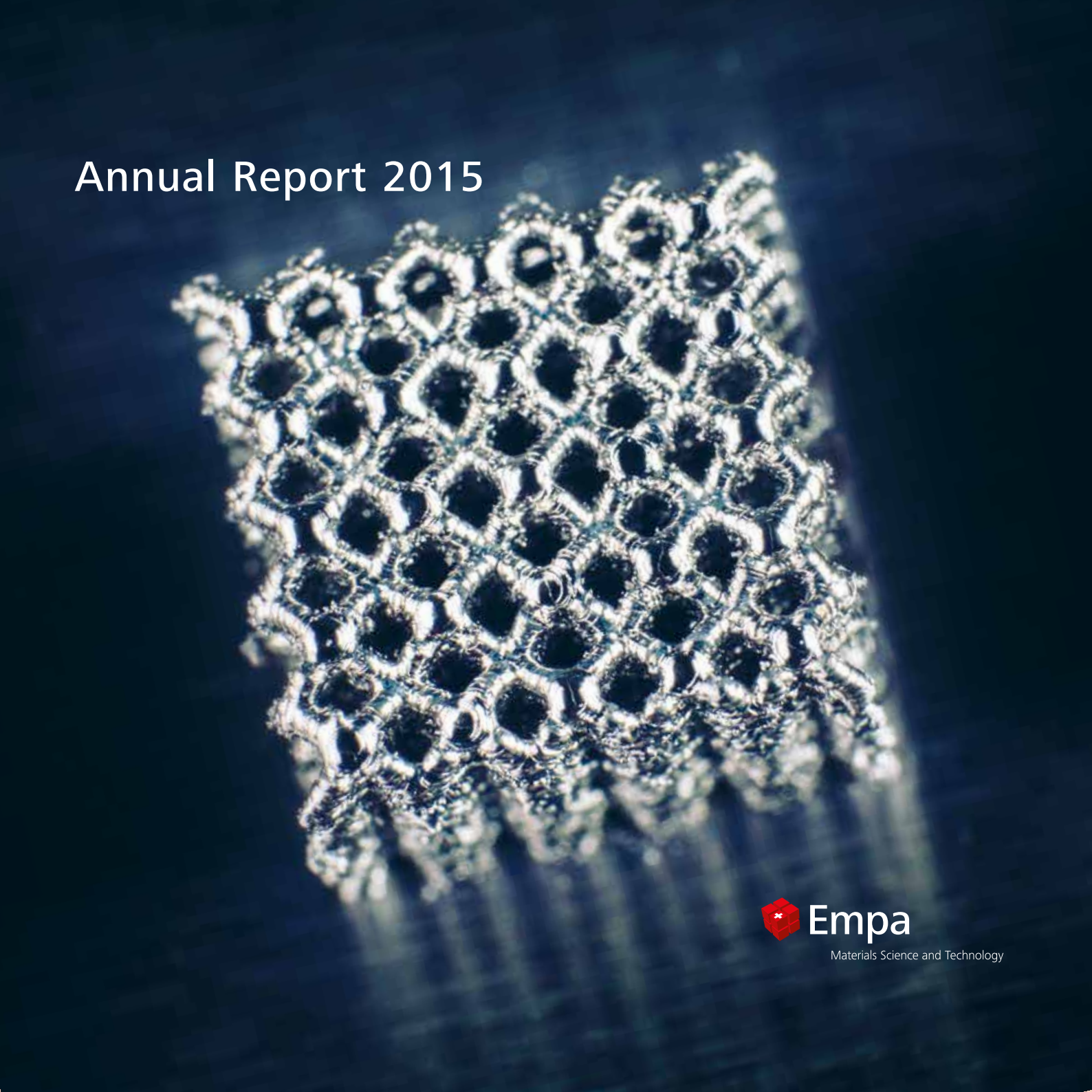
Annual Report 2015



Empa
Materials Science and Technology

Our Vision.
Materials and Technologies for a Sustainable Future.

Cover photo: Titanium aluminide cubes produced on a 3D printer with embedded ceramic particles. Thanks to its low density, this alloy is interesting for jet engines, but difficult to process. Test specimens reveal the parameters where 3D printing with metals works best. See also page 10.

Publisher: Empa; **Concept/Design/Layout:** Empa; **Printing:** Neidhart + Schön AG, Zurich.

ClimatePartner
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Print | ID: 53232-1604-1003

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Using research and cooperation platforms to boost Switzerland's competitive edge

It is no secret that Switzerland's economy can only keep developing and assert itself on the global stage thanks to innovations, i. e., new products with a real added value customers are willing to pay for. New product developments enabled through Empa are based on novel materials and technologies. Getting them ready for market entry, however, can be so resource-consuming that hardly any company is ready to take the risk, even if the underlying scientific basics are well established. For instance, it took more than a decade to develop flexible CIGS thin-film solar cells to such a stage that they could match silicon cells in terms of energy conversion efficiency. Besides tenacious researchers, this also required sufficient support from public funding sources; and even after a pilot production plant could recently be inaugurated in Niederhasli, Zurich, success on the mar ket is by no means guaranteed.

Intense collaboration and a regular exchange of ideas between researchers and their partners from industry are paramount if you want to translate scientific results into sustainable applications for the Swiss economy. Here at Empa, we have established various platforms for areas such as construction, mobility, energy, and new industrial production processes, where scientists will bring their expertise to the table and drive projects outside the protected confines of the lab environment. For companies, the platforms are places where they can keep tabs on the latest developments and collaborate at an early stage by submitting requests or specifying market requirements.

Our platform for the construction sector is called NEST, a building with a fixed core and exchangeable units that enable new, energy-efficient forms of living and working to be developed and experienced in operation. At the mobility demonstrator "move", research is conducted into new powertrain technologies for individual mobility, such as fuel-cell vehicles or gas and electric cars. Thanks to these two platforms, where our research converges with that of our partners, we were able to initiate a third one – ehub (Energy Hub), which is pioneering the energy supply of the future by studying, optimizing, and coupling energy flows between the mobility and the building sector. This enables decentralized solutions for our energy future to be explored and experienced in practice.

Moreover, novel coatings and functional components with well-defined mechanical and thermal properties are honed at the recently inaugurated Coating Competence Center (CCC). Here, the focus is on the upscaling of novel coating technologies from the lab to industrial-scale processes – of course always in close collaboration with our industrial partners. Surface coatings, but also new metal powders and ceramics for 3D printing of complex components, are developed on a larger scale than in the lab. Our long-term goal is to transform the CCC into a Center for Advanced Manufacturing in the form of a public-private partnership (PPP) at the Swiss Innovation Park in Dübendorf. Along with the "Internet of Things", advanced manufacturing is one of the cornerstones of "Industry 4.0", the next industrial revolution, where virtual data merges with actual production facilities.

These new platforms enable Empa to bridge the gap between research and industry based on scientific excellence and thus facilitate an efficient knowledge and technology transfer in order to boost Switzerland's competitive edge. After all, we have to stay ahead in the global innovation ranking, don't we?

Prof. Dr Gian-Luca Bona, *CEO*

01

Fireproofing for business jets
A new coating protects aircraft interiors against fire. Not only is the substance more environmentally friendly than previous flame retardants; it is also easier to apply.
Page 45

Sound masterpiece with Empa heart
A sound masterpiece by Belgian artist Aernoudt Jacobs, which he created with Empa technology, was on display at the "Kontinuum" exhibition in Vienna. Inside the work of art there is a membrane made of electroactive polymers (EAP), which simultaneously generates reflections and sounds.

02

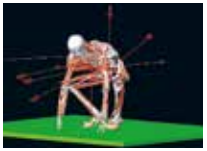
A passion for research
"Empa ambassadors": the unofficial new title for two Empa researchers. Karl-Heinz Ernst (left) and Oliver Gröning were appointed as "Distinguished Senior Researchers" – a new accolade for scientists and engineers whose reputation and work has stood Empa in good stead for many years, whether it be through excellent basic research or its subsequent application and implementation with industrial partners.

Research for the energy turnaround
Around 70 researchers from Empa, ETH Zurich, EPFL, Lucerne University of Applied Sciences and Arts, the University of Geneva, and the University of Applied Sciences and Arts Northwestern Switzerland convened for a workshop organized by the Swiss Competence Center for Energy Research, where they developed a research roadmap to reduce the energy demand of the Swiss building park fivefold by 2050.

03

Key energy of the future
The automobile industry is also involved in the transition from fossil and nuclear energy to renewable sources. In addition to the introduction of vehicles with new powertrain technologies, the supply of appropriate fuels is also pivotal. At Empa, representatives from politics, industry and research demonstrated how this might be achieved.

Backache – a matter of mechanics



Thanks to a collaboration with Zurich University Hospital and the University of Pittsburgh, Empa decoded the mechanics of the lower vertebrae. The researchers can now reveal how wear and tear comes about on vertebral bodies and spinal disks, which makes selecting the right course of treatment much easier.
Page 24

04

Techtextil Innovation Award 2015

In collaboration with partners from industry, a team from Empa developed a chest strap for the long-term monitoring of patients with heart problems. What makes the ECG strap so special: it keeps itself moist, which is essential for reliable signal monitoring. The strap won the Innovation Award at the Techtextil trade fair.

Empa goes bestseller
The spy thriller "Project Black Hungarian" combines current developments in e-mobility and IT security with a fictitious spy story, which unfolds, among other places, at Empa in St. Gallen. The story was inspired by events during the electric car rally WAVE 2013.

05

How do the holes get into cheese?
The holes in certain types of cheese are caused by hay particles, which release gases in the fermentation process. During traditional milking, hay gets into the milk pales, as researchers from Agroscope and Empa discovered. This also explains why certain cheeses have fewer and fewer holes: the milk is getting "cleaner" from machine milking.

Solar cells with 25 percent efficiency
The Sharc25 project has an ambitious goal: to increase the efficiency of thin-film solar cells made of copper indium gallium (di) selenide (CIGS) to 25 percent – three percent above the current record.

06

Clean in every way
In a CTI project Empa, ETH Zurich, and Bucher Municipal developed a pioneering hybrid electric powertrain for road sweepers. The concept is based on a gas engine, which powers an electric motor. Compared to conventional road sweepers, this halves the energy consumption and slashes CO_2 emissions by more than 60 percent.

Nine partners from eight countries
Empa is part of the "European Nanomedicine Characterization Laboratory", a project funded by the EU framework program "Horizon 2020". The goal is to achieve a level of international excellence in the characterization of nanodrugs for diseases such as cancer, diabetes, inflammatory conditions or infections.

07

Edobalance for future products

Empa scientists developed a method that enables companies to simulate production scenarios – and thus avoid poor investments. Here's an example: nanofibers made of carrot waste from the production of carrot juice, which can be used to reinforce synthetic components e. g. for motorcycle helmets.

Fuel crucial for eco-balance

Fuel cells are regarded as the technology of the future for both cars and household heating systems. But are they always more environmentally friendly? An international team of scientists headed by Empa came to the conclusion that it all depends on how sustainable the hydrogen production is.

08

Experience planned wind farms

Wind turbines alter the landscape and cause noise. In collaboration with ETH Zurich, Empa developed a computer simulation that enables an optical and acoustic assessment – even before the wind turbine is up and running.

Anesthetics in Antarctica

Inhalation anesthetics, so-called fluranes, are widely used during surgery. Just how much of these strong greenhouse gases is produced worldwide remains a mystery. Now, for the first time, an Empa team has succeeded in determining the actual quantity based on global air measurements, e. g. at a research station in Antarctica.

Page 12

09

NEST: the backbone is up

The building of the future is taking shape: about a year after the first cut of the spade, the backbone of the research and innovation building NEST is finished. On 11 September 2015, the backers from research, industry, and the public sector celebrated the topping-out ceremony with project partners in Dübendorf.

Using body heat to heat up a tent

In collaboration with the start-up „Polarmond" and two other research partners, researchers at Empa developed a self-heating, all-in-one tent system. Inside the tent, the conditions are supposed to remain comfortable thanks to a sophisticated dehumidifying system and a fine-tuned temperature control mechanism.

10

Empa researchers optimize diesel

If diesel exhaust gases could be denitrified, you'd have an economic clean engine. In collaboration with ETH Zurich and the Politecnico di Milano, Empa researchers have been studying different AdBlue injection methods with a view to achieving the optimum nebulization and distribution of the urea solution in the flow of exhaust gas.

Page 18

"Concrete disease" solved

When bridges, dam walls, and other structures crumble, the culprit is often AAR: the alkali-aggregate reaction, which is triggered by moisture seeping in, damages concrete structures all over the world and makes renovations or reconstructions necessary. Now, for the first time, researchers from the Paul Scherrer Institute (PSI) and Empa have solved the crystalline structure of the material produced in the course of AAR – the first step towards finding a possible remedy.

Page 27

11

"move" opens its doors

The demonstration and technology transfer platform "move" enables Empa researchers to develop new vehicle drive concepts with significantly lower CO_2 emissions and assess them in practice. It uses surplus electricity from photovoltaic plants or hydropower stations as an energy source. On the one hand, this enables batteries in electric cars to be charged. On the other hand, the electricity can also be converted into hydrogen for fuel cell vehicles or synthetic methane for natural gas/biogas vehicles.

12

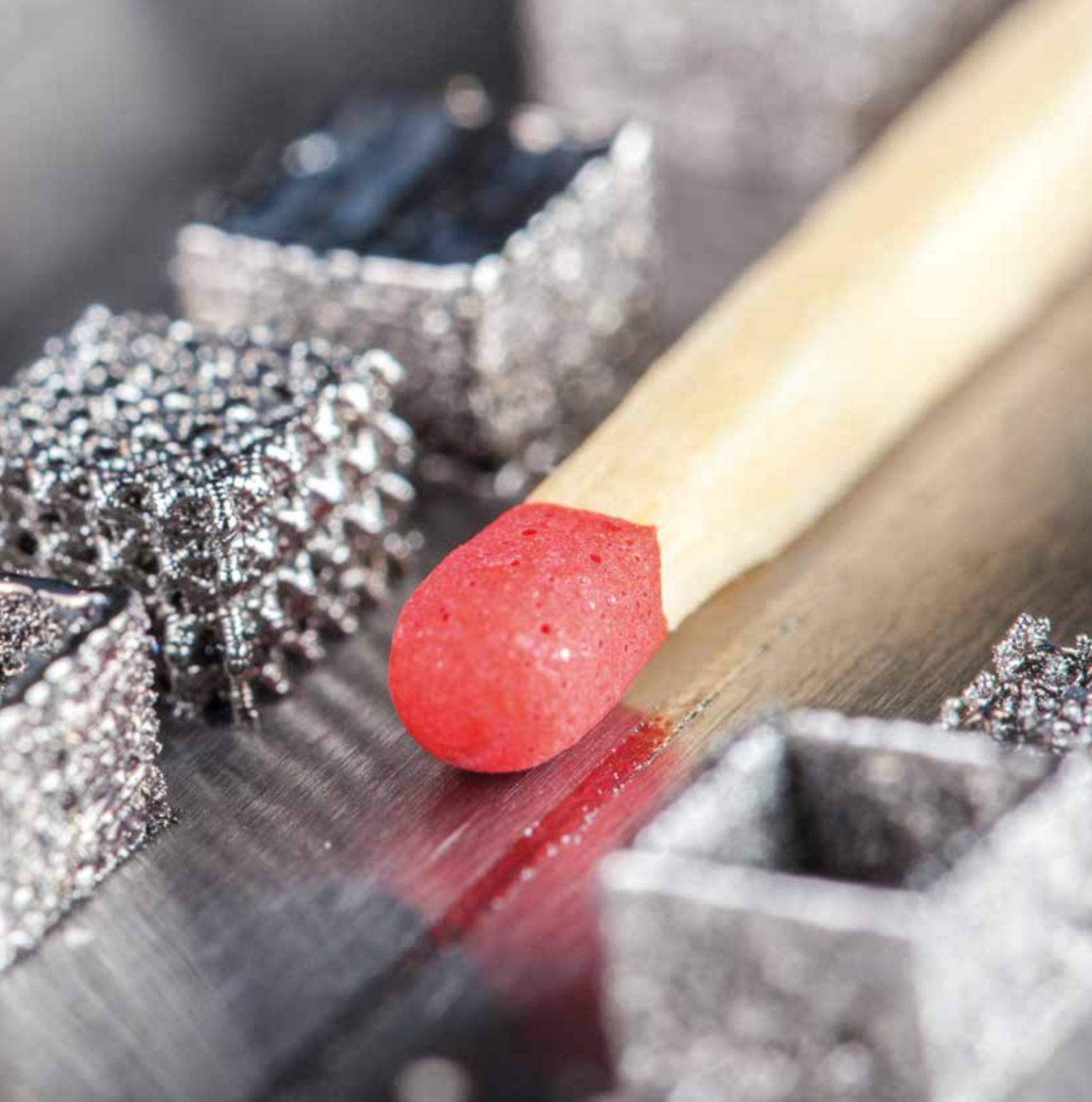
Ecological: "fool's gold battery"

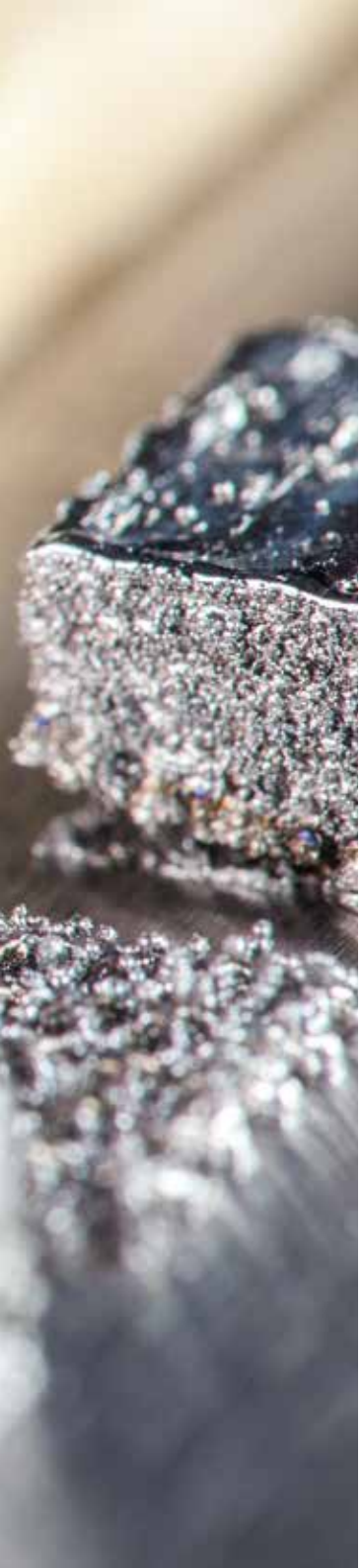
Researchers from Empa and ETH Zurich discovered an alternative to lithium ion batteries: the "fool's gold battery". It consists of iron, sulfur, sodium, and magnesium – all elements that are in plentiful supply.

Page 30

EU support for Empa researchers

Two Empa researchers – Rolf Erni, Head of the Electron Microscopy Center, and Josep Puigmarti from the Protection and Physiology lab – received two of the prestigious ERC Grants. Erni received a Consolidator Grant to the tune of EUR 2.5 million, Puigmarti a Starting Grant of EUR 1.5 million.





Selected Projects

Investigating new materials and accelerating the development of innovative technologies; supplying the stimulus for the sustainable development of our society; providing the scientific basis for political and societal decisions – these are Empa's core objectives, which it pursues through research and development, cooperation, networks, and partnerships, as well as services, expertise, and consulting activities. The following snapshots from the institute's laboratories give an insight into Empa's multifaceted research activities.

Anesthetics in Antarctica

They go by the names of desflurane, isoflurane and sevoflurane, and put patients in a deep sleep while surgeons patch them back up again on the operating table. But fluranes also have a dark side: they considerably heat up the Earth's climate and even travel to the other side of the world in the atmosphere. A global inventory would, therefore, be very much in the spirit of the Kyoto Protocol. However, this is proving more difficult than anticipated as industry is remaining tight-lipped. To date, only estimates are available, which were obtained using a bottom-up approach by projecting the consumption in hospitals and deducing an approximate production quantity.

A team of Empa researchers headed by Martin Vollmer chose the opposite route: top-down. They analyzed air samples from various stations for traces of inhalation anesthetics and used the results to calculate the global production quantity, which turned out to be equivalent to around three million tons of CO_2. While that might sound like a lot at first glance, Switzerland's public transport system alone produces around three times as much – every year. In other words, a comparatively low amount of greenhouse gas actually gets into our atmosphere via operating theaters. Nonetheless, desflurane in particular is thought to affect the climate and, with a half-life of around 14 years, is very long-lived. By comparison, sevoflurane and isoflurane "only" take one to three years to break down.

2,500

times more potent than CO_2 as a greenhouse gas is the anesthetic desflurane.

Measurements in Antarctica also revealed that these substances reach the remotest regions of our planet. It takes the greenhouse gases around one to two years to make the journey to the poles. Empa researchers traveled to the Korean King Sejong research station in Antarctica to carry out measurements and analyze the samples. As this is too time-consuming for long-term monitoring, however, Korean colleagues at the station regularly fill still canisters with air and ship them off to Dübendorf. Moreover, Vollmer's team can also fall back on samples from an "air archive" for their analyses: since 1978 Australian researchers have been collecting air from the atmosphere and storing it for later studies.

