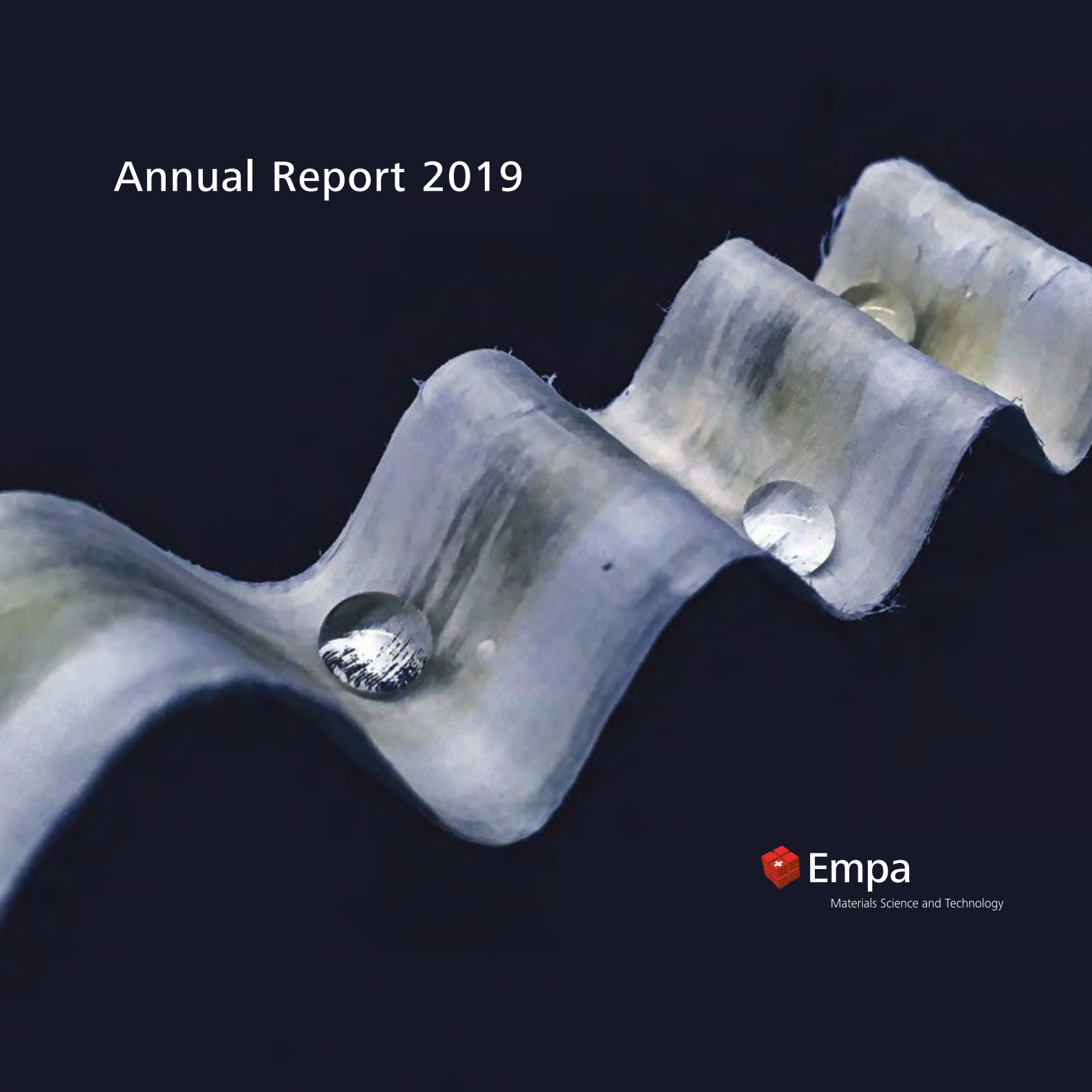
Annual Report 2019



Empa
Materials Science and Technology

Our Vision.
Materials and Technologies for a Sustainable Future.

Cover Photo: delignified, deformed, compacted and made water-repellent: the wood material developed by Empa and ETH Zurich has the potential to become a high-tech material, as it can be shaped at will and is three times stronger than natural wood. To achieve this, the researchers are removing precisely that part of the wood which gives it its stability in nature, the lignin. Image: ETH/Empa

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Image: Nicolas Zonvi

Empa's role in the innovation process

In April 2019, an international Expert Committee evaluated the six institutions of the ETH Domain. This was an excellent opportunity for us at Empa to reflect on and sharpen our role in the innovation process and our uniqueness in the Swiss research landscape. Let me say it in advance: our international peers highlighted the outstanding quality of the ETH Domain as a whole and acknowledged its achievements, but also made a number of recommendations for further development.

