AG, 6423 Seewen



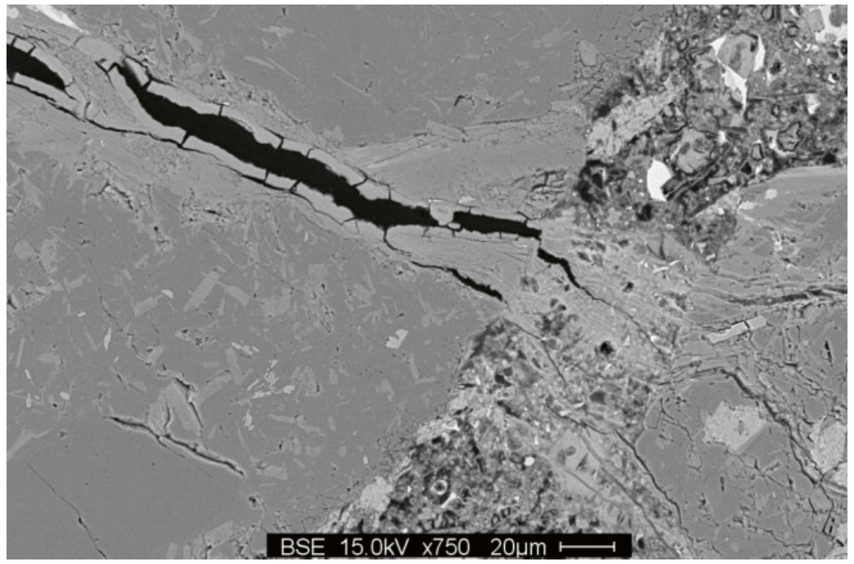
Why does concrete swell and crack?

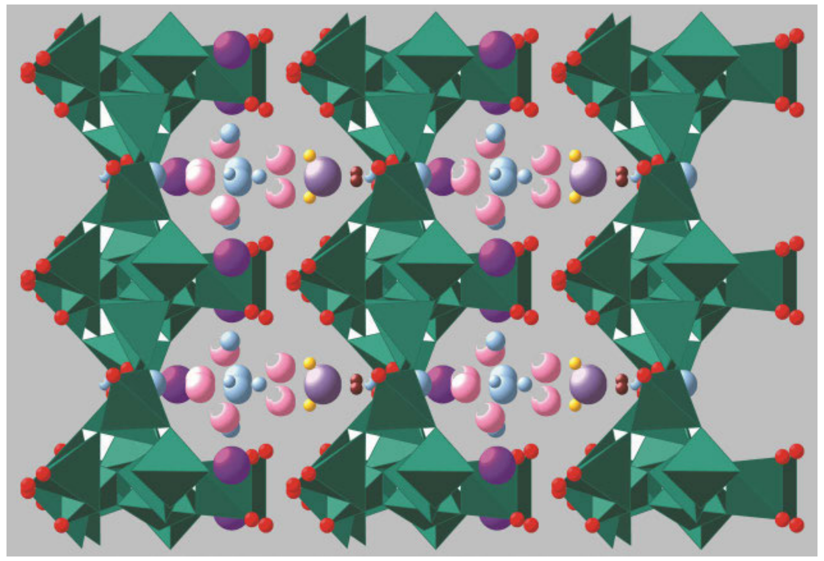
When bridges, dam walls and concrete foundations form cracks, AAR is often the culprit: the alkali-aggregate reaction. It causes the concrete to swell and renders renovations or even reconstructions necessary. A project funded by the Swiss National Science Foundation (SNSF) and coordinated by Empa is studying the “concrete disease”.

TEXT: Rainer Klose /PICTURES: Empa

Concrete structures that have been damaged by AAR (alkali-aggregate reaction) exhibit these typical cracks. The dark color around the edges of the cracks is caused by leaking AAR products.

>>





The cracks in the concrete caused by AAR form in tiny crystal fissures (middle photo) and are visible later to the naked eye (left-hand photo). An alkali calcium silicate hydrate, the structure of which was clarified with Empa's help in 2016, is behind the damage (right-hand photo).