1
King Sejong is a Korean research station located on King George Island off the Antarctic Peninsula.

2
Empa researcher Martin Vollmer flying the flag for Empa in Antarctica. The research station welcomes researchers from the four corners of the globe.

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1

2

Need for action disputed

But what should be the next step now that reliable statistics are available and we know that these substances are not just found in urban centers – i. e. where they are predominantly used – but travel to the ends of the world? Fluranes have already been produced since the 1980s and even back then had their opponents and supporters. Although they are extremely strong greenhouse gases, their absolute amounts are so low that they are merely a drop in the ocean in the grand scheme of things. What's more, they have no end of advantages for human and veterinary medicine. Vets use fluranes to quickly and easily anaesthetize livestock before castrations, for instance, which is considerably more cost-effective than drugging one animal after another with injections. While cost plays a lesser role in human medicine, inhalation anesthetics is still more pleasant for the patients. One should, however, be aware that the use of these long-lived substances also leaves traces in the remotest of regions – perhaps with repercussions that we don't yet know about. And as for the threat of global warming, the question remains as to whether more atmosphere-friendly alternatives can be developed. //

Waste not, want not

As part of the National Research Program "Energy Turnaround" (NRP 70), the Swiss National Science Foundation (SNSF) is supporting the interdisciplinary research project "THRIVE". Under the direction of IBM Research – Zurich and the Hochschule für Technik Rapperswil, scientists from Empa, ETH Zurich, the Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud (HEIG-VD), and PSI heave teamed up with industrial partners to develop a heat pump that is powered by waste heat by 2017. Compared to today's compression heat pumps, this technology requires considerably less electricity and can also use waste heat efficiently to air-condition buildings.

As heat is used to power the pumps, the technology could relieve the strain on the power grid on the one hand and harness heat from factories, power stations, and computer centers or other renewable sources such as solar power, geothermics, and biomass on the other. Through the extensive use of adsorption heat pumps like those to be developed in THRIVE, it could theoretically be possible to slash the electricity demand for heating and cooling purposes by up to 65 percent and the consumption of fossil fuels for heat production by up to 18 percent by 2040.

1,800,000

million tons of CO_2 could be saved through the extensive use of adsorption heat pumps by 2040.

Nowadays, heat pumps are mostly used to convert environmental heat, which lies at a temperature between −5 and 15 °C, into thermal heat for rooms or processes. Traditional heat pumps draw warmth from the surroundings, such as from the earth or air, to vaporize a refrigerant in an evaporator. The vapor produced rises into an electrically powered compressor, which condenses it and thus heats it up. The vapor turns back into liquid in an adjoining condenser and releases the heat into a heating cycle. This process can also be used to heat rooms and generate cool air, like in a refrigerator.

Powered by heat, not electricity

The thermally powered adsorption heat pump works in a similar way – the major difference being that, in place of a compressor, it has an adsorption heat exchanger that uses heat at temperatures from 60 °C as its driving energy instead of electricity. During the so-called adsorption process, the adsorption heat exchanger adsorbs considerable amounts of vapor from the evaporator and compresses it inside the heat exchanger, thereby releasing heat. The refrigerant adsorbed beforehand is forced (desorbed) back out of the adsorption heat exchanger by the supply of

driving heat from an external source. The hot vapor released as a result turns back into liquid in the condenser and the corresponding condensation heat is released into the heating cycle. The adsorption heat pump can also heat and cool. As the cooling or heat production takes place intermittently, however, at least two adsorption heat exchangers working in parallel are needed for it to run uninterruptedly.

Due to their low energy consumption, adsorption heat pumps achieve a much higher cooling or heat output in relation to the wattage used than conventional heat pumps. Moreover, pure water can be used as a coolant instead of refrigerants, which can sometimes be harmful for the environment. Another advantage of the technology is the fact that renewable heat sources can be used, such as solar-thermal systems, which typically generate temperatures of up to 90 °C.

1

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1
A coated adsorber heat exchanger, which is being tested at the Institute for Solar Technology at the Hochschule für Technik in Rapperswil in collaboration with IBM Research, Zurich.

2
Empa researcher Lukas Huber loading the tubular furnace with polymer resin samples, which are converted into functional carbons via pyrolysis.

2

By using heat, the adsorption heat pump is just the ticket for many interesting applications where conventional heat pumps would be pointless. For instance, it could use the waste heat from future, actively cooled, concentrated photovoltaic plants or computer centers that are cooled with hot water to air-condition office or residential buildings. //

Diesel exhaust gases without any nitric oxides – is that possible?

Diesel combustion is more efficient in respect to gasoline engines. Thus diesels emit considerably lower quantities of the greenhouse gas carbon dioxide (CO_2). This is mainly because diesel engines work with excess air in so-called lean-burn mode. Due to the "excess" oxygen in the exhaust gas, however, the three-way catalytic converter widely used for gasoline engines, reducing more than 98 percent of the toxic nitric oxides (NO_x), cannot be used in diesel engines.

In order to reduce NO_x in diesel exhaust, a method is used that was originally developed for power plant exhaust gases. Around ten years ago, the first trucks equipped with this new technology have been introduced into the market. The method uses an aqueous urea solution, tradename "AdBlue", to convert the NO_x into harmless nitrogen and water via various chemical reactions in a special SCR (selective catalytic reduction) catalyst. AdBlue is carried in a separate tank in the vehicle and needs to be regularly replenished.

90

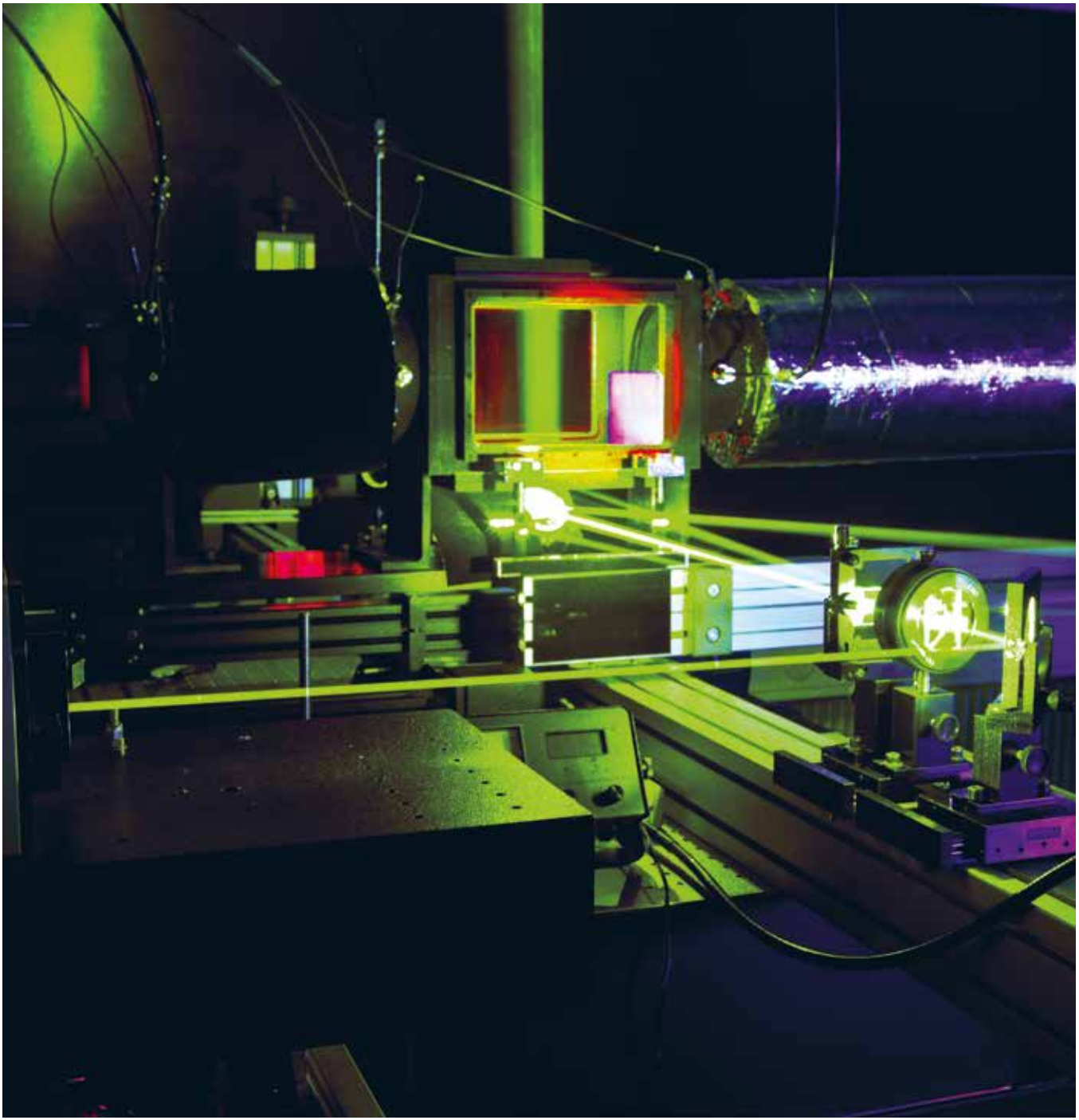
percent and higher is the conversion rate that SCR systems need to reach in dynamic operating conditions to comply with the current EURO-6 limits for NO_x.

However, SCR systems are considerably more complex than a conventional three-way catalytic converter for gasoline engines. For instance, the AdBlue dosage has to be precisely controlled to the amount of NO_x emitted by the engine. Too low quantities do not yield the NO_x reduction prescribed by law while too high quantities result in undesirable ammonia emissions. In addition, at temperatures below 200 °C, AdBlue tends to form solid deposits that eventually clog up the SCR catalyst. Consequently, SCR systems have to be optimized specifically to the various engine types and anticipated load changes – i. e. driving styles – a complex and thus expensive process.

EURO-6: same NO_x limits for gasolines and diesels

Implementation of SCR systems was only recently introduced in diesel cars. According to the EURO-6 norm valid since September 2014, identical NO_x limits apply for gasoline and diesel vehicles for the first time (the latter had always higher NO_x limits in Europe).

1
Laser-optical measurement techniques used in Empa's flow lab enable modern nitric oxide reduction systems to be optimized for diesel engines.



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1
Analyses conducted in Empa's flow lab reveal the planar distribution of AdBlue in diesel exhaust gas (red = high concentrations; blue = low concentrations). An even distribution of the "cleaning substance" AdBlue would be optimal.

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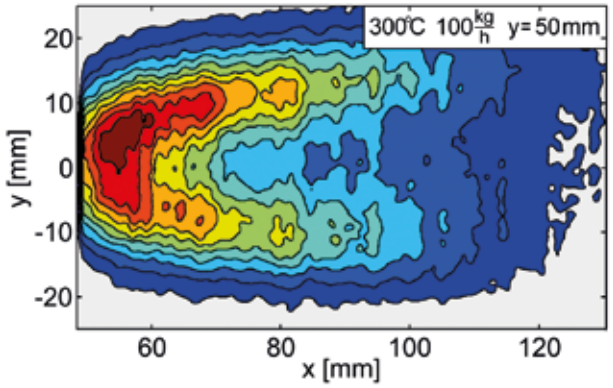
Researchers from Empa have set up a special high-temperature flow lab in order to study such systems in detail. They are currently investigating various AdBlue injection procedures for achieving the optimal atomization and homogenous distribution of the aqueous urea solution in the exhaust gas. The researchers use laser-based optical measurement techniques to quantify and visualize the AdBlue droplets in the flow of exhaust gas, and study their evaporation behavior and chemical decomposition processes.

A better technical understanding for cleaner diesel

The experimental results are then used in collaboration with colleagues from ETH Zurich and the Politecnico di Milano to parameterize computer simulations of the AdBlue injection physically correct and validate the simulation models. Such simulations predict the conversion rate of the catalytic converter under different operating conditions. Empa is therefore helping to reduce the amount of NO_x in exhaust gas from diesel vehicles even further. The better these technologies are understood in detail, the more efficiently diesel exhaust will be cleaned – until nitric oxide emissions are decreased substantially, also for diesels. The projects are supported by the Federal Office for the Environment (FOEN) and the Competence Center Energy and Mobility (CCEM), and conducted in collaboration with various industrial partners. //



1

Wood in a nutshell

8

computers are working on an MD simulation for around one and a half weeks to simulate processes in wood cell walls at molecular level.

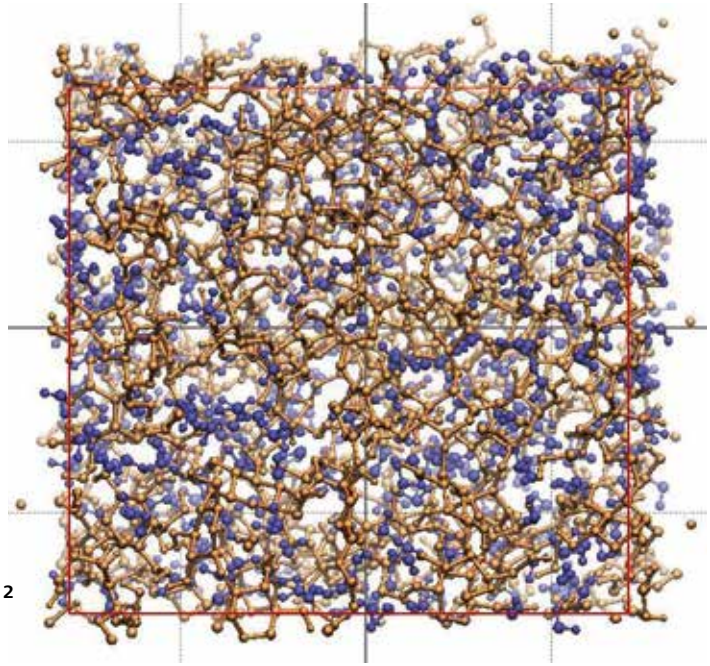
Wood is one of the world's oldest building materials. In order to adapt it to the demands of modern building and construction technology and understand the behavior of old structures and artworks, however, more research is needed on its properties and makeup – right down to its molecular structure, such as the cell wall; an impossible task until now. Thanks to state-of-the-art technology and ultra-fast computers, Empa researchers teamed up with ETH Zurich and succeeded in developing computer models of wood structures that enable them to simulate the processes in the wood cell walls at molecular level. This affords the researchers glimpses into a world that had remained concealed with even the most powerful microscopes until now.

Thanks to molecular dynamic simulation (MD), the Empa team managed to reveal what happens inside wood cell walls when water molecules (H_2O) seep in and are absorbed. The wood swells, loses parts of its stable structure and becomes porous. Although this is a well-known effect, its cause could now be observed at molecular level for the first time. As a result, the researchers finally understood why wood becomes porous: because the seepage of the water molecules destroys so-called hydrogen bridges, which hold the cell wall structure together in a dry state.

A computer used as a stronger microscope

But how can a computer make the invisible visible? The simulation program accesses a database with information on numerous molecules and atoms, as well as their force effect and behavior. For the analysis of the cell wall structure of wood in a damp environment, the researchers selected crystalline cellulose and amorphous hemicellulose from this data, which are known to be present in wood cell walls. Moreover, they generated an algorithm for the behavior of lignin and added water molecules to the selected model structures. This meant that, for the first time, they were able to observe how the individual molecules in the cell wall behave: Where do the water molecules migrate to? How do they accumulate inside the wood and how do they spread? This knowledge affords the researchers more detailed insights into the hygrothermal processes that take place in wood and opens up completely new possibilities to alter the material properties of wood with a view to optimizing its durability.

1



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Lots of computation, little lab work

MD simulations aren't lab experiments, however. While certain processes can be observed directly under a microscope, they are merely simulated on the computer, which requires the data available and the programmed properties of the individual molecules to be correct. As the basic program GROMACS is freely accessible as open source software, the Empa researchers needed to develop new algorithms for their tests themselves. The same went for an algorithm that calculates the systematics behind the different degrees of humidity with regard to the different molecules. The MD models tally optimally with known wood properties. Once all the data and parameters have been entered into the system, the calculation starts and can take up to ten days – in parallel on a cluster with eight computers.

Thanks to MD simulation, it is now possible to simulate phenomena that can't be studied with any microscope or lab test. For instance, the researchers succeeded in making wood cell walls waterproof. Using the simulation honed at Empa, it is now possible to observe the impact of the change on the structure and behavior of the individual molecules. //

1
The computer calculates how the water molecules behave in amorphous cellulose. It displays how the so-called hydrogen bridges (red) are destroyed by the water molecules (blue), which causes the wood to become softer, cavities to form and the wood to swell – and thus even more water molecules to seep in.

2
One of the simulations from the computer program: It displays the molecules of amorphous cellulose (yellow), which were located inside the red frame before water molecules were added. The more water molecules get into the wood, the more the cellulose molecules are forced out of the original frame. The wood swells and expands. If the water molecules are removed via drying, the cavities disappear and the wood regains its original properties.

Backache – a matter of mechanics

Empa is decoding the mechanics of the lower vertebrae in collaboration with the University of Pittsburgh and Balgrist University Hospital. The researchers can now reveal how wear and tear comes about on vertebral bodies and spinal disks, which makes choosing the appropriate therapy much easier.

In most cases, backache can be remedied by relaxing and strengthening the back muscles. In one in seven patients, however, only an operation can put an end to their suffering. In severe cases, defective vertebrae or spinal disks are bridged with a metal construction (intervertebral fusion). The fixed segment ossifies and is unable to trigger any more pain. However, this kind of reparatory operation only offers the patients a few years of relief before the problem eventually flares up again in the neighboring vertebrae. The big question is why this occurs and how it might be prevented.

34

percent more stress is exerted on spinal disks if the patient has a certain hereditary misalignment of the spinal column. People with this misalignment are at a significantly higher risk of spinal disk damage than their healthy counterparts.

Computer model of the back

The first step for the Empa team was to tweak the theoretical foundation and PhD student fed geometric spinal column data from 81 patients into the computer program OpenSim, a widely used simulation program for the human musculoskeletal system developed by the National Center for Simulation in Rehabilitation Research at Stanford University. The aim was to illustrate the biomechanics of the spinal column as accurately as possible: Does a spinal disk behave like a ball-and-socket joint? Or more like a rubber bearing? What influence do the muscles have? Does the rubber bearing always remain uniformly rigid or does the rigidity change depending on the angle of the curvature? Empa teamed up with Zurich University Hospital and the Institute for Biomechanics at ETH Zurich to find the answers.


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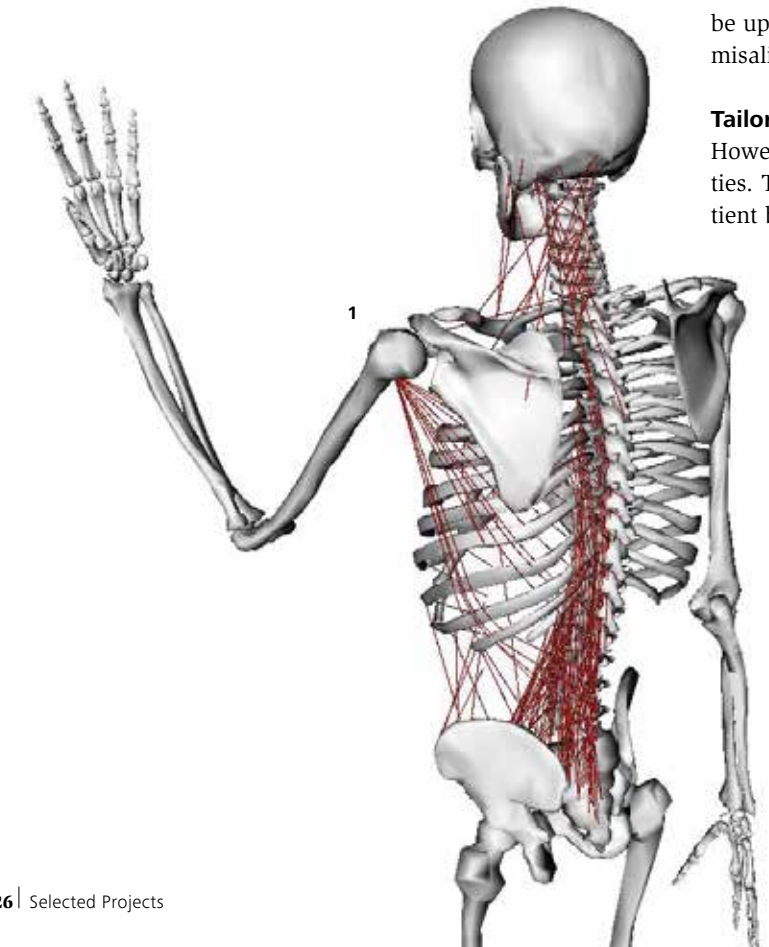
Computer program OpenSim enables Empa researchers to calculate the force distribution in the back when a person lifts a weight, for instance.



As the computer model of the human back revealed: In people with a particular misalignment of the spinal column, the spinal disks are already exposed to up to 34 percent more stress in a healthy condition. If a spinal disk breaks and is bridged, the strain on the neighboring vertebrae keeps on increasing and can be up to 45 percent higher than in people who don't have this misalignment.

Tailored therapeutic recommendations

However, the researchers don't just want to analyze probabilities. The goal is to make an individual diagnosis for every patient before recommending the appropriate therapy. A collaboration with US scientists funded by the Swiss National Science Foundation (SNSF) came in extremely handy in this respect: Researchers from the University of Pittsburgh developed a novel 3D X-ray video system called "Digital Stereo-X-Ray Imaging" (DSX), which can display the movement of the spinal column with 250 images per second down to an accuracy of 0.2 millimeters.