Empa's positioning within the ETH Domain as "the place where innovation starts" is reflected, among other things, in our byline: Materials Science and Technology. This is because groundbreaking innovation is, on the one hand, based on scientific excellence, but on the other hand, also requires a holistic approach that combines basic research with practical applications to solve real-world problems. At Empa, we live this principle by bringing together highly diversified scientists and engineers from a wide range of disciplines in small, powerful teams.

The numerous research and innovation projects lead to a continuous expansion of our know-how – and thus to the development of an "institutional" memory, which often represents a decisive added value in the many long-term collaborations with our partners from industry. After all, the path from discovery to the implementation of technological innovations often takes between 10 and 20 years, hence, scientific continuity is key.

By bringing together partners from research and industry, Empa scientists play a crucial role in the innovation process in Switzerland. This is the basis of our leading position in applications-oriented research and technology transfer, and it is precisely in this way that Empa distinguishes itself from Swiss universities with their focus on research and academic education.

A core element here are our knowledge and technology transfer platforms such as NEST, move, the Coating Competence Center and the Empa-led initiative on Advanced Manufacturing (AM; see p. 22 ff.), all of which are based on Empa's five Research Focus Areas (see p. 32 ff.). In these major projects, which act as a kind of beacon, our researchers work hand in hand with their partners from industry and the public sector – a network of more than 1,100 partner institutions – to accelerate the innovation process in various sectors, which are of central importance to our country. Only in this way can we offer real added value to our society and our economy with its numerous SMEs.

This approach is tailored to Switzerland's economic ecosystem and can be applied to a wide range of topics, from our built environment to energy and mobility all the way to medical technologies. At the interface of science and business, we want to anticipate and tackle both challenges and opportunities. For it is above all at the interfaces between various disciplines that new and surprising things are emerging.

***Prof. Dr Gian-Luca Bona**, Director*

Year at a Glance

Excellent trainees
Empa's cutting-edge research in the field of materials science and technology builds on the expertise of its staff. This also includes the more than 40 trainees in ten different professions. Many of them finish their final exams with top marks and distinction. Empa was also awarded the seal of approval "Best Training Companies in Switzerland – Recommended by trainees" by the consulting agency "Great Place to Work".

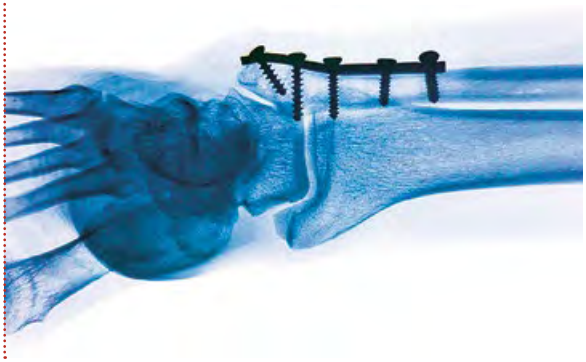
Award for CFRP pioneer
Urs Meier has worked at Empa since 1969, including as Director of the Dübendorf campus. As early as 1980 Meier started with the idea of using carbon fiber-reinforced polymers (CFRP) for ropes in large bridges. Using what was then an extremely expensive "super material" in the construction industry seemed so crazy that he began his first studies in secret. In 1982, the idea of reinforcing concrete structures by bonding extremely thin CFRP lamellas was born. In September 2019, Meier received a prestigious award for his pioneering work – the "SAMPE Fellow Award". This award is given in recognition of outstanding contributions in the areas of materials and processes.