Unfortunately, concrete does not last forever. The ravages of time also take their toll on concrete structures in Switzerland. Not only are reinforced structures like bridges affected, but also concrete buildings without any reinforcement, such as dam walls. One cause is referred to as the alkali-aggregate reaction (AAR). It can affect all concrete structures in open air.

With AAR, the basic ingredients in the concrete are actually the problem: Cement – the main component of concrete – contains alkali metals such as sodium and potassium. Moisture in the concrete reacts with these alkali metals to form an alkaline solution. The main components of concrete are sand and gravel, which in turn contain silicates such as quartz or feldspar. The alkaline water reacts with these silicates and forms a so-called alkali calcium silicate hydrate. This mineral accumulates moisture in its structure, which causes it to expand and gradually crack the concrete from within.

The striking thing here: The very same chemical reaction takes place in numerous pieces of gravel within the concrete; the small stones crack one by one. The pressure that can be exerted on an entire structure due to this micro-reaction is huge: A dam wall, for instance, can expand by a few decimeters. This can cause damage to the lateral connecting points to the rock or deformations in the sluice area. The reaction takes place gradually, with the first damage only becoming noticeable in affected structures after ten to 15 years. However, the continual swelling of the concrete can seriously reduce the structures' service life.

In 2015 a team of scientists from Empa and the Paul Scherrer Institute (PSI) succeeded in identifying the structure of the aqueous crystal that triggers the swelling in concrete. This structure had previously been the subject of much speculation.

The discovery inspired an interdisciplinary research project funded by the Swiss National Science Foundation (SNSF). Besides Empa and PSI, two EPFL institutes are also involved. The research activities are coordinated by Empa researcher Andreas Leemann. "We want to study and understand AAR in every dimension, from the atomic level and length scales in the Angstrom range to entire structures on a centimeter and meter scale," explains Leemann.

Six projects cover all dimensions

Six sub-projects were defined in the SNSF Sinergia project: PSI is using synchrotron radiation to study the structure of the reaction products in order to explain their sources. The key parameters for triggering the silicates and the composition of the reaction products formed at the outset are being studied at EPFL; moreover, computer simulations are being used to investigate the impact of the swelling on structures.

And at Empa, the formation of the cracks in the concrete is being investigated at spatial and temporal resolution using computer tomography at the Empa X-Ray Center, and the aqueous crystals are being synthesized in the lab. This enables the researchers to obtain larger quantities of the substance usually found in nano- to micrometer-sized cracks in pieces of gravel. Only with larger quantities of the substance in question can physical properties be determined accurately, however. Not only should the findings help understand AAR much better, they should also reveal ways to avoid damage – and thus costs.

"We are already in the throes of decoding the phenomenon, which has only been understood in fragments until now," says Leemann. The four-year project got underway in May 2017. The first results are already in. The next step will involve linking the individual groups more closely and building on the results of the partners. In the end, this should yield a more complete picture of AAR that enables the condition of and the risk to concrete structures to be gaged more effectively and the fate of the afflicted buildings to be supervised more scientifically. //

ACADEMIC PARTNERS

Karen Scrivener, EPFL
Jean-François Molinari, EPFL
Nanocem.org
Rainer Dähn, Paul Scherrer Institut