Initially, healthy people are being studied with the DSX system to understand the mechanics of the back. The researchers then want to use the method to fathom the problem of spondylodesis (spinal fusion). This involves filming patients with the DSX system before and after the operation and analyzing how bridging the vertebra has changed in the distribution of forces in the back. The study will help understand the degeneration of vertebrae and pinpoint the source of pain more effectively. In future, this kind of computer analysis could become standard for all patients scheduled to undergo back operations. //

Swiss Light Source helps decode “concrete disease”

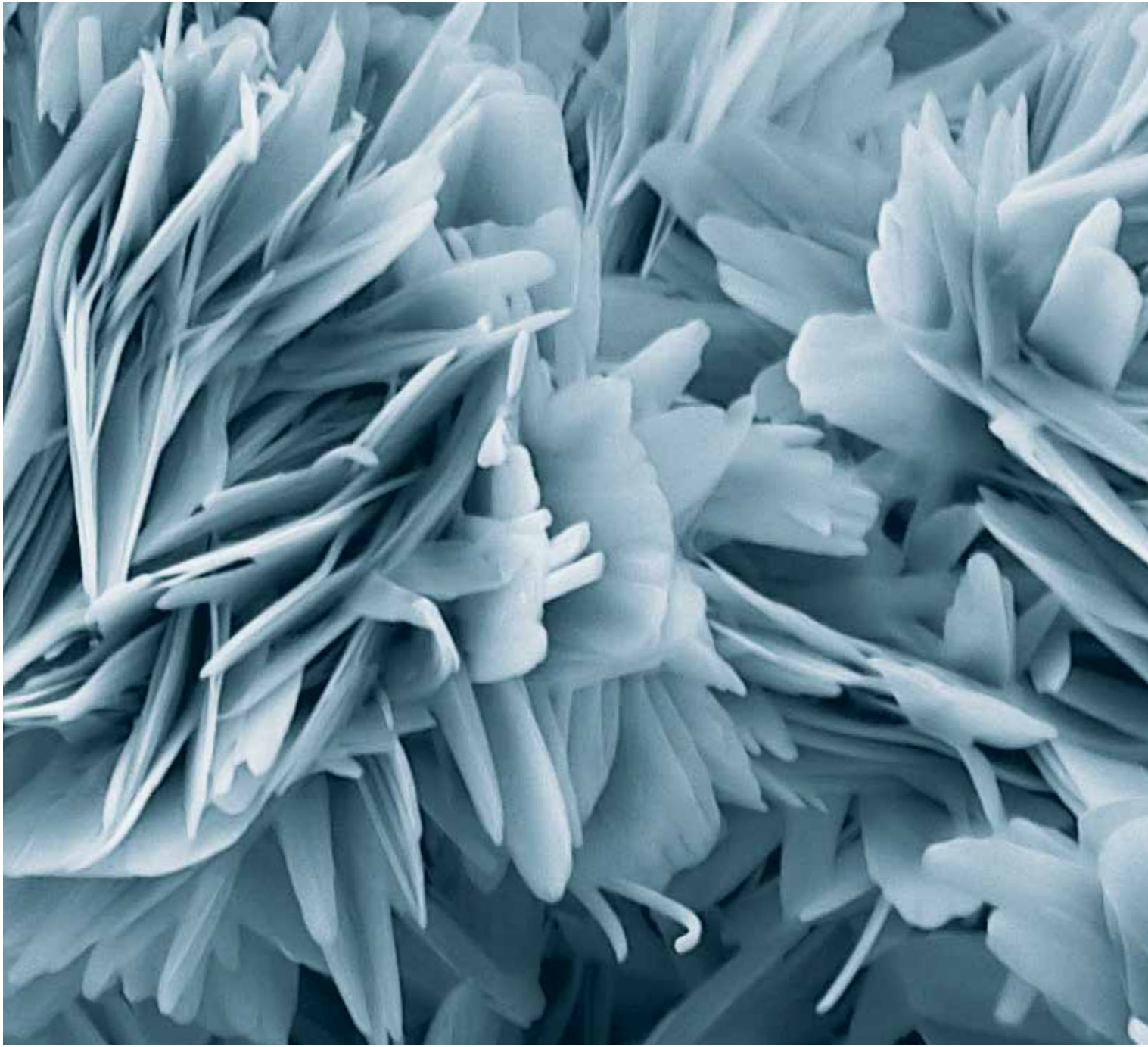
When bridges, dam, and concrete foundations crumble, the culprit is often AAR: the alkali-aggregate reaction. Triggered by the seepage of moisture, AAR damages concrete structures all over the world and renders renovations or even reconstructions necessary. Researchers from Empa and the Paul Scherrer Institute (PSI) have now decoded the crystal structure of the AAR product – the first step towards developing a possible remedy.

When AAR occurs in concrete, a chemical product that takes up more space than the base materials is formed. This causes so many cracks that, over the decades, the concrete gradually splits from within. The structure of the AAR product, however, remained a mystery. The specialist literature often referred to it as a gel. Researchers from Empa have now succeeded in decoding the structure of the substance in question in collaboration with colleagues from PSI and with the aid of its Swiss Light Source (SLS). The result: it’s a crystal. The alkali calcium silicate hydrate formed in the course of AAR exhibits a sheet-silicate structure that had never been observed in this form before. Empa researchers have been examining the topic of AAR for quite some time. Numerous bridges and up to 20 percent of the dam walls in Switzerland are affected by the problem. The samples for the research project were taken from the reinforced concrete foundations of a bridge built in Grisons in 1969. Empa researchers ground down the chunk of concrete until only a wafer-thin sample that was merely 0.02 millimeters thick remained. At the SLS, the sample was then irradiated with an extremely narrow X-ray beam, which was 50 times thinner than a human hair. Based on so-called diffraction measurements and a complex data analysis, the researchers were eventually able determine the crystal structure of the AAR product.

5 – 50

micrometers wide are the veins in concrete, where destructive AAR products accumulate. A classic X-ray structure analysis is not possible in such narrow cracks. The highly focused X-radiation at the SLS is necessary to decode the structure of the tiny crystals.

The findings may help gain control of AAR, which is sometimes dubbed “concrete cancer”. For instance, it might be conceivable to add organic materials to concrete that reduce the build-up of tension. The crystalline structure now discovered could pave the way for new material developments here. //



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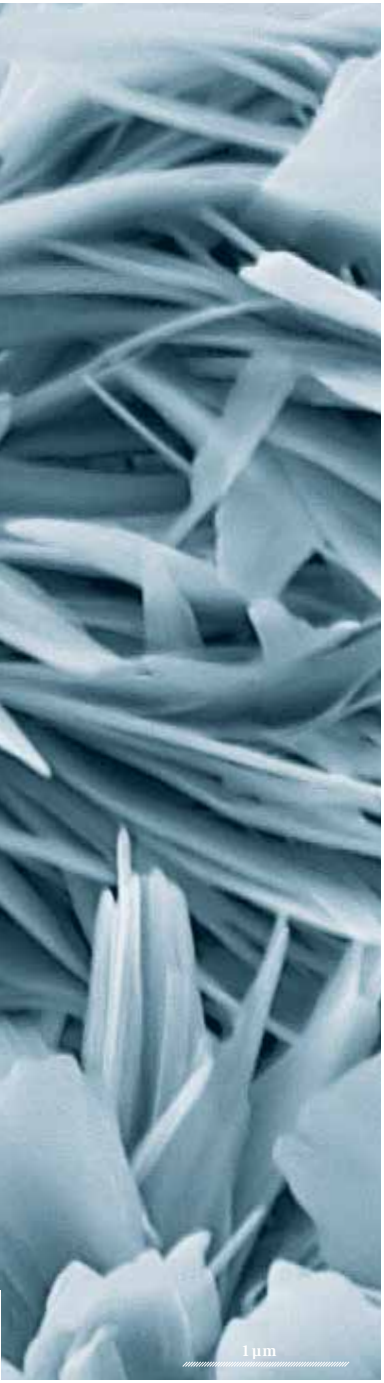

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So-called "concrete disease": close-up of cracks in concrete caused by the alkali-aggregate reaction (AAR).

2
Beauty in destruction: the AAR reaction product under an electron microscope.

2

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Super environmentally friendly: the “fool’s gold battery”

There is an urgent need to search for low-cost batteries to store electricity. Intermittency of green/renewable electricity is increasingly affecting the power grids, proportionally to its share in the energy bill, calling for stationary storage units to be connected to a smart grid. Electric cars are of increasing popularity, which will increase the need for (fast) charging stations. Efficient lithium ion batteries are not suitable for large-scale stationary storage of electricity; they are too expensive, and precious lithium is too scarce. Researchers from Empa and ETH Zurich intensely search for inexpensive solutions. They have now discovered an alternative: the “fool’s gold battery”. It consists of iron, sulfur, sodium, and magnesium – all elements that are in plentiful supply from nature. This means that giant storage batteries could be, in principle, built and used in buildings or next to power plants, for instance.

40

charging and discharging cycles without compromising its performance; the very good result of the test battery is calling for further optimization.

Safe, durable, and affordable

Researchers of the Kovalenko Group at Empa’s Laboratory for Thin Films and Photovoltaics have managed to combine a magnesium anode with an electrolyte made of magnesium and sodium ions. On top, nanocrystals made of pyrite – more commonly known as fool’s gold – serve as the cathode. Pyrite is a crystalline iron sulfide. The sodium ions from the electrolyte migrate into the cathode during discharge. When the battery is recharged, the pyrite releases the sodium ions back into electrolyte. This so-called sodium-magnesium hybrid battery already works in the lab and has several advantages: the magnesium at the anode is far safer than highly flammable metallic lithium. And the test battery in the lab already withstood 40 charging and discharging cycles without only moderate decrease in the overall charge-storage capacity, calling for further optimization.

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The key to success: pyrite (fool’s gold) as a cathode material (Photo: JJ Harrison/commons.wikimedia.org)

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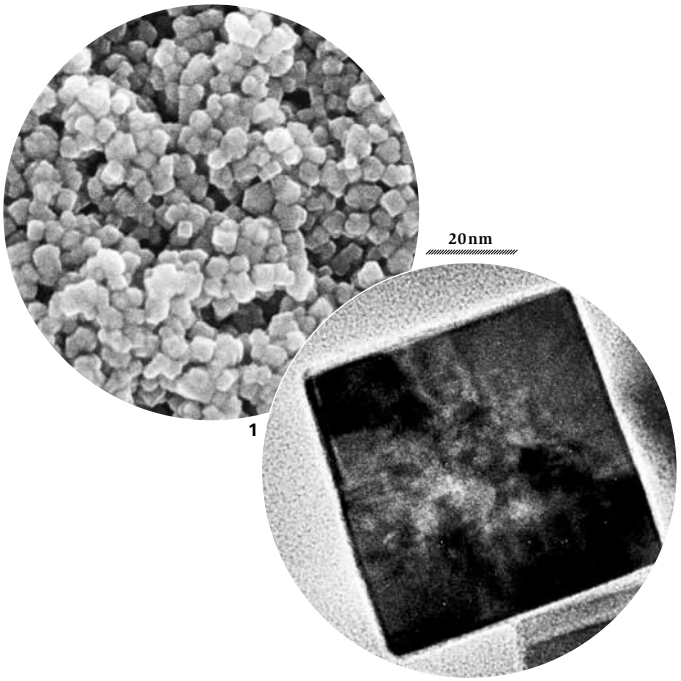
The biggest advantage, however, is the fact that all the ingredients for this kind of new battery are easily affordable and in plentiful supply: iron sulfide nanocrystals, for instance, can be produced by grinding dry metallic iron with sulfur in conventional ball-mills. Iron, magnesium, sodium, and sulfur hold 4th, 6th, 7th, and 15th place by the abundance in the Earth's crust (by mass). One kilogram of magnesium costs at most four Swiss francs, which makes it 15 times cheaper than lithium.

There are also savings that can be made when it comes to constructing the cheap batteries: lithium ion batteries require relatively expensive copper foil to collect and conduct the electricity. For the "fool's gold battery", however, inexpensive aluminum foil as a cathode current collector can be perfectly sufficient. The battery's full potential has not been exhausted yet. If the electrolytes can be refined further, it will be possible to increase the voltage of the sodium-magnesium hybrid cell and to extend its lifetime. It is also highly important to identify such electrolyte formulations that contain very high concentrations of Mg and Na ions per unit volume of the electrolyte. This is critical for obtaining high energy densities per unit mass of the whole battery. //



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Pyrite nanocrystals under the electron microscope, which make up the cathode in the fool's gold battery .

E-waste: a gold mine of raw materials

What is cheaper and makes more sense from an environmental perspective: obtaining indium from a mine or recycling it from displays? On behalf of the Federal Office for the Environment (FOEN), a team of researchers from Empa joined forces with the University of Applied Sciences Rapperswil, Bern University of Applied Sciences, and the engineering and consulting firm Basler + Partner Ltd. to investigate this and other questions related to recycling scarce metals.

In Switzerland, the industrial association Swico is in charge of recycling electronic devices, which are collected and partly disassembled by hand, before getting shredded. The actual recycling of the metals takes place in special refineries abroad. Of the 36 metals present in electronics, only half are already recycled today. Two rare and important metals, however, are not yet among them: indium, which is mainly used in flat screens, and neodymium, which is for example found in the magnets of computer hard disk drives.

36

different metals are found in the e-waste our society produces. Only around half of these metals are actually recycled.

Only manual dismantling makes sense

Dismantling monitors manually has key advantages over mechanical processing and makes a method of reclaiming indium ecologically and economically worthwhile. As the Empa team concluded, recycling indium would be economically viable. Although wages are high in Switzerland, many devices are dismantled by hand in order to increase the added value. Thanks to manual disassembly, it is possible to separate a mixed glass and plastic fraction with high indium content. This kind of recycling would cost around 19 Swiss cents per TV, around six Swiss cents per computer monitor and around four Swiss cents per laptop. The anticipated recycling fee already factored into the retail price would need to be increased accordingly. If the devices are processed mechanically without any prior manual breakdown, the indium would be spread among different fractions and the recycling would be considerably more lucrative. In this instance, the anticipated recycling fee would also have to be much higher.

From an environmental perspective, the amount of indium recycled manually is virtually dead-level with that obtained from ores. Although indium is rare, due to the fact that it is obtained as a by-product during zinc mining, the cost of producing indium is still within limits. If the metal really becomes so scarce in future that is needs to be sought out and extracted specifically, however, this recycling method would be significantly more advantageous than mining primary raw materials. Mechanical processing without prior manual breakdown, on the other hand, would have clear disadvantages compared to primary extraction.

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Neodymium from magnets: recycling pays off from an environmental perspective

Environmentally speaking, recycling is also worth it for neodymium. According to the researchers, recovering the rare earth metal is far more environmentally sound than mining it. And once again, dismantling the devices by hand causes 30 percent less environmental pollution. This is because the broken-up magnets stick to the iron components in the scrap during mechanical shredding. In order to prevent this, the computer scrap needs to be heated beforehand in order to demagnetize the magnets, which means more energy is consumed and more pollutants are emitted.

The research results confirm that recycling indium and neodymium makes sense environmentally. Unfortunately, the large-scale technical facilities to recover these metals are still lacking. Nonetheless, the results pave the way for a possible future recycling strategy in Switzerland. The extended producer responsibility could in future be expanded to include the recovery of rare technical metals. //

2914,0 kg

1
Metals that are worth recycling especially "lie dormant" in displays.

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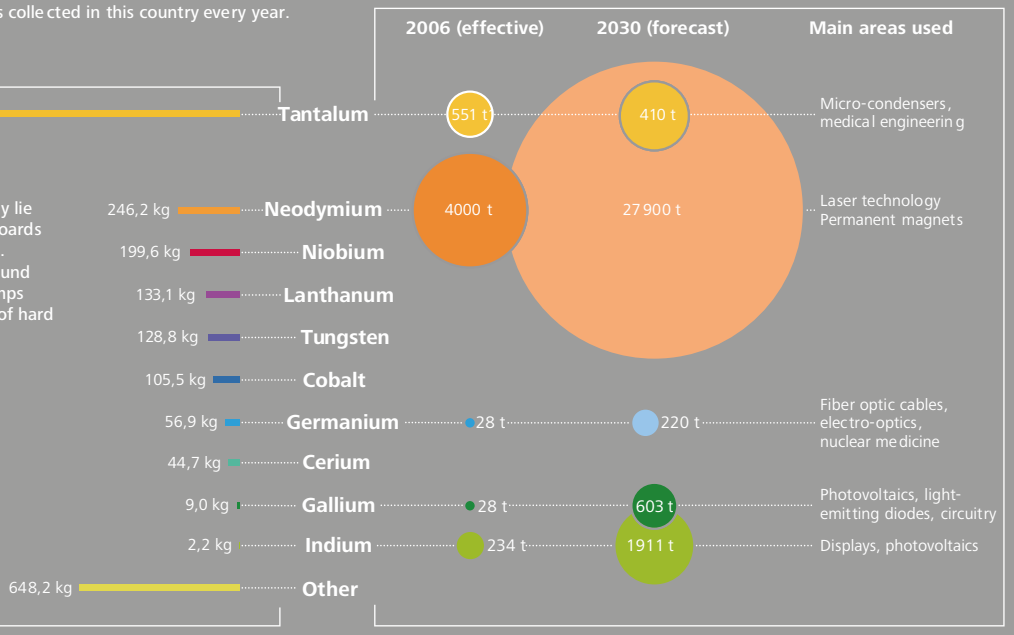
2
The figure reveals why old devices should be recycled. The rare metals in our electronic devices are important for our future. (Graphic: Beobachter/AS)

Rare metals in electronic waste

Some rare metals are not recycled in Switzerland. Enormous quantities are contained in the circuit boards of electronic devices collected in this country every year.

The metals especially lie dormant in circuit boards in electronic devices. And they are also found in monitors, LED lamps and the read heads of hard drives.



Consumption increases with new technologies

How the demand for rare metals might develop in key application areas all over the world in years to come:

INFOGRAFIK: BEOBACHTER/AS

Second life for metal bridges

30

percent of Europe's metal bridges have been in service for over a century. Due to material fatigue, many are in need of renovation.

An increasing number of steel bridges show signs of fatigue. The bridge builders in the 19th century did not count on the increased stress levels that are exposed to bridges nowadays. Modern vehicles are considerably heavier, faster, and more frequent than in the past. The consequence: some bridges have to be reduced to a single lane or closed entirely. Researchers from Empa have come up with a cost-effective alternative to rehabilitate such bridges by taking a well-established method for strengthening concrete bridges and adapting it for metallic bridges: ultra-light, pre-stressed plates made of carbon fiber-reinforced polymer (CFRP) are "stuck on" like plasters, which prevents fatigue crack initiation or arrest the existing cracks to grow. However, the plasters stick much less effectively to corroded or unsmooth metallic surfaces because of several anti-corrosion coatings applied over the bridge within many years. Moreover, rivets often prevent the plates to be bonded properly. The CFRP plates in the proposed system are attached to the metallic bridge using mechanical clamps. The mechanical clamps are attached to the girders with friction without using any bolts and making holes in the original structure.

Strengthening of bridge cross-girders

Münchenstein Railway Bridge is 120-year-old bridge in the Canton of Baselland. Researchers from Empa's Structural Engineering Research Laboratory came up with a retrofit solution, which has registered as an international patent. Together with industrial partners, the Swiss Federal Railways (SBB) and S&P Clever Reinforcement AG, researchers at Empa developed a novel method in a CTI-funded project to demonstrate how to strengthen the cross-girders of the Münchenstein Railway Bridge against fatigue using pre-stressed CFRP plates.

The pre-stressed un-bonded retrofit (PUR) system was attached to the two girders that were most prone to fatigue. The pre-stressed CFRP plates are clamped to the ends of the bridge cross-girders. Saddles in the middle of the girder ensure that the plates are forced downwards until they are optimally stressed. Two V-shaped columns are added to these points and the saddle is removed again. If larger compressive stresses are required in future, the trapezoid system can be re-stressed by using higher plinths. The developed system can be easily disassembled,

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The Münchenstein Bridge is 120 years old. Two cross-girders of the bridge were retrofitted using the PUR system developed and patented at Empa.

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which makes the system interesting for strengthening of cultural heritage bridges, where the reversibility of the strengthening system is of great importance. A wireless sensor network (WSN) system was used for long-term monitoring of the behavior of the retrofitted girders after strengthening.

The PUR system now provides bridge operators with a fast and cost-effective alternative instead of replacements of the whole bridges.

Follow-up projects

Two follow-up projects are already underway in Switzerland. One is funded by the Swiss National Science Foundation (SNSF), with EPF Lausanne as the project partner. Its aim is to strengthen metallic members against mixed-mode fatigue initiation and propagation.

The second study recently began in Australia: The project funded by the Australian Research Council and run by Monash University examines the reinforcement of riveted metal bridges. The project partners are Swinbourne University, S&P Clever Reinforcement AG, and VicRoads (the transport authority of the Australian State of Victoria). The aim is to develop a flat PUR system that can also be used on girders where there is not enough room beneath the bridge. At the end of the project in 2017, Melbourne's Chandler Bridge will be retrofitted with the new system developed by Empa. //

1
A cross-girder of Münchenstein Bridge that has been strengthened with three pre-stressed CFRP plates. Wireless sensors have been used for long-term monitoring of the retrofitted girders.

1

Why “rustproof” threaded rods corrode

When salt is scattered on roads in the wintertime, chlorides get into road tunnels, where they can attack structural components. About three years ago, Empa researchers found evidence of early-stage chloride-induced stress corrosion cracking on steel threaded rods in the suspended ceiling of the Gotthard road tunnel. However, the Empa experts and the Swiss Federal Roads Office (FEDRO), which commissioned the tests, lacked empirical data on how and in which timeframe this can cause the components to fail.

All that was clear was that chlorides affect the water- and non-oxidizing-acid-resistant material, which causes the components to lose tensile strength and eventually malfunction. This knowledge gap makes it difficult to plan maintenance measures. As a precaution, the damaged threaded rods were replaced with new ones in 2013 and transported to Empa in Dübendorf for further tests.

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ton is the weight of the test set-up installed by the Empa researchers in the Gotthard road tunnel.

Tensile strength devices “made by Empa“

In the fall of 2014, the Empa laboratories of Joining Technology and Corrosions and Mechanical Systems Engineering launched the FEDRO project “Quo Vadis”, which is expected to shed light on the failure mechanism of the threaded rods taken from the Gotthard tunnel in the course of the next decade. The rods are made of chromium-nickel steel with a two-percent molybdenum content. A silvery-white metal, molybdenum boosts the steel’s corrosion resistance, but sends the price sky-high.

For the long-term experiment, the Empa experts fitted especially constructed tensile strength devices with six threaded rods apiece and installed them in the Gotthard road tunnel. Although they no longer perform a function in the suspended ceiling, they are exposed fully to the road tunnel’s climatic conditions. Moreover, the researchers applied tensions of 120, 240 and 400 MPa (megapascals) to the rods. 120 MPa is equivalent to a load of 1.7 tons and therefore the weight that the rods in the suspended ceiling of the Gotthard road tunnel have to bear. The rods from the Gotthard tunnel’s exhaust air duct were placed in three devices; one piece of apparatus contained brand new threaded rods made of hot-dip galvanized steel and chromium-nickel steel with a seven-percent molybdenum content. On every tensile device, a measuring system records the force acting upon it, how much the rods stretch, the temperature and the relative humidity. The data is then transmitted to the Empa researchers every day via an internet connection. The team will remove individual rods from the test environment at two-year intervals and study the progress of the corrosion in the lab at Empa.

More than just safety

On the one hand, this test set-up enables the scientists to observe how the stress corrosion cracking on the original threaded rods is progressing. On the other hand, they can research whether other types of steel might also work – or even be more suitable – for use in the chloride-containing environment of road tunnels. The focus here is on corrosive behavior and therefore tunnel safety. However, the economic factor can also affect the choice of material. Chromium-nickel steel with a seven-percent molybdenum content is the most durable and expensive. Compared to cheaper anticorrosive chromium-nickel steel with a two-percent molybdenum content, the material has grown in popularity in recent decades. Hot-dip galvanized steel is the most cost-effective of the three materials used in the exposure tests. However, there is a lack of sufficient information on its corrosion behavior: Does hot-dip galvanized steel meet the safety requirements for Swiss road tunnels?

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Although chromium-nickel steel doesn't rust, the threaded rods can corrode under the influence of chlorides. As these rods are under tensile stress, this can cause stress corrosion cracking.

2
18 of the 24 threaded rods to be tested were used in the Gotthard road tunnel until they were replaced with new ones due to the onset of stress corrosion cracking. A team of Empa researchers are using tensile stress devices to study how the corrosion progresses.

3
Empa scientists have fitted every tensile stress device with a measuring system, which records the tensile force, the change in the threaded rods' length and environmental data before transmitting the information to the researchers.

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Tunnel safety and maintenance planning

After the completion and evaluation of the exposure test, those responsible at Empa and FEDRO will have information on the corrosive behavior of rust-proof, high-alloyed steels with different molybdenum contents and hot-dip galvanized steel. In particular, they will know what influences chloride-induced stress corrosion cracking – such as tensile strength, local climatic conditions, the time or the exhaust gas concentration. These findings should enable FEDRO to plan the necessary maintenance measures for tunnel safety more effectively. Moreover, if the comparatively cost-effective hot-dip galvanized steel can be used without compromising safety, this would carry additional economic advantages in tunnel construction and maintenance. And with their findings on the failure mechanism of the steel threaded rods, the Empa scientists would – at least to some extent – plug a knowledge gap in a scientifically, politically and socially relevant area. //

Simulations for the buildings of tomorrow

Switzerland's energy supply is on the brink of fundamental change – the energy transition. As the majority of the country's energy demand flows into buildings, Empa is committed to reducing the energy needs for existing and future buildings. Consequently, Empa is a member of the Commission for Technology and Innovation's (CTI) energy promotion program Competence Centers for Energy Research (SCCER) and runs the competence center Future Energy Efficient Buildings & Districts (FEEB&D), in which ETH Zurich, EPFL, Lucerne University of Applied Sciences and Arts, and the University of Applied Sciences and Arts Northwest Switzerland are also involved. The aim is to slash the energy needs of Switzerland's building stock by a factor of three in the next few decades through efficient, intelligent and networked buildings.

Up until now, energy flows between buildings have been planned with simplified calculations. However, rules of thumb are no longer suitable as buildings need to become considerably more energy-efficient compared to today's standards. In order to simulate the energy flows in future buildings, Empa researchers have developed several combinable computer program modules.

20

software modules developed by Empa researchers enable the energy flows in existing and planned buildings to be simulated.

An energy hub reduces carbon dioxide emissions

Such a simulation is advisable when a new building or district is being planned. Instead of every house needing its own heating system or storage, several buildings can share the infrastructure. As a result, buildings can be connected via an energy hub in the future, which stores energy, converts it, and redistributes it among the users – as and when needed. Via such a hub, the Empa researchers' software ensures that every building receives a reliable supply of electricity, heat, and cooling. This kind of energy supply slashes costs and carbon dioxide emissions.

If the district includes wind turbines and solar arrays, the energy initially flows into the hub. The program then decides where this energy can be used (or stored) best and the most efficiently. If the wind turbines or solar arrays generate excess electricity, the heating system may be switched on before the

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On the computer cluster Ipazia, Empa researchers calculate a vast range of projects and simulate, among other things, energy flows in buildings and districts.

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programmed minimum temperature has been reached. Today, every building individually regulates when it begins heating. The researchers also calculate a district's annual energy consumption via simulations and eventually find an optimized design.

Combining many modules

The Empa researchers didn't want to write complex, individual programs as they are bulky and complicated to maintain. Instead, they created a number of small modules, each of which tackles a specific issue and can be interconnected with others. This requires good organization, which is also why the researchers compiled a web-based platform called Holistic Urban Energy Simulation (HUES), where developers can file their latest programs. The advantage of the online platform is that existing software can be used and re-used. And it adds a certain transparency: Everyone can see what has already been done in energy research – including planning offices, who are to use software from the HUES platform to plan and design the buildings of tomorrow more energy-efficiently in future. //

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The software modules developed by the Empa team enable the simulation of energy flows in existing and planned buildings, not to mention entire districts.

Environmentally friendly flame protection for business jets

Wealthy customers want their business jets to look nice inside; the aviation safety authorities and the owners of the jet want the furnishings to be fireproof. And the jet should never stand around in the hangar for too long while it is being refurbished as that costs money (unnecessarily). The aircraft equipment supplier Jet Aviation touched down at Empa with these basic requirements in the hold to ask for some support on the project. Jet Aviation has been refurbishing private jets for customers from all over the world since 1977. Until now, the existing flame retardant additives were not effective for all kinds of materials used in the aircraft, it always took several steps to fireproof the individual layers of the lightweight furniture while the expensive business jet remained grounded, which raised important questions: Are there more efficient and environmental friendly flame retardant solutions available? Can this be achieved more quickly?

Cue Sabyasachi Gaan, whose work in St. Gallen includes developing new fireproofing materials for polymers. After numerous lab investigations, Gaan and his team eventually found a coating that struck the right chord with the specialists at Jet Aviation: The new fire protection is more effective and environmentally friendly compared to its predecessor, doesn't require any chlorinated or brominated chemicals, versatile for most woods, is non-leaching due to higher molecular weight, which gives it additional advantage: The flame-retardant material doesn't evaporate, which means the refurbished jet is not filled with any unpleasant odors.

200 – 500
micrometer thin is the coating applied to the wood.

One coating is sufficient

The Empa team also managed to guarantee the all-important time-saving aspect The newly developed flame-retardant material can be applied on th top layer (instead of in several layers), which saves on labor hours and drying time, and enables the new-look (and more fireproof) jet to roll onto the runway several days earlier. The project was co-funded by CTI and launched in 2012 within the scope of the special measures to counter the strong Swiss franc. Meanwhile, the method is patent pending.

Project leader Gaan is already thinking one step ahead: Such a design strategy of flame retardant can be applicable to other materials. With suitable modification of the new flame retardants, the researchers envisage similar applications in flame retarding textiles, wooden furniture or wall and ceiling cladding in buildings. The team aims to study these potential applications next. //

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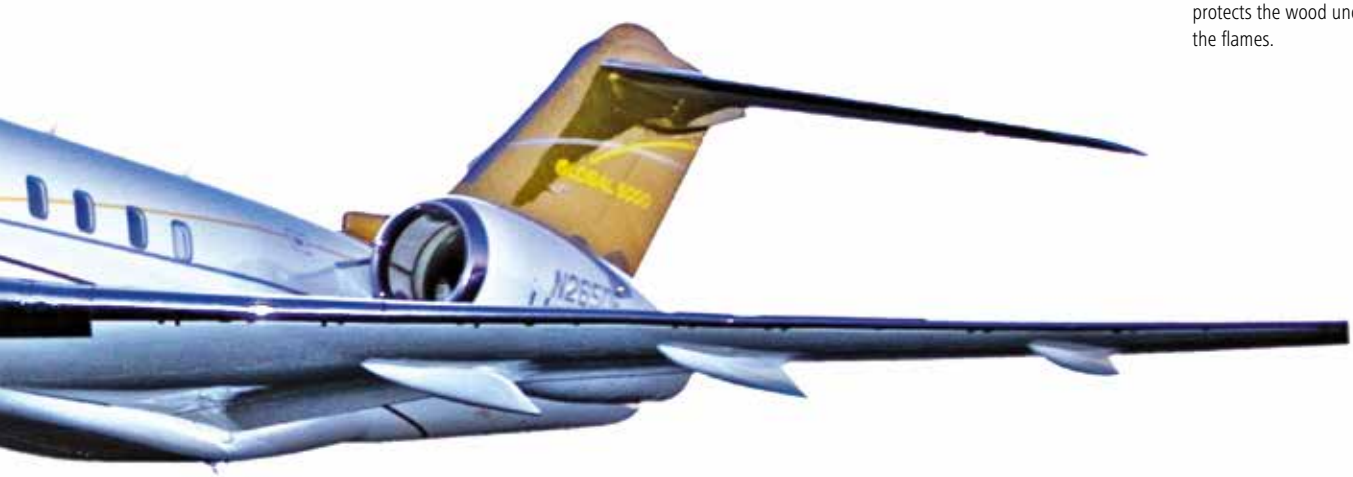
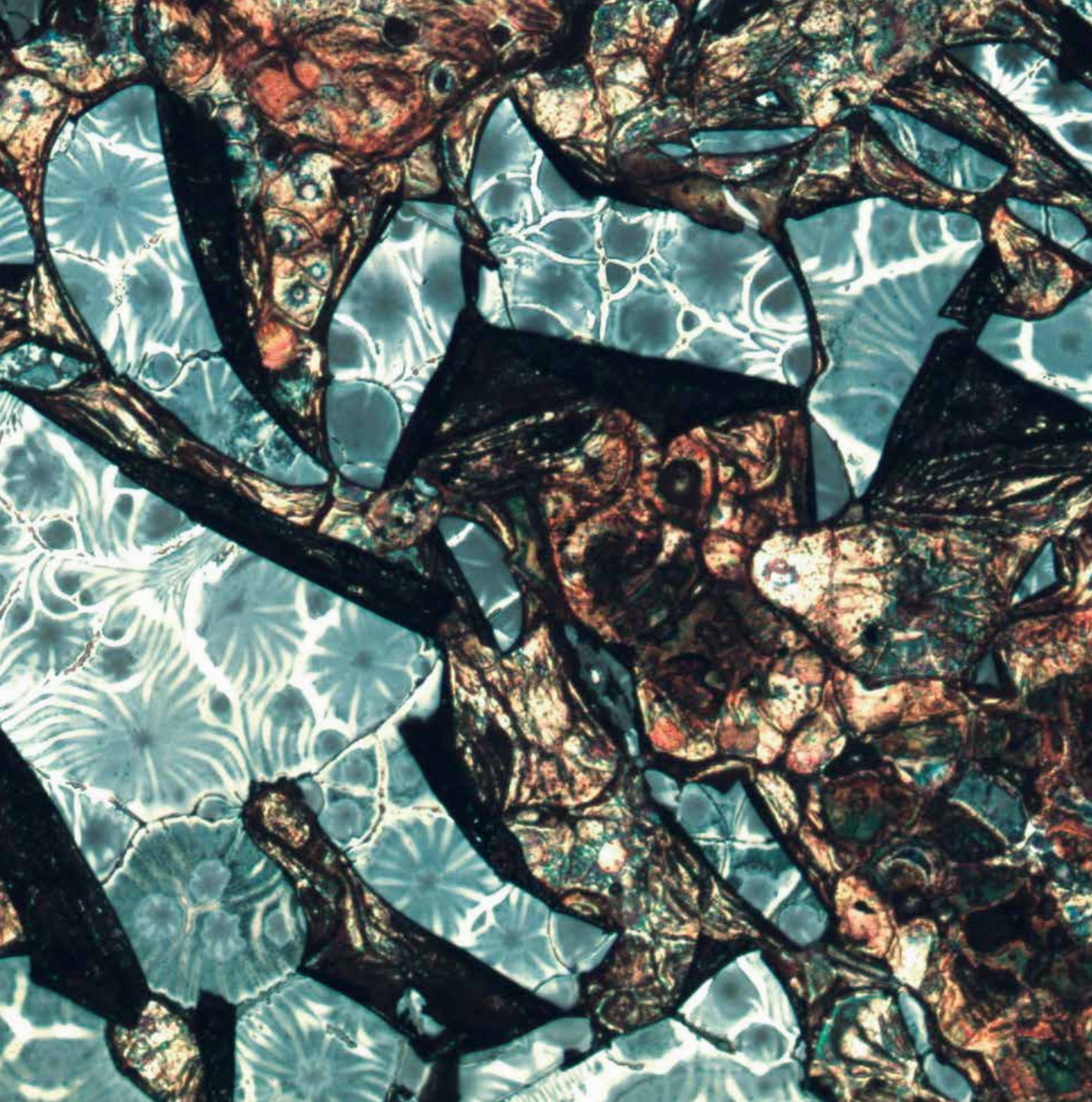
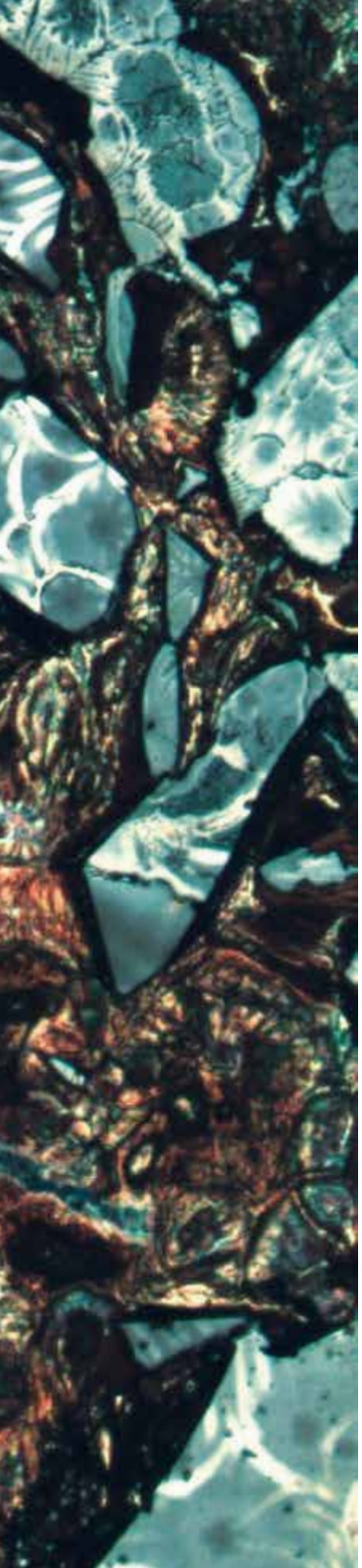
1
The interior of private jets is often furnished with a lot of fine wood.

2
How the flame-retardant coating developed by Empa works: When the coated wood is exposed to fire, the coating turns black due to the formation of charcoal, which protects the wood underneath from the flames.



Iron oxide deposits from solar cell developments: the reddish hematite differs from the gray magnetite in both color and function: one has magnetic properties, the other converts sunlight into electric current.





Research Focus Areas

Where do the major challenges of our time lie? Undoubtedly in the fields of human health and well-being, climate and the environment, dwindling raw materials, a safe and sustainable energy supply, and the renovation of our infrastructure. In its five Research Focus Areas, Empa pools the expertise of its 30-plus research labs and centers and develops practical solutions for industry and society.

The architecture of materials

Nanostructured materials owe their excellent, sometimes even novel properties to their components and their structural arrangement – their nanoscale architecture. Only if components and architecture are coordinated do the desired properties unfold – much like in a building. The development of nanostructured materials, therefore, includes synthesizing nanoscale components, the architectural nanostructure and the tools, i.e. techniques, to produce them.

Tailored nanocomponents

One special class of nanoscale components are nanocrystals. Via colloidal chemistry, i.e. through coagulation from a solution, nanocrystals with extremely different compositions measuring five to 100 nanometers in size can be produced virtually monodispersely. At Empa and ETH Zurich's joint Functional Inorganic Materials Laboratory, a team headed by Maksym Kovalenko specializes in the synthesis of colloidal nanocrystals. The latest nanocrystals are perovskite compounds such as $CsPbX_3$ (X=Cl, Br, I), which are just the ticket as light absorbers for the next generation of solar cells; or CH_3NHPbI_3, which displays a high absorption level for X-ray radiation and, at the same time, is a good semiconductor, which makes it a highly promising material for the cost-effective production of large-scale X-ray detectors. Batteries likewise need to be cost-effective if they are one day to be used for temporary storage to help balance out seasonal or weather-related fluctuations in the production of eco-power. Lithium ion batteries appear to be too expensive for this purpose. And the global lithium reserves are limited. One alternative is the sodium/magnesium hybrid battery, which uses magnesium as the anode and pyrite (FeS_2), also dubbed fool's gold, as the cathode. The first Empa cathodes made from pyrite nanocrystals are extremely stable when charged and discharged repeatedly.

The ability to self-organize

Self-organization and self-structuring are elegant and highly efficient approaches to building stable nanoarchitectures because they follow the fundamental physical principle of minimizing a system's energy. Weak intermolecular forces, such as van der Waals forces, are already sufficient for nanocrystals and/or molecules to form spontaneously arranged one-, two- or three-dimensional structures. At Empa, several research groups use the principles of self-organization or self-structuring in a vast range of systems and for different applications. In collaboration with the University of Basel, for instance, a team headed by Rita Toth deployed the Langmuir-Blodgett technique, i.e. dipping in and removing from solutions, to produce a complex nanostructured catalyst for photocatalytic water splitting. Initial tests showed these layers to be extremely efficient and stable.

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Photoluminescent PMMA synthetic material with integrated $CsPbX_3$ nanocrystals. These perovskite compounds are just the ticket as light absorbers for solar cells of the next generation.

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1
High-precision printing machine for upscaling wet-chemical coating processes, such as for printing organic light-emitting diodes (OLEDs). This equipment was set up at Empa's Coating Competence Center especially for this purpose.

2
High-resolution image of a synthesized nanoribbon.
The image was taken with an atomic force microscope (NC-AFM).

The team led by Jakob Heier uses the principle of self-organization to produce crystalline organic semiconductors. Via the process conditions, the researchers are able to control whether one-, two- or three-dimensional crystals form. In these ordered structures, interactions between the transition dipole moments during the absorption of light cause collective electronic excitations. Comparable effects are not observed in inorganic semiconductors. The resulting extraordinary electro-optical properties can be used in sensors, nonlinear optics and photovoltaics.

For the synthesis of graphene nanoribbons, Roman Fasel's team uses heterogeneous catalysis to produce a solid, covalently bound carbon nanostructure instead of an aggregate. Defined by the starter molecule, different forms of graphene nanoribbons can be produced with atomic precision. Depending on the ribbon's width and its edge shape, these graphene nanoribbons exhibit different electronic properties. The youngest "child" is a nanoribbon with a zigzag-shaped edge structure. With this ribbon type, the electron spins are split on the edges, which makes the ribbons highly interesting for spintronic applications.