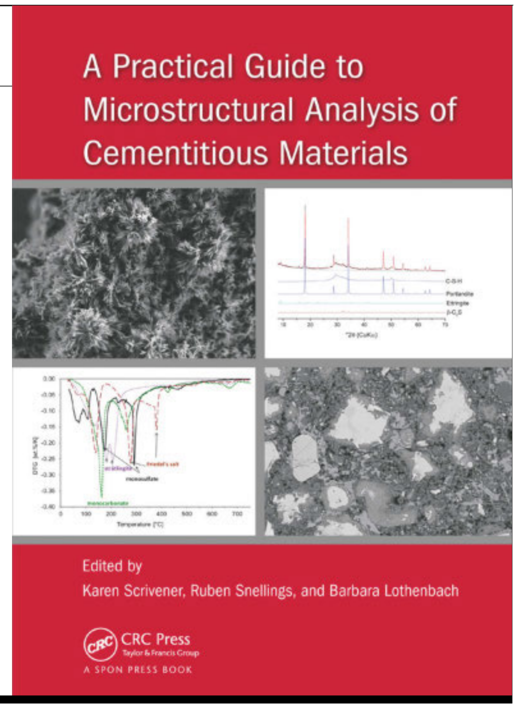
Research on low-CO_2 cement

Not only does Empa's Concrete / Construction Chemistry lab deal with cement-based building materials such as concrete, but also with the composition of cement itself. This is the field of Barbara Lothenbach, who has developed a close collaboration with EPFL's Laboratory of Construction Materials under Karen Scrivener since 2004. The cooperation even spawned a joint textbook in 2016 (A Practical Guide to Microstructural Analysis of Cementitious Materials, CRC Press, Oxford / UK).

Due to the immense amount of concrete that is needed to build and maintain our infrastructure, it is estimated that concrete production is responsible for five to eight percent of man-made global CO_2 emissions. If this figure is to be reduced, the composition of what is known as Portland cement – invented in 1844 and by far the most widely used cement in the world ever since – needs to change.

The CO_2 emissions caused by cement production can be curbed by adding additives such as blast furnace slag, flue ash or burnt clay. The additives react with Portland cement to form calcium silicate hydrate (C-S-H). The CO_2-favorable substitutes have one drawback, though: The cement's chemistry changes – and thus the composition of the C-S-H, which gives the cement its solidity. And this, in turn, might affect the solidity and long-term stability of the concrete produced with the cement.

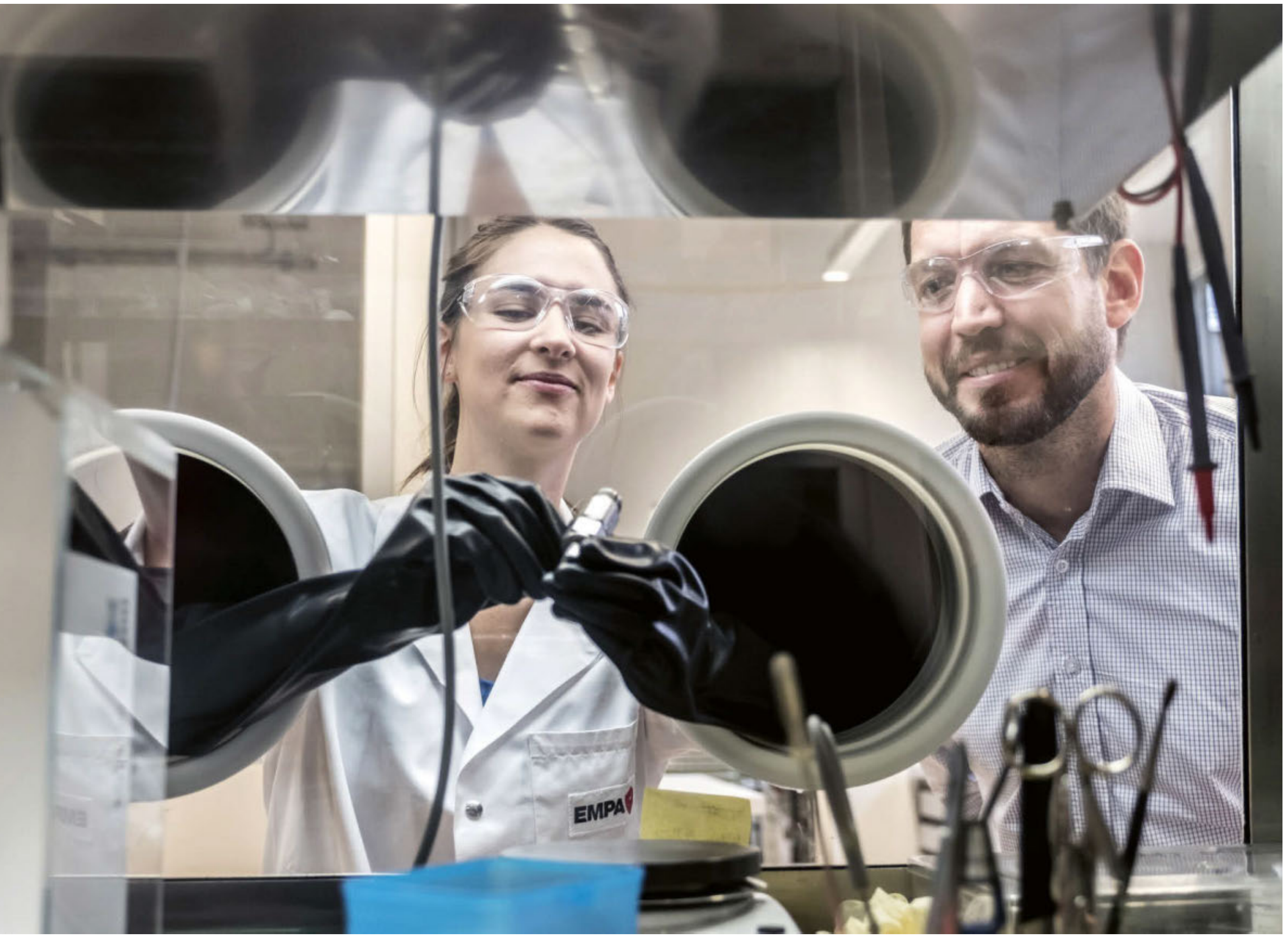
Basic research with the aid of chemical syntheses, electron microscopy, X-ray structural analyses and other methods is thus called for. The collaboration between Empa and EPFL has yielded five dissertations so far; three more are in the pipeline. The projects are funded by the Swiss National Science Foundation (SNSF) and the international cement research network, nanocem.