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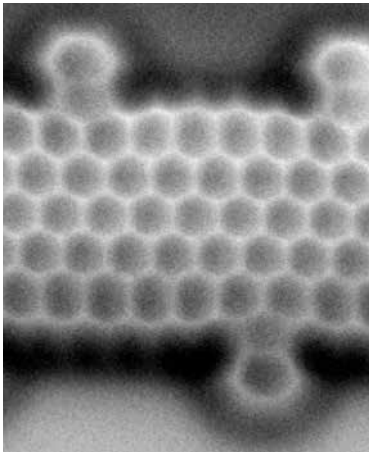
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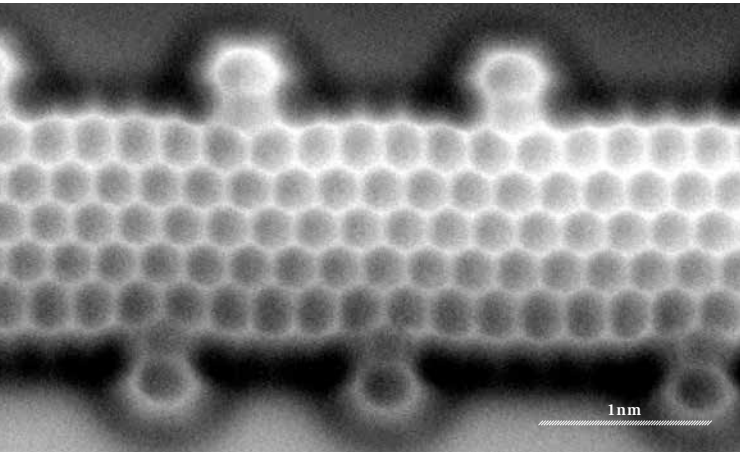

Empa's Coating Competence Center

The final and crucial step in successful materials development is process technology on an industrial scale. For novel materials, upscaling from the lab to an industrial scale is always very challenging, complicated, and expensive. Challenging because it requires the intensive collaboration of materials scientists and process technicians; cost-intensive because the research infrastructure required has to model industrial processes on the one hand and enable scientific work on the other. Empa has just set up one such research and development infrastructure in the form of the Coating Competence Center. Its vacuum coating and high-precision printing systems are equipped with comprehensive analytical devices for process characterization. The insights gained with these devices can minimize the effort for Empa's industrial partners in the further upscaling to the production plant – an enormous advantage in the global and increasingly stiffer innovation competition. //

Solutions with added value: durability, stability and ecology

Nowadays, we take safe and efficient supply and transport infrastructures, and attractive, comfortable living and work spaces for granted. In order to maintain this quality of life, economically, ecologically, and socially attractive solutions need to be developed. This includes the economical use of resources that are not completely renewable or recyclable, especially the most important building materials concrete and asphalt. And it is just as important to maintain the quality of the existing structures and to adapt them to new requirements.

Thanks to its Research Focus Area "Sustainable Built Environment", Empa is helping to improve our understanding of building materials and develop solutions that can be implemented in practice and thus generate real added value for society.

Concrete corrosion: structure of "concrete disease" decoded

When bridges, dam walls and other concrete structures crumble, the culprit is often AAR: the alkali aggregate reaction. AAR, which is triggered by the seepage of moisture, damages concrete structures all over the world, and renders complex renovations or reconstructions necessary. In the course of AAR, a material forms that takes up more space than the original concrete and, over the decades, gradually splits it from within. For the first time, researchers from Empa and the Paul Scherrer Institute (PSI) have now decoded the previously unknown crystalline structure of AAR's by-product – $[Si_{20}O_{48}]$ layers with wide intermediate layers and channels – an initial step towards developing potential countermeasures (see also page 27).

Damping bridge vibrations with controllable wings

Modern suspension and cable-stayed bridges are extraordinary structures that can span more than 1,000 meters. Due to their considerable slenderness and low damping level, however, wind can easily make them vibrate heavily and thus limits their service and lifespan. In practice, high vibrations are mitigated by reducing the wind-induced loads, which is achieved by shaping the bridge cross-section and improving the structure's damping via passive measures (so-called vibration absorbers). In collaboration with EPFL, Empa is developing a novel damping concept that consists of many little wings, which are attached along the bridge. By constantly altering their inclination, the wind flow around the bridge cross-section can be controlled in such a way that it stabilizes the bridge. The potential impacts of the technique have been studied in wind tunnel experiments conducted on a bridge model fitted with eight individually controllable wings. So far, the tests have revealed that the vibrations can be effectively mitigated with a simple cyclical asynchronous control of the wings. Even unstable conditions that cause vibrations

1
Visualization of a suspension bridge fitted with numerous movable wings to dampen the vibrations.

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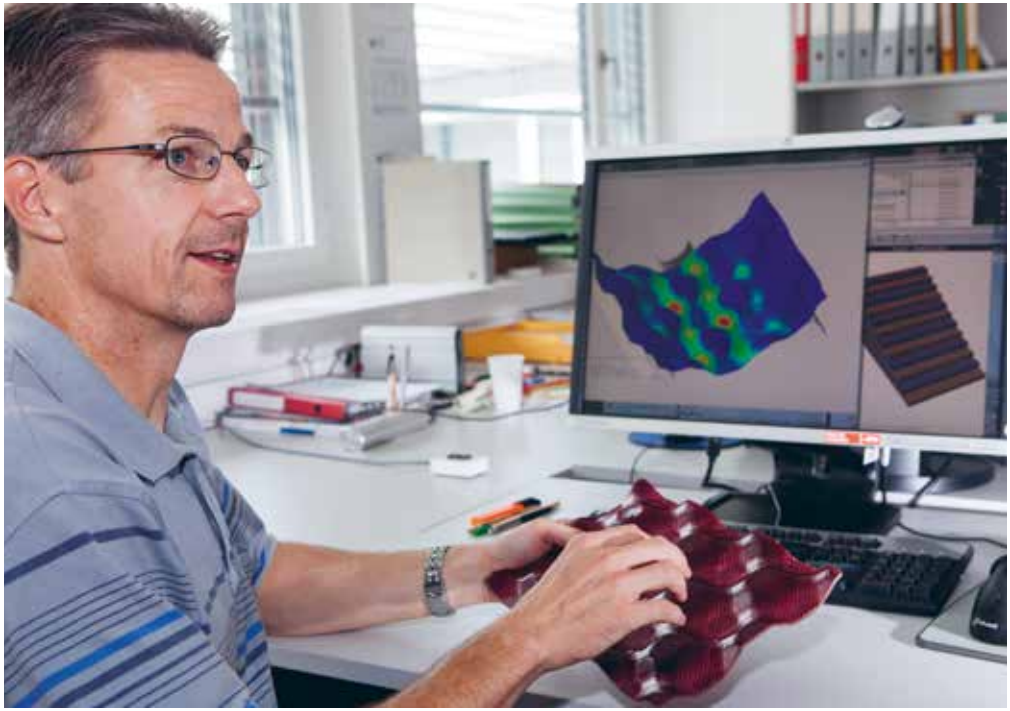

2

3

1
The novel event tiles protect the ground and don't let through any mud.

2
The lightweight floor tiles, which can be laid over a wide area, were developed on the computer and tested extensively in the lab …

3
… and tested extensively in the lab.

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could be completely prevented with the novel adjustable wings. These positive results have encouraged the researchers to enhance this damping concept with the perspective of constructing even more slender and wide-span bridges in future.

Novel paving tiles: clean feet even after the festival

Empa teamed up with the company Supramat-Swiss GmbH to develop light paving tiles made of a fiberglass-reinforced polymer that can be laid over a large area. The rectangular tiles' minimal thickness of 10 millimeters and area of around one square meter make them easy to transport and lay, enabling larger areas to be covered with little effort. What makes them so novel, however, is not only the special, very stable, yet light composite material they are made of, but also the concept for interconnecting them. Conventional honeycombed tiles are linked with a kind of hook system. Here, the installation team simply slots the Scobavent® tiles developed within the Empa project, which was funded by the Commission for Technology and Innovation (CTI), together via special tabs on the edges. The result is a gapless "tile carpet" that barely lets in any mud whatsoever. Currently patent-pending, Scobavent is now being tested at various events by a major Swiss serviceprovider for festivals.

The research, however, was not merely limited to Scobavent tiles for large-scale events; it also yielded a "heavy-duty" product: Scobamat tiles, which are straightforward to produce and, thanks to a new connection technology, can be used wherever heavy equipment threatens to ruin or sink into the soft ground. Laid as a pathway, the tiles can form a safe temporary road for large vehicles to places that are difficult to reach. They can also help rapidly rescue aircrafts up to an A380 size that have come off the runway. And these temporary roadways can even be used in permafrost during oil and gas production. The potential customers for the tiles also include construction companies and the army. The tiles have already successfully passed tests involving diggers, fire engines and a 60-ton crane. //

Technological development in tune with the environment

Tackling the mounting challenges in the age of globalization requires innovative technical developments and new concepts, especially in the field of energy use and mobility. It is essential for these developments to factor in a sustainable use of our resources and, at the same time, minimize the impact on the environment caused by process emissions. Sustainable and environmentally friendly innovations are one of Empa's core goals within its Research Focus Area "Natural Resources and Pollutants" (NAREP).

Efficient reduction of cold-start emissions

Thanks to catalytic exhaust converters, vehicle emissions have been slashed in the last 30 years, which has helped improve the air quality significantly. During cold-starts and operating phases with low exhaust temperatures, however, emission levels are still high. Measures to curb cold-start emissions result in increased fuel consumption, which ultimately conflicts with the goal of reducing CO_2 emissions.

Owing to its good absorption properties for microwaves, silicon carbide (SiC), a substance with comparable thermal properties to conventional catalytic converter coatings but with a considerably smaller specific surface area, can heat up the catalytic converter to operating temperature in a very short period of time before the engine starts. The initial lab results reveal that adding SiC to the coating of the catalytic converter almost halves cold-start emissions. The further optimization of the microwave resonator is set to reduce these emissions even further in future.

Batteries without critical and toxic materials

Batteries will play an increasingly important role in the future energy system. In order to achieve the greenhouse gas reduction laid down in the Paris Agreement, more than 80 percent of the electricity supply needs to come from renewable energy by 2050, for instance. This can only be continuously provided with the aid of batteries. In collaboration with the company Fiamm Sonick, Empa scientists are developing new processes to increase the reliability and energy and power density of industrial sodium nickel chloride batteries while minimizing the reject rate, which directly results in material and CO_2 reductions. The major advantage of these batteries, which are made from table salt (NaCl), aluminum oxide (Al_2O_3) and nickel powder, is that none of the starting products is critical or toxic and the materials are available in sufficient amounts to produce these batteries in large quantities for stationary applications with minimal harm to the environment.

1
Experimental setup for emission measurements on an aircraft engine at Zurich Airport.

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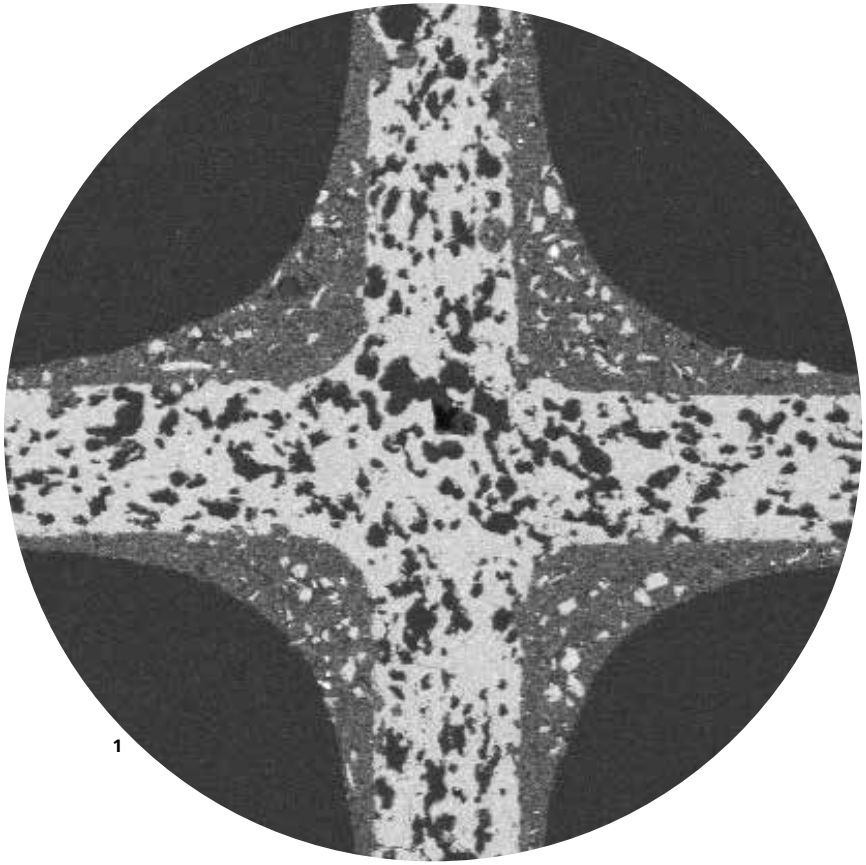

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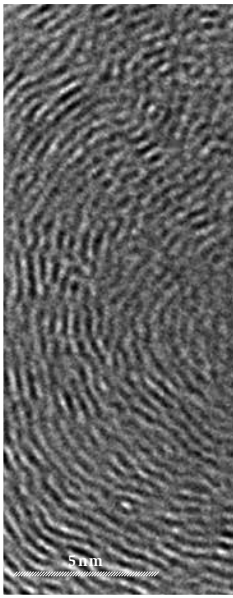

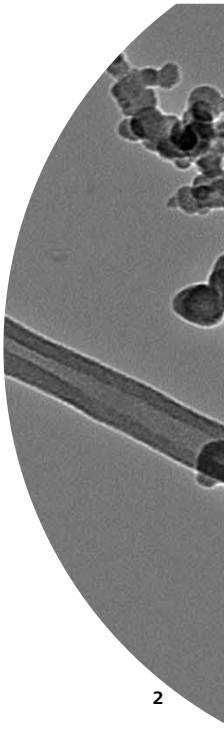

2

1
Section of a catalytic exhaust converter carrier: coarse silicon carbide (SiC) grains are dispersed in the finer aluminum oxide matrix (Al_2O_3) so that microwave energy is absorbed to heat up the cat before the engine starts. This enables cold-start emissions to be curbed.

2
Transmission electron microscopy (TEM) image of an aircraft engine's particle emissions during takeoff.

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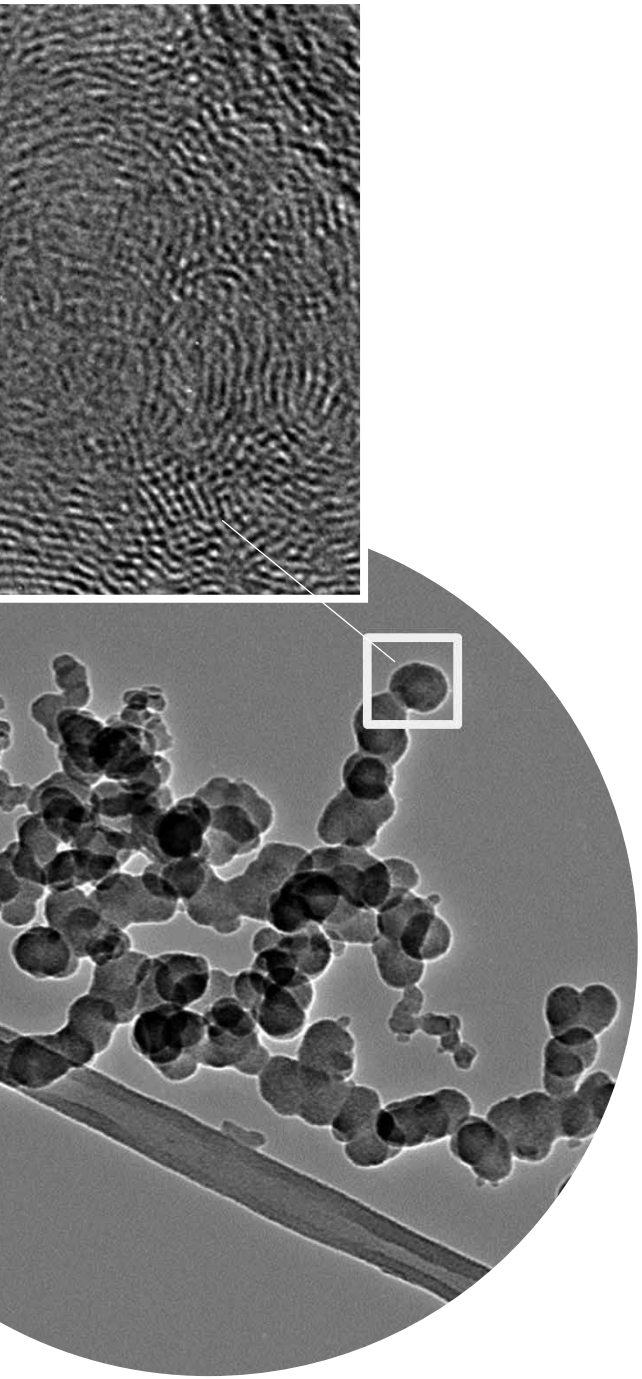


Jet engines to become cleaner in future

As a result of a close collaboration with SR Technics and the Swiss Federal Office of Civil Aviation (FOCA), Empa is setting an international benchmark by developing a method for measuring emissions of fine particulate matter from aircraft engines. The Committee on Aviation Environmental Protection of the International Civil Aviation Organization (ICAO) recently approved a preliminary standard governing the emission of particulates by aircraft engines. As of 1 January 2020, all engine types for passenger aircraft will have to be certified in accordance with the new standard. Most engine manufacturers have already developed their own measuring systems that comply with the new standard and started remeasuring their engines. Technologies are also emerging that will further reduce the emission of fine particulates. //

Energy research – options for the future

Energy is at the heart of many aspects of our society. It has long been recognized that developing individual, stand-alone technologies isn't enough for our future energy system. Hence, in our Research Focus Area "Energy" last year we established a sustainable infrastructure for a comprehensive approach to energy production, storage, conversion, and supply – with three main focuses: materials and technology research, demonstration platforms, and a more sustainable energy supply at the Empa-Eawag campus in Dübendorf. As a result, Empa is in a prime position to conduct interdisciplinary research in the next few years with a view to developing various options for Switzerland's energy supply.

Materials and technology research

Materials research is absolutely essential in energy and covers an extremely broad field: the refinement of aerogels, for instance, is aimed at more cost-effective production to make this efficient high-performance insulation feasible for "normal" buildings as well as for special applications. And in battery research, Empa scientists are not only interested in increasing capacity, durability and safety, but also intensifying the search for new, simpler and more affordable materials. In collaboration with the Max Planck Institute for Iron Research, experiments were continued on the hydration of carbon dioxide (CO_2); significant quantities of methane were detected in a mixture of hydrogen and CO_2 on the metal ZrCoHx and the catalytic effect of the metal hydride was investigated. The observed effects are also expected for other catalysts made of hydrogen-absorbing materials.

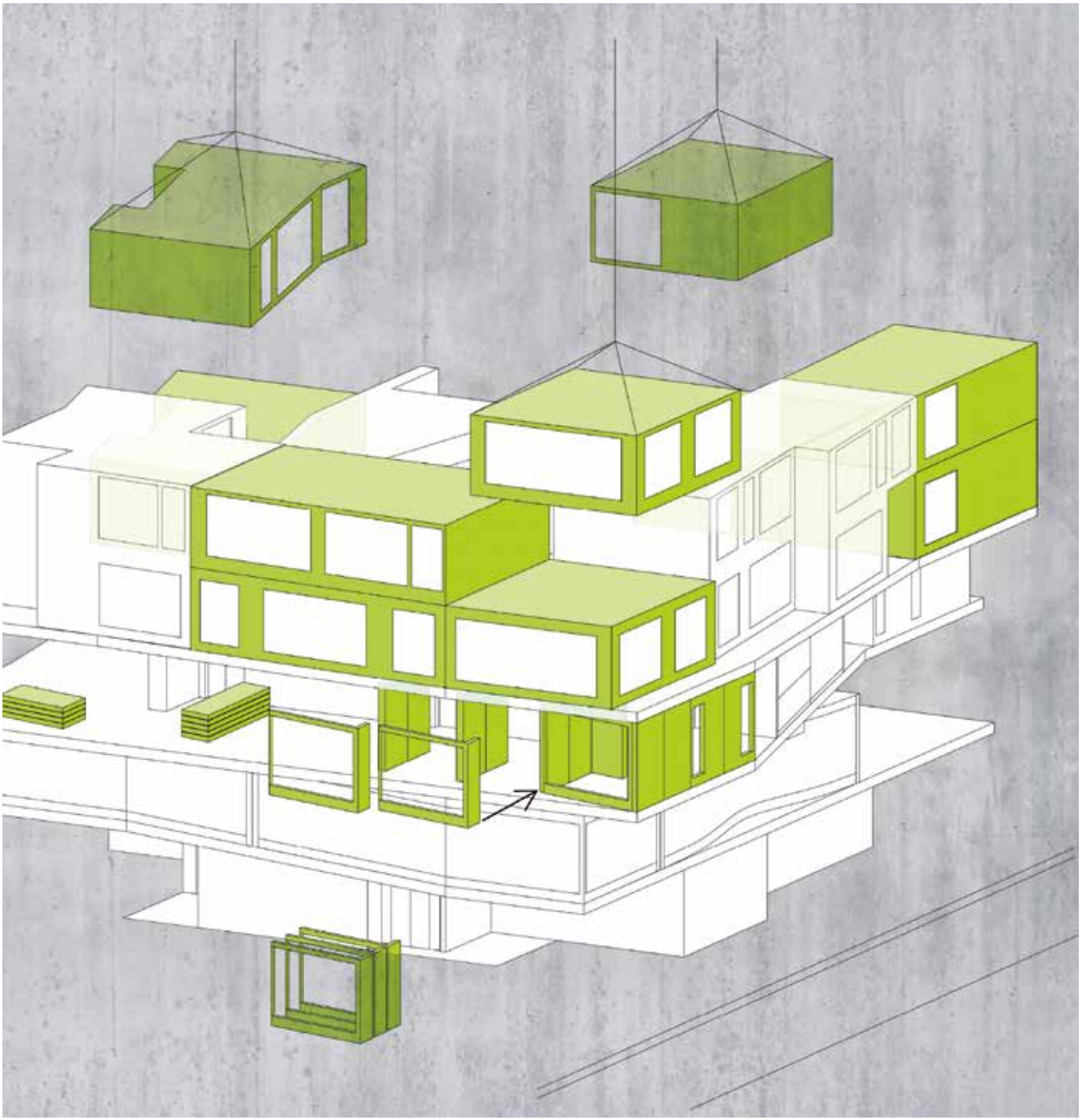
In the mobility sector, diesel engines were optimized in terms of efficiency and emissions in collaboration with industrial partners. Moreover, a feasibility study for the power-to-gas concept has been launched and is expected to yield results on whether and how this form of energy conversion might best be used.

In energy production, Empa stepped up its research in the field of solar cells by developing a solvent-free coating for electrodes in perovskite solar cells. And in the EU project TREASORES headed by Empa, cost-effective alternatives to indium tin oxide (ITO) were found for electrode materials in organic solar cells. The development of novel materials and methods to operate high-voltage power lines optimally under heavily fluctuating temperature and wind conditions is another example of materials science for energy applications.

Demonstration platforms

With the topping out ceremony for NEST and the inauguration of "move", two large-scale energy projects entered the crunch phase in the fall. At "move", the comprehensive mobility demonstration and research platform, a 35 MPa hydrogen refu-

1
Installation of the research units in NEST: the first unit, Meet2Create, is being built as an area for various future work forms. (Illustration: Gramazio & Kohler)



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eling station has already been installed, and at NEST the first unit, Meet2Create, is currently being installed as an office area to develop various work forms of the future. And another platform has also been launched: ehub (energy hub), an energy research platform aimed at optimizing energy management at district level and evaluating the impact on the overall energy system. Together with "move" and NEST, ehub enables energy concepts to be tested under real-world conditions and energy flows in the residential, work, and mobility sectors to be coupled.

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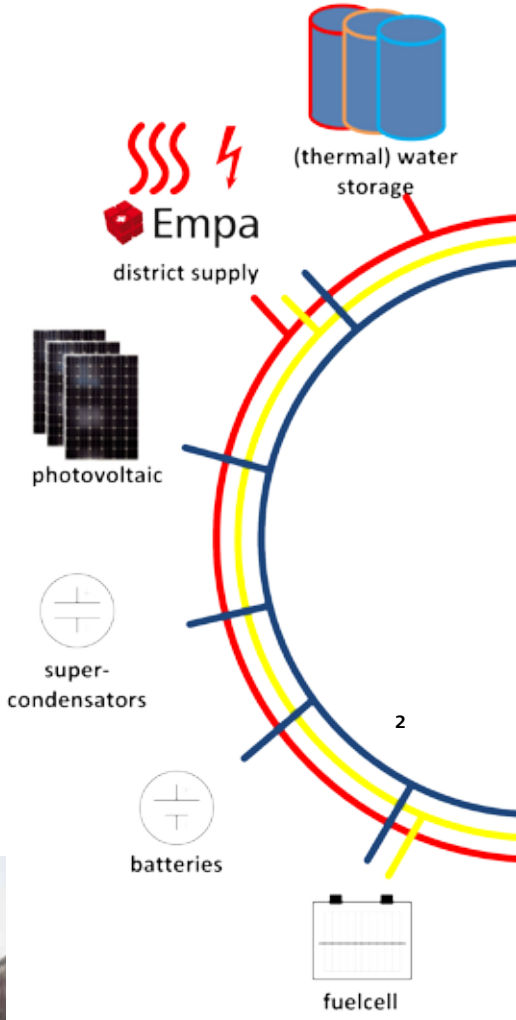

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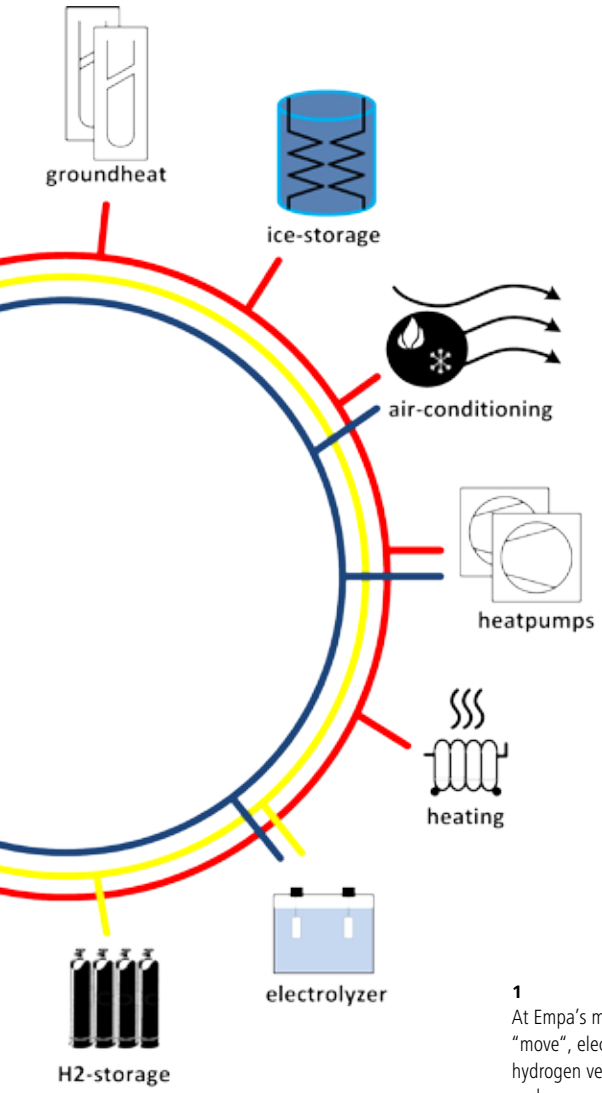


1
At Empa's mobility demonstrator "move", electric, gas, and even hydrogen vehicles can be refueled and compared in practical use.

2
The various components of ehub: together with move and NEST, ehub enables energy concepts to be tested in real-world conditions and energy flows to be coupled between the residential, work, and mobility sector.

Energy supply on the Dübendorf campus

A new energy concept was developed for the Dübendorf campus, which is to be implemented in the coming years. Different methods, such as a biogas-combined heat and power plant, a solar plant, a large geothermal store for seasonal energy storage, and the simultaneous use of the waste heat, are set to guarantee Empa-Eawag's electricity and heat supply. CIGS solar modules developed at Empa will also play an instrumental role here. The new energy concept for the Empa-Eawag campus echoes the aim of presenting options for our future energy supply. It offers an opportunity to study energy flows in-house and exploit optimization opportunities.

The impending challenges in the energy supply can only be tackled if they are considered in their entirety and across systems. With this in mind, Empa aims at freely combining different technologies and investigating new paths in the urban energy supply. The demonstration and research platforms – along with the new campus energy concept – enable new materials and technologies to be used in practice and the impact of individual technologies on the entire energy system to be taken into consideration. As a result, Empa's energy research helps render new technologies usable all the way to marketable applications. //

Innovative materials for medical applications

Protecting people, promoting good health in a sustainable manner, maintaining and improving our quality of life and physical constitution – these are and will remain major challenges, especially in light of our increasing life expectancy. In the Research Focus Area "Health and Performance", Empa combines its interdisciplinary know-how in the fields of textiles, materials science, biology, and nanotechnology. It focuses on the development of materials for medical applications in and on the human body, and investigates materials and new systems that protect and support people in their daily lives. Moreover, Empa closely scrutinizes the safety of new materials and develops new biological and physiological models and methods to study this under real-world conditions.

Which materials are suitable to maintain human health or even restore it? Which products improve the quality of life or safety for elderly people? How can we improve performance in sport or under extreme conditions? How can we functionalize fibers and textiles to give them specific properties? Can the safety of new materials be guaranteed in future? And how can the reliability of biological models be increased? This are some of the questions Empa scientists are tackling.

Shuttle service through the body

Getting drugs to the right place in a patient's body at the right time, in the right concentration and for the right duration is no trifling matter. The materials that "smuggle" the drugs around the body have to be easy to control, which is achieved via the pH value and light or temperature impulses, for instance. With this in mind, Empa is developing intelligent materials, such as plasters or encapsulations for medication. Researchers from the "Protection and Physiology" and "Particles-Biology Interactions" laboratories have been collaborating to study the physical properties of these drug carriers, which govern the transport and release of the drug, and to analyze via cell tests, i. e. in vitro, how the new materials can be applied in practice.

Sensors – as comfy as clothing

Understanding the complex processes that take place in the body requires sensors that record physiologically relevant data such as blood pressure, pulse rate, the heart's electrical activity, and body temperature. This is particularly difficult if people are on the move. However, sensors also need to provide reliable data in complex, constantly changing situations, which is virtually impossible with the current, somewhat bulky equipment and its wealth of wires. Consequently, Empa is working on the development of novel, flexible and biocompatible sensors that can be integrated in clothing and accessories such as T-shirts and watches. This requires comprehensive interdisciplinary knowledge in the fields of materials science, processing, the biosciences, and biotechnology.

1 Micron-sized pH sensors from electrostatic emulsion spinning.

1

Functional surfaces: integrating implants more effectively

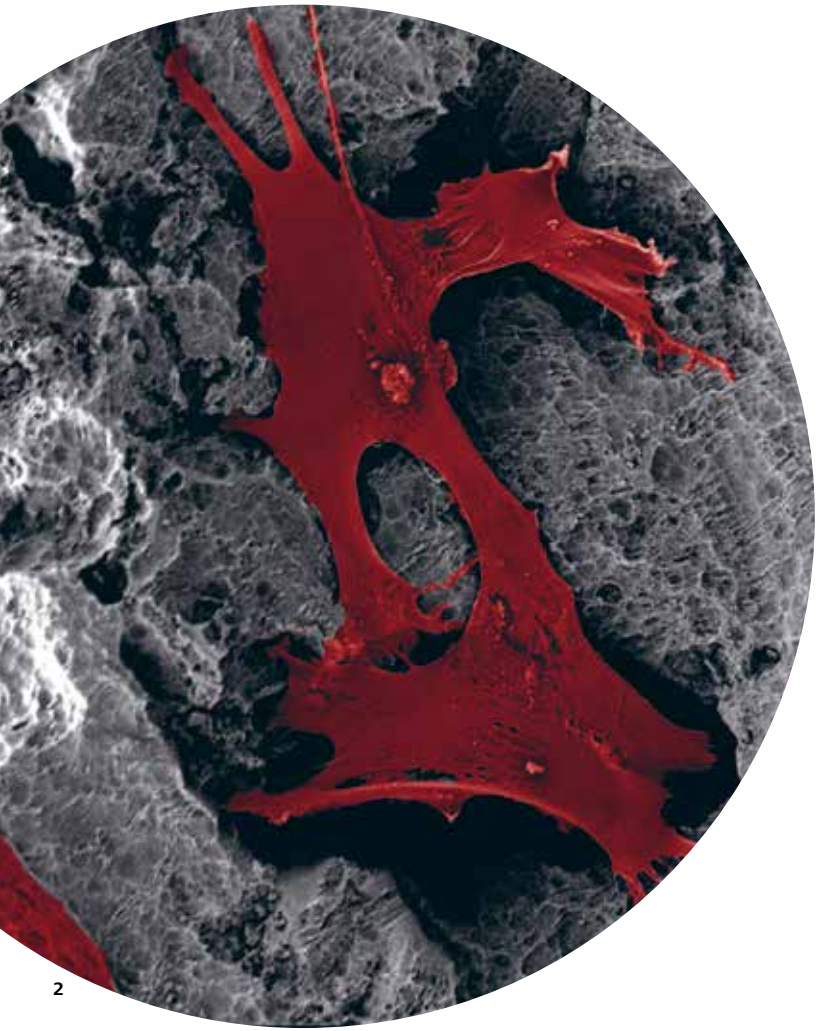
How well an implant can be integrated in the body depends on its surface as this is what interacts with the body's cells. Empa is developing special tissue-compatible coatings that support ingrowth – or, if necessary, prevent it. Empa also conducts research on drug-bearing coatings. These substances are supposed to trigger a specific cell or tissue reaction. Antimicrobial coatings in novel wound-healing materials prevent or curb bacterial infections, for instance.

However, despite strict hygiene standards during operations infections can't always be avoided. To provide additional protection, Empa teamed up with an industrial partner on a CTI project to develop a method for incorporating silver ions in an implant's medically engineered coating. The ions have an antimicrobial effect and can thus prevent the serious consequences of an infection.

1

1
In collaboration with industrial partners, Empa is developing an antibacterial coating for hip implants that also helps them to grow into the bone. (Image: Medicoat AG and Atesos Medical AG)

2
A cell attaching itself firmly to bone material.



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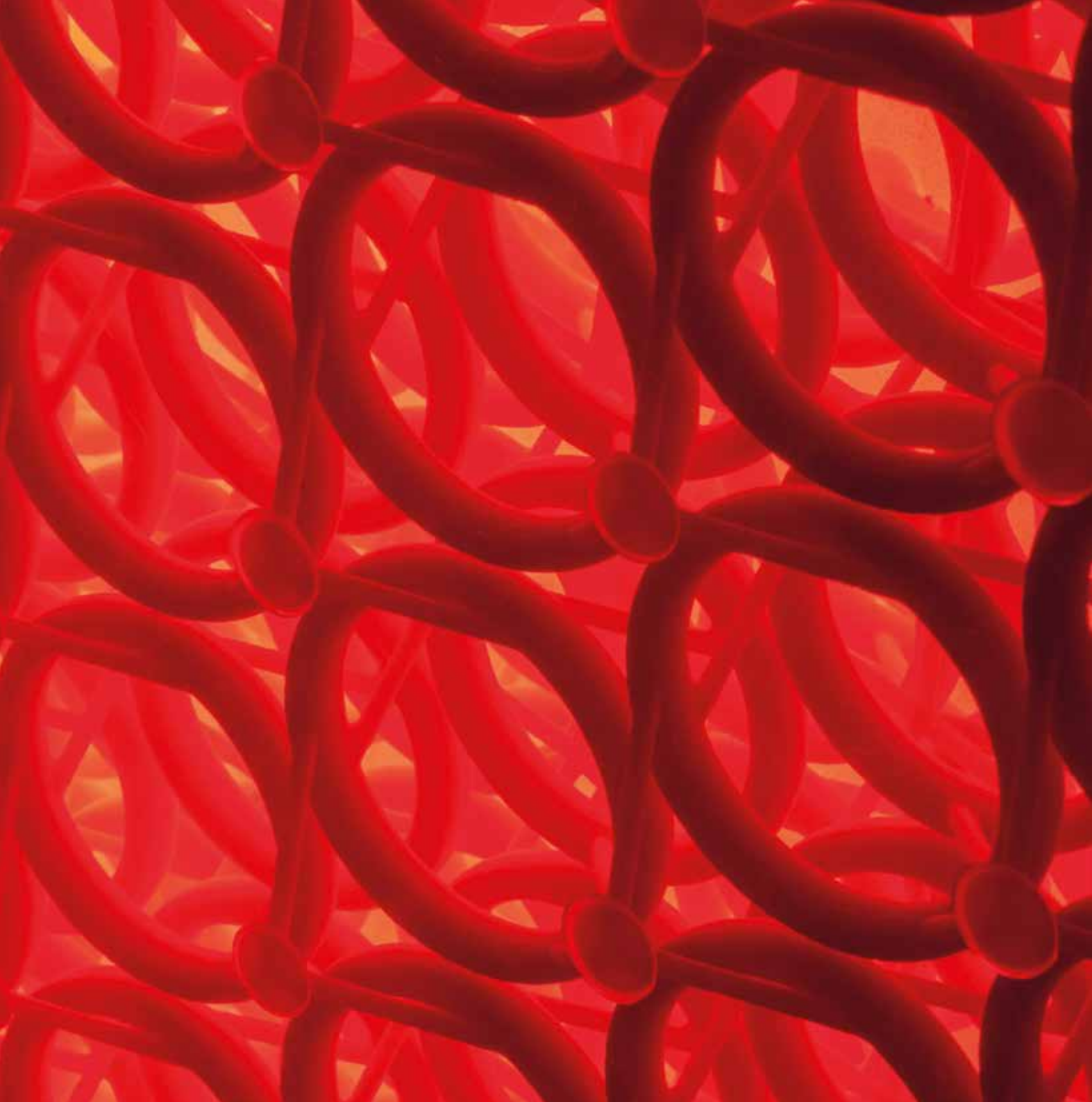
Cell tests for increased safety

Empa has been developing diverse biological and computational methods to model microbiological environments, human tissues and organs. This enables the health risks of biomedical materials to be tested at an early stage – and ultimately the amount of animal testing to be reduced.

These methods have already proven their worth for graphene, dubbed the "miracle material of the 21st century". The Particles-Biology Interactions laboratory used them to verify the human and environmental toxicity of graphene by testing it in all its shapes and sizes. And it's good news: regardless of whether it is synthesized industrially or in the lab, on a micro- or nanometer scale, graphene does not seem to cause any stress in human cells. //

Close-up of a phononic crystal model (from the 3-D printer).



From Research to Innovation

Topflight research and a proximity to industry – the two poles between which Empa operates. The institute is able to offer its partners tailored solutions thanks to efficient and individual forms of collaboration and a broad spectrum of services. Whether it be with a view to developing new products and applications, optimizing technologies, solving specific problems, or bringing technical specialists up to the state of the art – with around 550 highly qualified scientists and topclass infrastructure, Empa truly is the place where innovation starts.

Making Swiss companies fit for the global competition

1

Switzerland's manufacturing industry is fighting on several fronts, especially given the current strength of the Swiss franc. But it still invests in innovative ideas, too. And once again, industry banked on Empa's multifaceted expertise in numerous new research and development projects in 2015, which just goes to show that close collaboration boosts the international competitiveness of Swiss SMEs and gives rise to innovations that are able to succeed on the market.

With around 150 contracts – a new record –, the number of new research agreements rose again last year compared to 2014. Moreover, Empa registered 18 patents and signed 20 new license and technology transfer contracts with industrial partners.

Measuring blood sugar without taking

Empa and the University Hospital Zurich joined forces to develop a sensor that gages the blood sugar through the skin. And best of all: no blood samples are necessary, not even to calibrate the sensor. "Glucolight" is initially to be used in premature babies to avoid hypoglycemia and subsequent brain damage. The now patent-pending sensor comprises several parts: a microdialysis measuring head and a microfluidics chip with a fluorometer (both developed at the University Hospital Zurich), a "smart" membrane developed at Empa, light sources, and a pump. The first clinical studies are scheduled at the

University Hospital Zurich for 2016. However, it could be years before the use of Glucolight becomes standard. Empa and the University Hospital Zurich are currently in negotiations with partners for the industrial production of the sensor, which might also be used in other fields, such as diabetes, in future.