Batteries that no longer burn

Researchers at Empa and the University of Geneva have developed a prototype of a novel solid state sodium battery with the potential to store energy more safely in the future.

TEXT: Rainer Klose / PICTURES: Empa



Where the prototype of a new battery is born: Marie-Claude Bay and Corsin Battaglia work in a “glove box”, free from oxygen.

Nowadays, everyday life would be inconceivable without lithium ion batteries. They are becoming ever lighter, more powerful and last longer. However, they partly contain scarce materials and, if used incorrectly, can catch fire or even explode. In search of a new generation of batteries that should be light, efficient and safe, researchers from Empa and the University of Geneva developed a prototype of a novel solid state sodium battery. It is based on sodium, a more cost-effective alternative to lithium normally used, and solid borohydrides. The Sinergia project is coordinated by Arndt Remhof at Empa and funded by the Swiss National Science Foundation (SNSF).

The advantage of the new concept over existing battery technologies is clear: When a lithium ion battery charges, the ions leave the cathode and move through the liquid electrolyte to the anode. The anode in commercially available batteries is made of graphite to prevent the formation of dendrites – tiny, microscopic metal deposits that trigger short circuits in the battery and can cause a fire. However, this considerably restricts the battery’s performance. The use of a solid electrolyte suppresses the formation of dendrites, which in turn enables the use of anodes made of metal and thus higher energy densities.

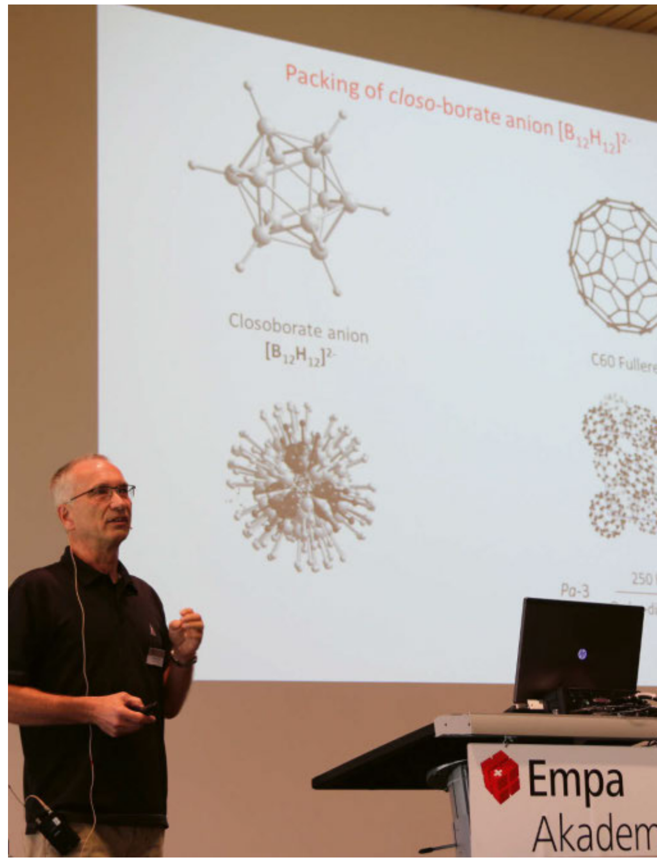
A non-flammable solid sodium battery

And so the research team from Empa and the University of Geneva set out in search of a suitable solid ionic conductor that, as well as being non-toxic, should be chemically and thermally stable, and would allow the sodium ions to move easily from anode to cathode. The boron-based substance class of closo-boranes displayed the desired properties. “The difficulty consisted in establishing close contact between the three components: between the anode, consisting of solid metallic sodium; the cathode, made of sodium chromium oxide; and the electrolyte, the closo-borane,” explains Léo Duchêne, a researcher at Empa’s Materials for Energy Conversion lab and a PhD student in the Department of Physical Chemistry at the University of Geneva. The researchers eventually found a solution: They made a powder composite of the electrolyte and cathode material, dried it and compressed the individual layers into a solid battery.

The Empa team then tested the battery’s efficiency. “The electro-chemical stability of the electrolyte can withstand three volts. Most other solid electrolytes are damaged at the same voltage,” says project head Arndt Remhof. And after 250 charging and discharging cycles, 85 % of the energy capacity was still available. “But we would need 500 cycles before the battery can be launched on the market,” says the researcher. Therefore, the team is on the lookout for other optimization options to explore the system’s limits. If the next steps prove successful, the closo-borane solid state battery could be refined for the market with a little help from industrial partners. //

ACADEMIC PARTNERS

Hans-Rudolf Hagemann, Universität Genf
Radovan Cerny, Universität Genf



At a battery symposium at Empa, Radovan Cerny, a crystallographer from the University of Geneva, presented the structure of borates, which serve as the basis for safe solid state batteries.

The man who filters electrons

Scientists from Empa and the University of Geneva are using methods from chemistry to unravel an atomic physics question. It concerns the association between electron spin and chirality, i.e. the "handedness" of molecules – the so-called CISS effect (chirality-induced spin selectivity), first described in 1999. The researchers would like to use it to make an electronic filter capable of separating electrons with different spins.

TEXT: Rainer Klose / PICTURE: Empa

Empa scientist Karl-Heinz Ernst is a specialist in chiral molecules.

ACADEMIC PARTNERS

Jérôme Lacour, Universität Genf
Thomas Bürgi, Universität Genf

Karl-Heinz Ernst is used to explaining complex things in simple terms. "Let's start with the desired result," he says. "We'd like to build a spin filter, i.e. sort electrons that fly only through a substrate according to their spin." He spends the next few minutes talking about gold and sulfur, egg boxes and left and right hands – and microscopes that can be used to move and manipulate single atoms.

A brief glance back into the history of science sets the stage, upon which the subatomic spectacle is to take place: The chirality of molecules was discovered in the 19th century; chemical molecules exhibit a similar symmetry to our right and left hands. Then, in the 1920s, came the principle of electron spin: In an atomic shell, two electrons that are completely identical, cannot occupy the same orbital. Only the introduction of the spin – a kind of directional rotation – makes it possible to explain a helium atom that unites two electrons in one orbital, for instance.

An association between molecular chirality ("right-" or "left-handed") and the electron spin ("up" or "down") was first made in 1999 by Ron Naamann from the Weizman Institute of Science in Israel. He referred to the phenomenon as CISS ("chirality-induced spin selectivity"); in other words, a spin filter made of handed molecules. Scientists have been seeking ways to understand this effect better and put it to good use ever since. Understanding it more profoundly might help comprehend the role of spin effects in biological and bioactive molecules.