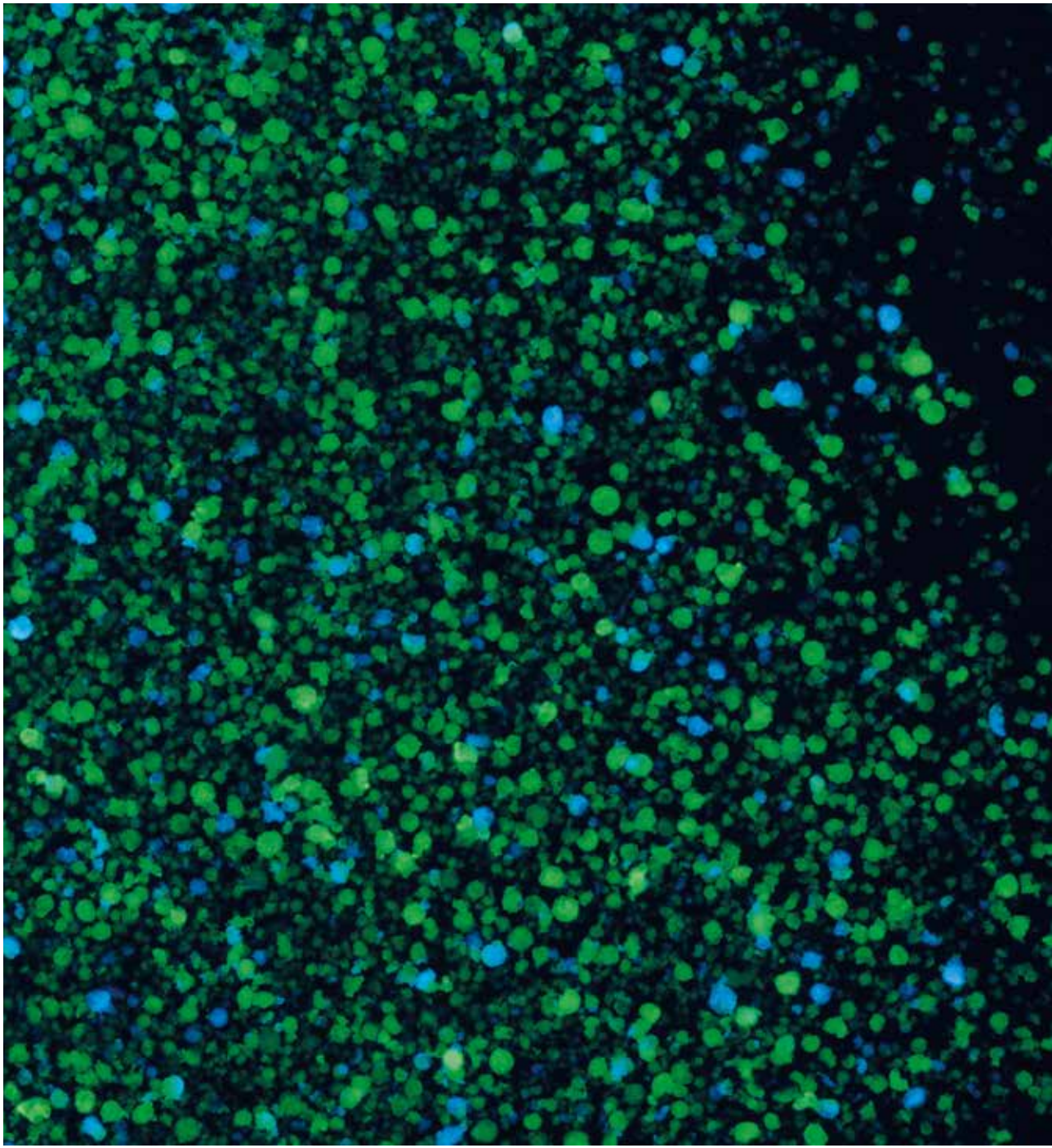
Ceramic knives in the wood-processing industry

Ceramic kitchen knives are ten a penny. What has become the norm in Swiss kitchens, however, could soon work to industry's advantage, too. Researchers from Empa teamed up with the companies OERTLI Werkzeuge AG, Metoxit AG and W. Blösch AG on a project funded by the Commission for Technology and Innovation (CTI) to develop a ceramic blade for industrial wood cutting. It is capable of withstanding the high temperatures of up to 800 degrees that build up during the cutting process and is also competitive as regards production costs. The new knife recently made its debut at a joinery in Embrach. The blade cuts just as well as conventional models made of carbide metal, but are a lot lighter and faster, which means that the timber industry's production can be increased. OERTLI Werkzeuge AG is current preparing the market launch of the ceramic knives.

2

1
Measuring head of the "Glucolight" sensor with Empa's "smart" membrane.

2
Thanks to the cutting technique developed at Empa based on ceramics instead of carbide blades, wood can be processed around three times faster than before.



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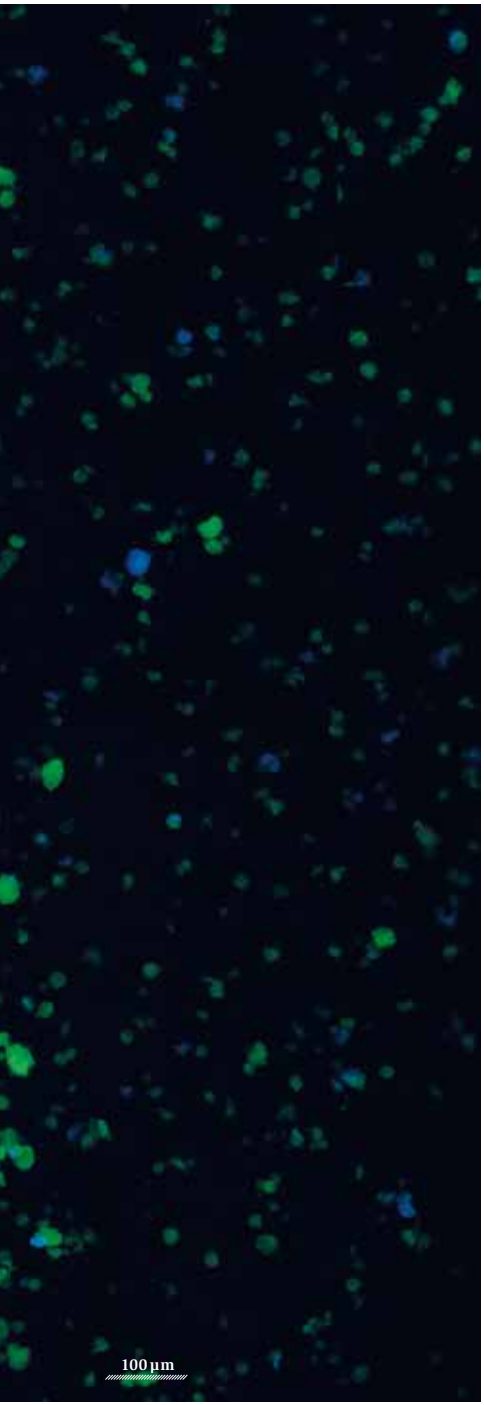

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Luminescent solid particles under the light microscope, the phosphorescence of which was improved in a CTI project.

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Luminescent solids cast light into the darkness

Whether it be on clock faces or emergency exit signs, luminescent materials are omnipresent in our world. Around a century ago, it was radium that, mixed with light pigments, lit up our clocks in the dark. Radium was eventually replaced by the less radioactive tritium. Since 1998 non-radioactive luminescent solids have been used as phosphorescent pigments, which are constantly being improved to make them shine more brightly and for longer. Teaming up with the University of Geneva and the company LumiNova AG on a CTI project, Empa has now developed a new generation of these phosphorescent substances. The researchers have succeeded in increasing the intensity and duration of the light significantly. Today, the now patented innovation is marketed by LumiNova AG under the brand Swiss Super-LumiNova® Grade X1 for the clock industry. //

Business incubators for fledgling hightech start-ups

Empa has successfully been promoting the commercial realization of research results in spin-offs and start-ups for years. Many of these fledgling companies recorded impressive results last year.

From start-up to successful SME

Following a three-to-four-year supporting phase in the incubators glatec and STARTFELD, the fledgling companies have to go it alone in the harsh market environment. Well-equipped, however, the young SMEs pass this acid test with flying colors. Customers refer to the company Optotune as the world's market leader in the field of flexible optics, for instance. The SME exports 97 percent of its products and currently has 50 employees.

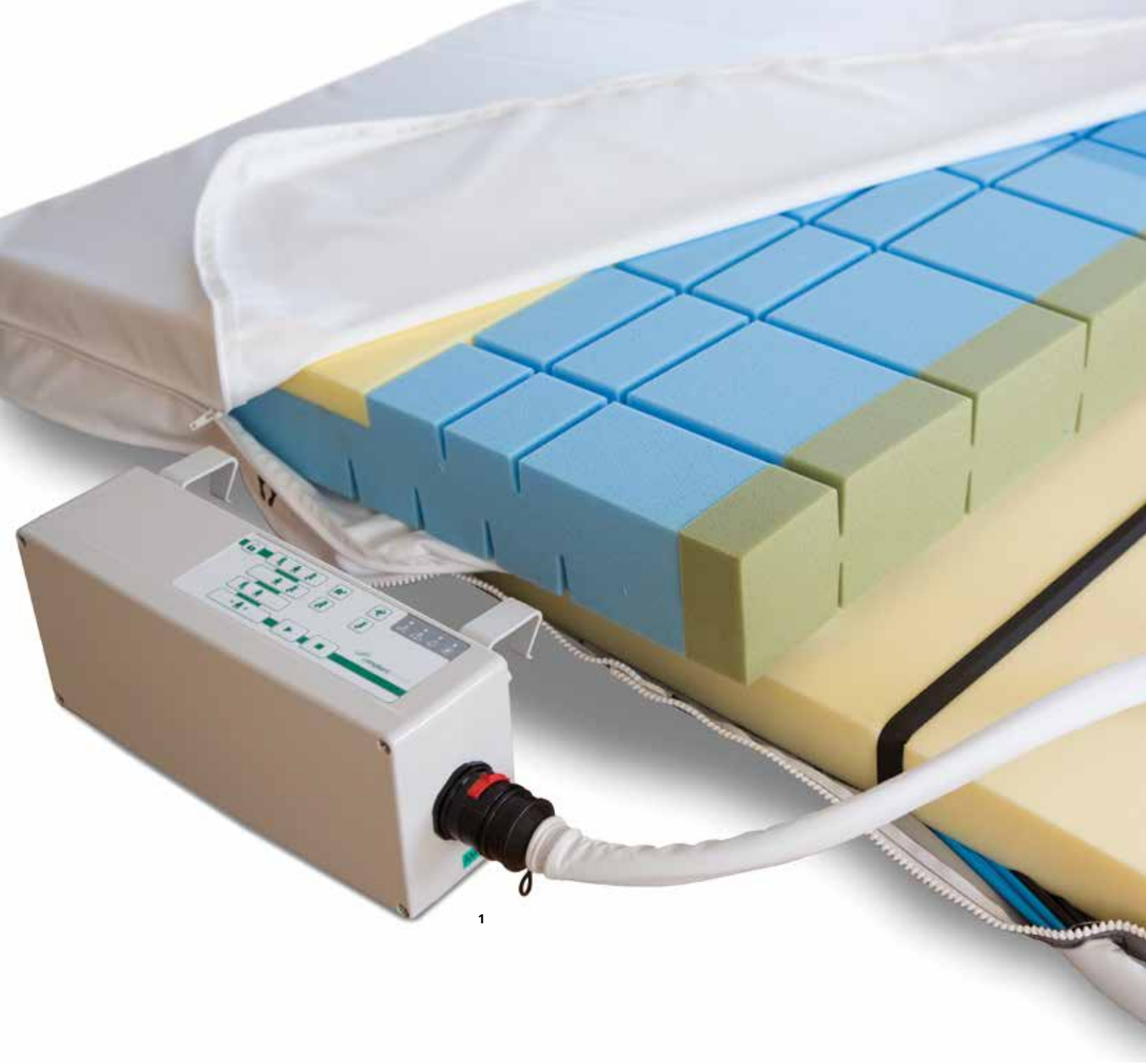
More than 100 hospitals and care institutions in Switzerland and abroad, including Curanum – with 100 retirement homes and care centers in Germany, Europe's number one on the healthcare market – currently use the "Mobility Monitor" by Compliant Concept to monitor bedridden patients and people suffering from dementia. Much is also expected from the Empa spin-off's latest product, an automatic repositioning system to prevent decubitus (bedsores).

With its workforce of 30 employees, QualySense once again ranked among the top ten Swiss start-ups in 2015 and received the High-Potential SME award at last year's Swiss Economic Forum (SEF). The start-up Polarmond is also being supported by both glatec and STARTFELD. Polarmond was chosen as the GOLD Winner during the OutDoor Industry Awards 2015 at the 22nd European OutDoor trade fair in Friedrichshafen. And in 2015 the now eight-strong team at Meteomatics won the STARTFELD Diamant for developing a drone that enables extremely accurate weather forecasts to be made for the next 24 hours. Exact weather forecasts are crucial for energy producers, the insurance industry, aviation, trading companies, and road and rail transport. In 2015, the (existing and former) start-ups and SMEs incubated at Empa employed more than 350 people in total.

New innovation center next to Empa in St. Gallen

STARTFELD is developing a new innovation center right on Empa's doorstep in St. Gallen. Technologically, the center focuses on combining the topics "Material meets Life" and "Precision meets ICT", which generates major synergies with the high-tech competence clusters in the Lake Constance region. The new innovation center benefits from its proximity to Empa, the university, St. Gallen University of Applied Sciences, and the cantonal hospital in St. Gallen. The corporate development of innovation projects is also supported, regardless of whether it be for start-ups or established companies. This is

1
The Active Mobilization System by Empa spin-off Compliant Concept is a mattress that constantly mobilizes patients who are at risk of bedsores without them even realizing or waking up.



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because innovation always means economic sustainability for the center, too.

Innovative processes are driven by curiosity and the center provides the necessary leeway for explorative thinking and experimental action. Examining different perspectives inspires and challenges, which is why the center encourages and urges networking among people and organizations, such as by organizing regular events. It is primarily start-ups and exploration groups from established companies that are eligible as tenants – in other words, groups that are to be separated from daily business for a limited period to concentrate on finding new development possibilities for a technology or business field. //

1
Diagram of Polarmond's self-heating bivouac system: sleeping bag (dark blue) with a zip ventilation hole and inlet. (Photo: Polarmond)

From the kernel of an idea to innovative product

1
The demonstration and technology transfer platform "move" enables Empa researchers to develop vehicle drives with lower CO_2 emissions using surplus electricity as the energy source.

The Place where Innovation Starts" is Empa's motto. Knowing only too well that the path from research to the market is often long and sobering, Empa goes to extraordinary lengths to prepare new technologies for the market faster and more efficiently in collaboration with its industrial partners. This especially includes the demonstration platforms that Empa has built on its campus in Dübendorf.

"move" – a platform for the mobility of the future

At the end of November, "move" was officially inaugurated in the presence of renowned energy and mobility experts. The name "move" doesn't just stand for motorized mobility, but also the switch from fossil to renewable energy – all the way to the realization of a closed carbon cycle modeled on nature. "move" is an Empa demonstration platform backed by numerous partners from research, industry, and the public sector, such as the ETH Board, the Swiss Federal Office of Energy (SFOE), the City of Dübendorf, Glattwerk AG and the companies AtlasCopco, H_2 Energy and Hyundai. These are joined by a series of academic and industrial partners who are involved in individual projects.

The new demonstration and technology transfer platform enables Empa researchers to develop new vehicle drive concepts with significantly lower CO_2 emissions and test them in practice. Over the next few years, they will study how surplus renewable electricity can be converted into fuel for cars, utility vehicles, and machinery in the summertime and thus be rendered utilizable as energy.

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In Niederhasli near Zurich, Flisom built a 4,500-square-meter pilot production plant that is designed for an installed solar energy capacity of 15 megawatts.

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Flisom production plant opens its doors

Ayodhya N. Tiwari has been investigating of high-performance CIGS (copper-indium-gallium-(di)selenide) thin-film solar modules on flexible plastic sheets for over two decades. Present highlight of this development was the inauguration of a pilot production plant belonging to Flisom, the start-up Tiwari founded. A new financing round to the tune of 10 million Swiss francs guaranteed the further development of the company, just two years after an investment of 42.5 million. The Swiss start-up develops innovative technologies for the production of low-cost, high-performance thin-film solar modules. Thanks to its roll-to-roll method, Flisom is able to manufacture up to one-meter-wide "solar films", which hadn't been possible up to now. The successful technology transfer is based on a long-standing research collaboration between Flisom and Empa, which has yielded a number of world records for the efficiency of flexible thin-film solar cells in recent years, including 20.4 percent in 2013. Both partners have been collaborating for a number of years to develop a unique industrial-scale production platform for CIGS solar modules on an industrial scale. The scale-up for large-area solar modules and the adaptation of these complex, innovative processes for industrial manufacturing is a major challenge that requires close collaboration between research labs and industrial partners. //

Lively exchange beyond Switzerland and Europe's borders

Nanosafety research remains a key priority for Empa, which it pursues with various international partners. On July 23, 2015, for instance, Empa CEO Gian-Luca Bona and Hyun Min Park, Vice-President of the Korea Research Institute of Standards and Science (KRISS), signed a Memorandum of Understanding (MoU) to intensify the collaboration between the two institutes in the field of nanosafety research.

The research cooperation with Los Alamos National Laboratory (LANL) in the United States and other renowned international partner institutions was also stepped up last year. In January, for instance, a two-day workshop on energy research with LANL researchers was held at Empa in Dübendorf to identify various fields where the two institutes will work together more closely in future.

In September, the 6th World Materials Research Institutes Forum (WMRIF) took place at Lawrence Livermore National Laboratory (LLNL) in California. This year's theme was critical materials and computational science. Representatives of the world's chief materials research institutions convene regularly at the WMRIF. Back in March, a young LANL researcher – the winner of last year's WMRIF Young Scientist Award – visited Empa as part of a research exchange.

A key element for international collaborations is also Empa's EU-funded postdoc program COFUND, which has already been running since 2011. One particularly positive point as far as European research collaborations are concerned: so far, unlike other institutions, we have not noticed any significant decline in the involvement of Empa researchers in EU projects within the scope of Horizon 2020.


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On 23 July 2015, Vice-President of KRISS Hyun-Min Park (left) and Empa CEO Gian-Luca Bona signed a Memorandum of Understanding (MoU) between Empa and the Korea Research Institute of Standards and Science (KRISS) to step up their collaboration in nanosafety research.

2
In September, SMAR 2015, the third biennial conference on the intelligent monitoring, assessment, and renovation of buildings, was held in Antalya, Turkey. It was co-organized by Empa and Istanbul Technical University.

3
Otto Lampe, the German ambassador in Switzerland, listening attentively to Empa CEO Gian-Luca Bona's explanations.

On a political level, Gian-Luca Bona exchanged ideas with Otto Lampe, the German ambassador in Switzerland; the Canadian and American ambassadors Jennifer MacIntyre and Suzan LeVine; a delegation from Taiwan's (unofficial) embassy; and EU representatives at an event organized by SwissCore, the liaison office of the Swiss National Science Foundation (SNSF) for the EU in Brussels. Moreover, Pierangelo Gröning, a member of Empa's General Management, and Marc Hansen, Luxembourg's State Secretary for Higher Education and Research, agreed to intensify Empa's collaboration with research institutions in Luxembourg, especially in setting up the Luxembourg's new Institute of Science and Technology (LIST). //


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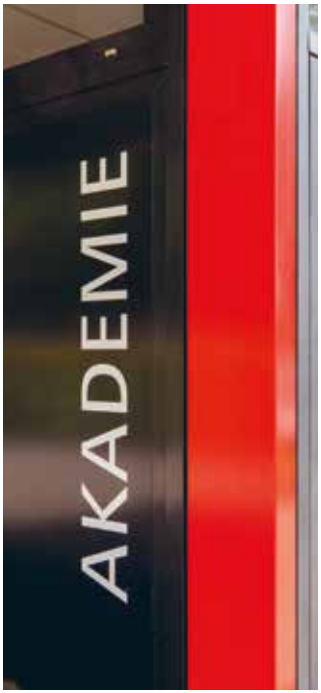
Bouncing ideas off industry



For the Empa Academy, 2015 was a year marked by an intensive exchange of ideas with industry. 105 events were attended by a total of more than 6,000 people, way over half of whom were from industry and commerce. The demonstration platforms NEST and "move", which were recently completed in Dübendorf, especially attracted a lot of interest. Once again, the events calendar featured a good mixture of conferences, congresses, courses, talks, and exhibitions.

Power to gas – converting electricity into chemical energy sources

Switzerland's energy supply is on the brink of fundamental changes. The primary aim is to minimize CO_2 emissions and switch from fossil and nuclear energy sources to renewable ones. The automobile industry also has a key role to play. Besides introducing vehicles with new drive systems, supplying the corresponding fuels is also pivotal. Representatives from politics, industry and research convened at Empa to demonstrate how this might work, including the power-to-gas approach, which involves converting renewable surplus electricity into chemical energy sources such as hydrogen or methane.

Apart from energy research, innovative building technology is another key topic for Empa. The first specialist "Energy + Construction" congress, which Empa organized as part of the "Energy Days St. Gallen", showcased possible solutions, examples, and concrete proposals for realizing energy-efficient building projects on topics such as sustainable renovation concepts, smart homes, and cladding.

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Critical materials – when the future runs out of raw materials

Numerous metallic elements are classed as "critical": on the one hand, they play an increasingly important role in so-called future technologies; on the other hand, there is a high risk of supply bottlenecks. Swiss SMEs are also affected as they often don't realize which of these materials they depend upon. Strategies for handling critical materials in a more sustainable way were presented and discussed at a technology briefing.

Given that medical technology is such a crucial (and research-intensive) growth market for Switzerland's economy, it is hardly surprising that the topic also features prominently at Empa: ten of the 30 research labs study the development, characterization and analysis of material, as well as surface coatings in the field. Empa researchers showcased the latest findings from their labs at the MedTech Day 2015.

Moreover, Empa organized the 20th European Conference on Chemical Vapor Deposition (EuroCVD20) in July 2015. Leading international experts spent a week exchanging ideas about the current developments in dozens of talks, poster sessions, and the informal part of the conference at Lake Sempach.

Wood – surprisingly versatile

Wood is one of the oldest raw materials and the only naturally produced material resource in Switzerland. Nowadays, it is used in countless different ways, but primarily as a construction material and fuel. What many people don't realize, however, is that wood-based materials can also be used in medicine or to combat an oil spill. Empa seized the event "Wood – surprisingly versatile" as an opportunity to demonstrate everything that wood can do. //

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Once again, the Empa Academy events held in 2015 were met with a great response.

2
Member of the Swiss National Council Kathy Riklin at the "Gasmobil Symposium" at the Empa Academy in October.

Public relations – digital and real

The public interest in Empa's research and innovation projects is as great as ever. On the one hand, this is reflected by the 3,250 visitors who attended tours of Empa's labs last year, a new record. However, the various online platforms – especially Empa's brand-new homepage – have also been notching up some impressive click, "like", and download figures.

An attractive showcase for every format

2015 was dominated – at least behind the scenes – by the relaunch of our website. In December, it was finally released: www.empa.ch went live with a completely new look-and-feel. And it was high time, too: the previous Content Management System (CMS) had been in operation for more than 12 years – practically a prehistoric fossil in ICT terms. Besides an attractive appearance, the new website also aims to make it easier for visitors to access the wealth of information on Empa's research, regardless of whether they use a laptop, tablet or smartphone.

There was also a frenzy of activity on Empa's other online channels last year, the social media. For instance, the podcast channels on YouTube, iTunes and iTunes U recorded a total of 1,500,000 downloads in 2015. And Empa had more than 5,500 followers on the Facebook, Twitter, and LinkedIn platforms, and that in just three years.

New visitor record at Empa

Not quite as many people (about 3,300) actually visited Empa's diverse labs in person last year – a new visitor record, having reached the 3,000 milestone for the first time thanks to an increase of roughly 10 percent. Around a quarter of them – and rising – were students from cantonal and vocational schools, i. e. the next generation, who gained a firsthand insight into the fascinating world of science and engineering from Empa researchers.

Numerous representatives from public authorities, politics, and the administration also visited Empa last year to swap ideas and experiences on various aspects of Empa's research, but also innovation policy in general. For instance, Empa had the pleasure of welcoming three Federal Councilors to various events in 2015 – a first in the institute's 136-year history. Federal Councilor Evelin Widmer-Schlumpf paid a visit to Empa along with the entire BDP federal parliamentary faction on its outing and learned about various large-scale projects in the energy sector. During an energy workshop at Empa, Federal Councilor Doris Leuthard visited "move", the technology transfer platform for sustainable mobility. CVP, SP, and FDP delegations – the latter with Member of the National Council, Ruedi Noser – also seized the opportunity to find out about innovations at Empa at first hand. And Zurich Government Councilor Carmen Walker Späh

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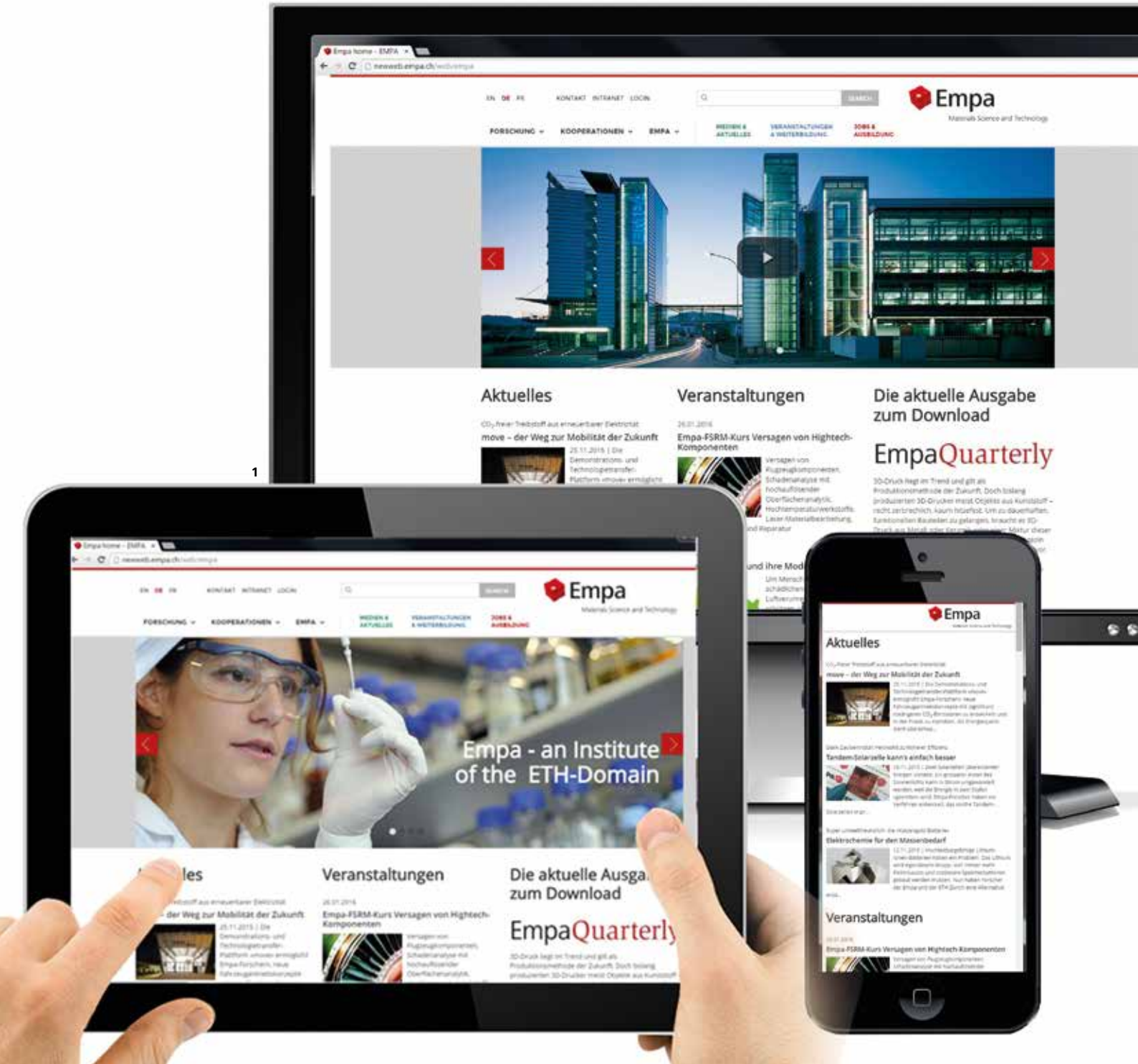
Besides an attractive appearance, Empa's new website also aims to make it easier for visitors to access the wealth of information on Empa's research, regardless of whether they use a laptop, tablet or smartphone.


Empa
Materials Science and Technology
Aktuelles
Veranstaltungen
Die aktuelle Ausgabe zum Download
EmpaQuarterly
Empa - an Institute of the ETH-Domain

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A new absorbent material developed by wood researchers at Empa could help combat future oil spills: chemically modified nanocellulose. Tanja Zimmermann, head of Empa's lab for Applied Wood Materials, shows Federal Councilor Johann Schneider-Ammann how it works.

2
Member of Zurich's Government Council Carmen Walker Späh learning about Empa from the institute's CEO Gian-Luca Bona at the topping-out ceremony for NEST.

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Dr Michael Hagmann
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spoke to Empa CEO Gian-Luca Bona about how innovative companies from abroad might be attracted to the Swiss Innovation Park in Dübendorf.

Numerous visitors from abroad, including German Ambassador Otto Lampe and various delegations from Korea, Japan, Russia, the USA, Italy, Great Britain, Peru, and Colombia, also dropped by. The groups from Italy and Great Britain were actually science and technology journalists who had been invited on a "Tour de Switzerland" by the Federal Department of Foreign Affairs (FDFA) and the Swiss Embassy, which included visits to various Swiss research facilities. //

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Equal opportunities and more

Equal opportunities and diversity have been a priority at Empa for quite some time. This is reflected in Empa's staff, who come from more than 50 countries, and Empa's focus on family. Last year, the institute won the Prix Balance award for its varied working hour models and successful reconciliation of a career and family. Empa has its own crèche, the Kinder Pavilion in Dübendorf, as well as places reserved at crèches at its other locations in St. Gallen and Thun, and offers parents the possibility of sending their children to its own week-long summer camp, which will take place from 18 to 22 July in 2016. This year's National Future Day will be held on 7 November – a special opportunity for Empa to get girls interested in science and engineering.

Under new management

In the spring of 2015, after many years in her role as equal opportunities officer, Christiane Löwe left Empa to run the equal opportunities office at the University of Zurich. Her successor is Marianne Senn, an archaeometallurgist who is also responsible

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The goal at Empa's Future Day is to arouse interest in engineering and science.

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for Empa's archives. She has set her sights on the percentage of women at Empa, which is still fairly low, and would like to encourage men to work part time.

Action plan as a means to a renewed support culture

In the spring of 2015, Empa once again managed to achieve the "Best Practice" rating of "Family AND Profession", which is awarded by the independent agency "UND – Familien- und Erwerbsarbeit für Männer und Frauen". The accolade especially recognizes Empa's dedication in the key fields of leadership and human resources development. A few years ago, Empa drew up an ambitious action plan primarily aimed at supporting women at all levels and function groups. Other focuses include diversity, and reconciling a career and family. Although the action plan expires this year, Empa aims to compile a new, effective action plan for 2017 – 2020. //

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Risk management: forewarned is forearmed

Look before you leap!" This quote from Prussian Field Marshall Helmuth Graf von Moltke the Elder (1800–1891) fittingly describes the spirit and purpose of Empa's risk management policy. Its aim is to recognize, analyze, assess, and monitor potential risks to the institute and its staff with a view to ultimately controlling them.

Principles of tackling risks

As part of the ETH Domain, Empa geared its risk regulations towards the risk management standards of the ETH Domain and the Swiss federal government. Its security and risk policy officially stipulates the homogeneous, systematic, and consistent handling of the various risks. All measures prioritize the protection of Empa's staff, visitors and anyone else in the institute's sphere of influence. Other goals include protecting the environment from negative effects, safeguarding intellectual property and the know-how acquired as well as protecting Empa's reputation. The main focus of these efforts is to prevent damage.

Empa's risk management policy is implemented according to a standardized process, which begins with a periodical risk review. Every risk is assessed according to its potential impact and likelihood of occurrence, and evaluated in at least the dimensions "financial risk" and "risk to reputation". Finally, measures are defined and implemented to contain the risk. In risk controlling, the risk management process is verified regularly and – if need be – modified. Moreover, it helps gauge how successfully measures have been implemented.


Measure!
Assess!
RISKS
Evaluate!
Manage!

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Successful reorganization

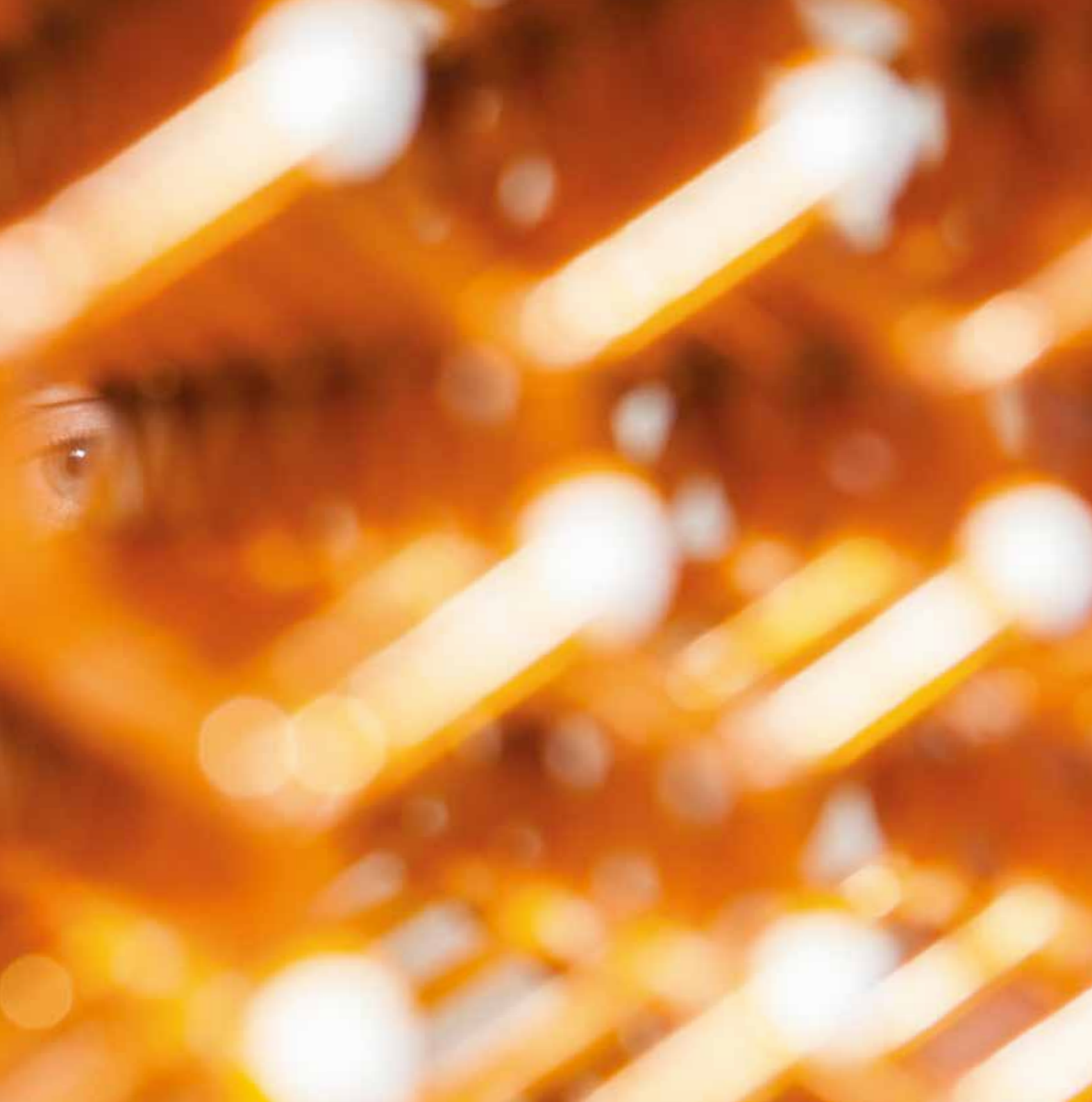
Empa's risk management was reorganized in 2015 with a view to making it more streamlined and professional. This led to a higher resource input, increased activities, and heightened awareness last year. Thanks to periodical reassessments, risks are now perceived more consciously and can therefore be controlled more effectively. And the measures developed as a result, such as intensified training activities, are already showing results.

A new emergency concept for evacuations or attacks is currently in the implementation phase. New evacuation organizations and alarm devices have been set up on the Dübendorf and St. Gallen campuses and assembly points defined for people to head to in an evacuation. In the course of the implementation phase, a visitor pass was introduced, which also lists the main emergency instructions. The Thun campus is integrated in the emergency organization of the Swiss army training grounds located nearby.

To boost chemical security, the lab labeling has been standardized. Hazardous substances are now listed in all labs, along with the names and telephone numbers of the lab heads – vital information for the emergency services. A set of ICT guidelines, which will particularly focus on handling confidential data, is currently in the pipeline – a particular challenge in the world of open science. //

1
A small but concrete point in implementing risk management: stipulate assembly points for staff in the event of building evacuations.

Researcher Andrea Bergamini looking through the model of a diamond structure. He is researching whether such crystal structures can eradicate vibrations in suspended ceilings in buildings, for instance.



Facts and Figures

Researchers like to measure things – including their own performance: in 2015 Empa researchers and engineers published more than 630 scientific papers and patented almost 20 developments. By the end of the year, roughly 110 projects funded by the Swiss National Science Foundation (SNSF), nearly 90 projects backed by the Commission for Technology and Innovation (CTI), and nearly 60 EU projects were underway at Empa. And the 21 spin-offs employ a total of around 360 employees together with other start-ups in Empa's two business incubators – and counting.

Key Figures

You can find the profit and loss statement online in Empa's Financial Report 2015 under: *www.empa.ch/web/s604/annual-reports* (available only in German)

At the end of 2015, 942 (2014: 950) persons were working at Empa. Because of the many part-time positions, this corresponds to 868.7 (2014: 878.5) full-time equivalents.

Scientific staff numbered 501 (2014: 524). This number includes 117 (2014: 123) senior scientists. 400 (2014: 383) persons were employed as technical and administrative staff in the reporting year. The table above does not include 26 professors, because Empa as a research institute does not award its own academic titles.

The share of female employees of 27.5 (2014: 27.6) percent reflects the graduate numbers of the universities and of ETH Zurich in the faculties represented at Empa.

The number of foreigners is 388 (2014: 383), which accounts for roughly 41 (2014: 40) percent of the total workforce. 265 (2014: 273) of those persons, i. e. 68 (2014: 71) percent of all foreign employees, come from the EU.

After repeated increases in the number of temporary positions in recent years, this number declined again slightly to 398 (2014: 416) persons. The average contract duration did not change; it continues to be determined by the usual agreements for PhD students and postdoc students.

Empa offers a wide range of vocational trainings, employing 41 (2014: 43) apprentices. Once again in 2015, all apprentices successfully completed their final examinations.

STAFF (AS OF 31 DECEMBER)

	2014	2015
Scientific staff	**524**	**501**
Technical and administrative staff	**383**	**400**
of which apprentices	43	41
Total	**950**	**942**

SCIENTIFIC OUTPUT

	2014	2015
ISI publications	486	634
Conference contributions	1,222	1,121
Doctoral studies completed	32	38
Doctoral studies in progress	171	175
Teaching activities (in hours)	3,732	3,760
Prizes and awards	62	35

MEDIA EXPOSURE

	2014	2015
Radio and TV	80	73
Print	1,000	1,000
Online	2,750	2,853
Total	**3,830**	**3,920**
Languages	30	32

EMPA ACADEMY

	2014	2015
Empa events	**81**	**105**
Participants	4,100	6,100
Scientific conferences	15	12
Events for industry	33	44

KNOWLEDGE DISSEMINATION AND TECHNOLOGY TRANSFER

	2014	2015
New R&D agreements	127	157
Active exploitation contracts	75	80
New exploitation contracts	16	20
New patent applications	18	18

SPIN-OFFS AND START-UPS (tebo and glaTec)

	2014	2015
Companies total	**37**	**45**
thereof spin-offs	21	21
Employees total	**281**	**359**
thereof employees of spin-offs	102	105

CURRENT PROJECTS

	2014	2015
Swiss National Science Foundation (SNSF)	119	112
Commission for Technology and Innovation (CTI)	103	89
EU projects	63	58

Bodies of Empa

ETH Board

The ETH Board has overall responibility for the management of the ETH Domain, which incorporates the two Federal Institutes of Technology (ETHZ, EPFL) and the four federal research institutes (PSI, WSL, Eawag and Empa).

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Markus Stauffacher Dr, ETH Zurich
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A body of leading personalities which advises the Empa management on fundamental concerns.

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Eugen Voit Dr, Leica Geosystems, Heerbrugg

Research Commissions

The Commission advises Empa's Board of Directors on questions of research, the choice of R&D spectrum and the evaluation of internal R&D projects.

MEMBERS
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Dimos Poulikakos Prof. Dr, ETH Zurich
Heike Riel Prof. Dr, IBM, Rüschlikon
Marcus Textor Prof. Dr, ETH Zurich
Alexander Wokaun Prof. Dr, PSI, Villigen

Organizational Chart

as of May 2016

RESEARCH FOCUS AREAS

Nanostructured Materials
Dr Pierangelo Gröning

Sustainable Built Environment
Dr Peter Richner
Dr Giovanni Terrasi

Health and Performance
Prof. Dr Alex Dommann

Natural Resources and Pollutants
Dr Brigitte Buchmann

Energy
Dr Peter Richner
Urs Elber

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Dr Pierangelo Gröning

Electron Microscopy Center
Dr Rolf Erni

Civil and Mechanical Engineering
Dr Peter Richner

Materials Meet Life
Prof. Dr Alex Dommann

Center for X-ray Analytics
Dr Antonia Neels

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Prof. Dr Thomas Graule

Joining Technologies and Corrosion
Dr Lars Jeurgens

Nanoscale Materials Science
Prof. Dr Hans Josef Hug

Advanced Materials Processing
Prof. Dr Patrik Hoffmann

nanotech@surfaces
Prof. Dr Roman Fasel

Mechanics of Materials and Nanostructures
Dr Johann Michler

Thin Films and Photovoltaics
Prof. Dr Ayodhya N. Tiwari

Functional Polymers
Prof. Dr Frank Nüesch

Road Engineering / Sealing Components
Prof. Dr Manfred Partl

Applied Wood Materials
Dr Tanja Zimmermann

Structural Engineering
Prof. Dr Masoud Motavalli

Mechanical Systems Engineering
Dr Giovanni Terrasi

Multiscale Studies in Building Physics
Prof. Dr Jan Carmeliet

Mechanical Integrity of Energy Systems
Prof. Dr Edoardo Mazza

Center for Synergetic Structures
Dr Rolf Luchsinger (PPP Empa – Festo)

Concrete / Construction Chemistry
Prof. Dr Pietro Lura

Building Energy Materials and Components
Dr Matthias Koebel

Urban Energy Systems
Viktor Dorer

Protection and Physiology
Dr René Rossi

Advanced Fibers
Prof. Dr Manfred Heuberger

Particles-Biology Interactions
Dr Peter Wick

Biointerfaces
Dr Katharina Maniura

Reliability Science and Technology
Dr Urs Sennhauser

KNOWLEDGE AND TECHNOLOGY TRANSFER

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Reto Largo

move
Dr Brigitte Buchmann

Empa Academy
Anja Pauling

glaTec – Technology Center in Dübendorf
Mario Jenni

STARTFELD Innovation Center
Peter Frischknecht

Reliability Network
Dr Urs Sennhauser

International Research Cooperations
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Materials for Energy Conversion
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Stephan Koch

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Heidi Leutwyler

Communication
Dr Michael Hagmann

Human Resources
André Schmid

Marketing, Knowledge and Technology Transfer
Gabriele Dobenecker

Construction 3 RI / Technical Services
Hannes Pichler

Empa – The Place where Innovation Starts

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