In a collaboration with the University of Münster, Naamann succeeded in showing the spin effect directly on chiral DNA molecules standing upright on a gold surface in 2010. Empa's Karl-Heinz Ernst, together with colleagues from the University of Geneva, is now looking to take this approach even further by using gold nanoparticles. With an atomic weight of 197, gold is ten times heavier than the carbon (atomic weight: 12), nitrogen (14) and oxygen (16) atoms found in DNA, and around six times heavier than phosphorous (31). As the interplay between the electron spin and the atomic electron shell of the "filter atoms" is much stronger for heavy atoms, a chiral construction made of gold atoms, aligned cleanly, would have a considerably more significant influence on electrons flying through it.

A Synergia project launched this year and funded by the Swiss National Science Foundation (SNSF) will run for four years. Jérôme Lacour from the University of Geneva will synthesize molecules, which should hold individual gold nanoparticles in a chiral configuration like a pair of tongs. Thomas Bürgi from the University of Geneva is making the chiral gold particles and dividing them into "right-handed" and "left-handed" ones. And at Empa the particles are then aligned cleanly – like eggs in an egg box, with the tips pointing upwards. The researchers then want to find out whether the golden atomic ensemble actually works as a spin filter. "As yet, we're probably the only ones in the world to use such heavy atoms to investigate this phenomenon," says Ernst. "Let's wait and see what we end up with. Hopefully, the world's most effective spin filter." //

A strong alliance

TEXT: Annette Locher (FSRM) / PICTURE: Empa

The collaboration between Empa and FSRM (Fondation Suisse pour la Recherche en Microtechnique) on vocational training launched in 2011 is set to continue in the future. With 720 participants in eight years, the figures have been impressive. They signal that vocational training is taking on a national, multilingual dimension in Switzerland.

FSRM and Empa both pursue the goal of translating brand-new knowhow from research and technology into skills for everyday working life. As FSRM is based in Neuchâtel and Empa has three campuses in the German-speaking part of Switzerland, a collaboration across the language border thus seemed logical and promising. Once initial contact had been made in 2011, it wasn't long before the first co-developed courses were conducted at the Empa Academy in Dübendorf.

The success of the endeavor just goes to show how the two institutions complement each other: To date, around 70 one or two-day courses have been co-organized, imparting knowhow to engineers, technicians and decision-makers from industry, which they can use directly in practice.

Fresh impetus

The collaboration is ongoing. The majority of the 2019 courses at the Empa Academy have already been set with experienced lecturers either from a pool of over 150 external experts that FSRM has at its disposal, or from Empa. FSRM, which turns 40 this year, has specialized in vocational training courses since 1992. Over 20,000 engineers and technicians have taken part in the courses, which are held in Switzerland – including at Empa – and sometimes even abroad.

However, Empa and FSRM also collaborate in other fields, such as organizing the Swiss NanoConvention, Switzerland's largest nano-congress, which is held at different cities every year. //

Joint courses (in German) scheduled at the Empa Academy in 2019

- Adhesive Technology for Practitioners
- Graphene and Carbon Nanotubes
- Corrosion and Electrochemical Characterization
- Criteria for Selecting an Electric Motor
- Hightech Ceramics
- Material Processing with Lasers
- Additive Manufacturing for Metals
- Polymer Materials for Technical Applications: Evaluation and Selection

Course descriptions and dates:
www.fsrm.ch; www.events.empa.ch

COOPERATION PARTNERS

FSRM, Neuchâtel

Events (in German)

10. Oktober 2018
Kurs: Klebetechnik für Praktiker
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/klebetechnik
Empa, Dübendorf

17. Oktober 2018
Kurs: Materialbearbeitung mit Laser
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/laser
Empa, Dübendorf

29. Oktober 2018
International Workshop on CIGS Solar Cells
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/sharc25
Empa, Dübendorf

30. Oktober 2018
Externe Vorspannung mit memory-steel als Bauwerksverstärkung
Zielpublikum: Ingenieure aus der Praxis, Forscher aus dem Bereich Fe-SMA
www.empa-akademie.ch/memory-steel
Empa, Dübendorf

06. November 2018
Kurs: Additive Fertigung von Metallen
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/addfert
Empa, Dübendorf

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

Your way to access Empa:

portal@empa.ch
Phone +41 58 765 44 44
www.empa.ch/portal

@EmpaMaterialScience
Empa_CH
EmpaChannel
Empa
empa_materials_science