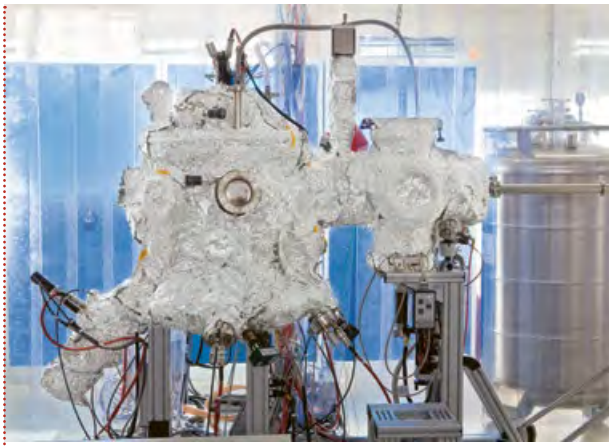
Scarce metals in electronic waste
Electronic waste contains more scarce metals than any mine. But what happens to the valuable raw materials? And how much of the precious metals is in mobile phones, computers and screens that are still being used today? Empa researchers have been investigating this. Gold is largely recovered today, while other scarce metals such as indium and neodymium are lost. Even a small increase in the recycling fee would be enough to make their recovery economically viable. Until then, it would at least make sense to temporarily store components with a high proportion of indium and neodymium – so that the precious materials are not lost forever. Image: iStockphoto

Romantic replicas
Playing a piece of music exactly as it was conceived by the composer is the trend. But where do the rare historical instruments come from? The solution would be exact replicas of the coveted originals. Empa researchers analyze both the materials and the sound of historic instruments and their copies. The aim is to recreate trombones from the Romantic era with their typical sound and in accordance with the craftsmanship of the time, using authentic materials.

Battery award for Empa researcher
In October, Léo Duchêne received the prestigious Battery Division Student Research Award from the Electrochemical Society in Atlanta, USA. This research prize is awarded to promising young scientists in the field of electrochemical energy storage. The prize is awarded for Duchêne's results on solid state batteries, which he has been working on for the last four years as part of his PhD thesis at Empa. In future, this type of battery should make it possible to store almost twice as much energy as in current batteries, while at the same time ensuring a high level of safety and reliability. Image: iStockphoto

Magnesium screws for surgery
When bones burst, surgeons must join the fragments together with implants. Conventional metal implants made of titanium or steel stably hold bone fragments together after a fracture. But to remove them, another operation is necessary. Orthopaedic screws made of magnesium, which dissolve in the body over time, spare patients a second operation after healing and thus reduce the risk of infection. However, what happens with such implants in the body is largely unknown. Empa researchers are analyzing the corrosion processes of magnesium in order to develop optimized alloys and orthopedic screws with functionalized surfaces. Image: iStockphoto

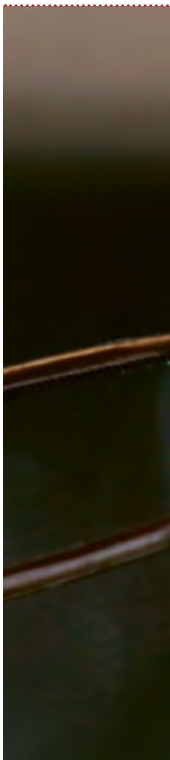




New record for thin-film solar cells
Never before has such an efficient flexible CIGS solar cell been created: Empa researchers have broken their own world record. They improved the energy conversion efficiency of CIGS solar cells on flexible polymer substrates to 20.8 percent. This is 0.4 percent higher than the previously achieved mark – which was held by the same team. The technology of choice is copper indium gallium diselenide (CIGS), which enables the production of flexible, lightweight solar cells on polymer foils.

Floating power plants
Giant solar islands at sea, which produce enough energy to enable CO_2-neutral global freight transport: What sounds like science fiction has been simulated for the first time by researchers from Empa, ETH Zurich, the Paul Scherrer Institute (PSI), the Universities of Zurich and Bern and the National University of Science and Technology in Trondheim. The idea is based on floating platforms equipped with photovoltaic systems. Since solar power cannot be stored there and is difficult to transport, a solar power plant at sea makes little sense at first. However, liquid methanol (CH_3OH), but also gaseous methane (CH_4) can be produced from carbon dioxide (CO_2) and hydrogen (H_2). The starting materials could be obtained directly from the ocean or produced there, according to the researchers. Image: Novaton

Reducing aircraft noise during landing
Approach and landing are among the most complex phases of a flight. In order to allow pilots to make approaches with as little noise as possible, the German Aerospace Center (DLR) has developed a new assistance system (LNAS). Via a display in the cockpit, the LNAS indicates when exactly the pilot has to perform which maneuver for a low-noise approach. Empa acoustics researchers have evaluated the new system at Zurich Airport; first results are expected in spring 2020. In the medium term, the LNAS is to be installed as an industrialized solution in the flight management system of commercial aircraft. The signs are good that this innovative solution will be "flying" worldwide. Image: iStockphoto



Cooperation with Lexus

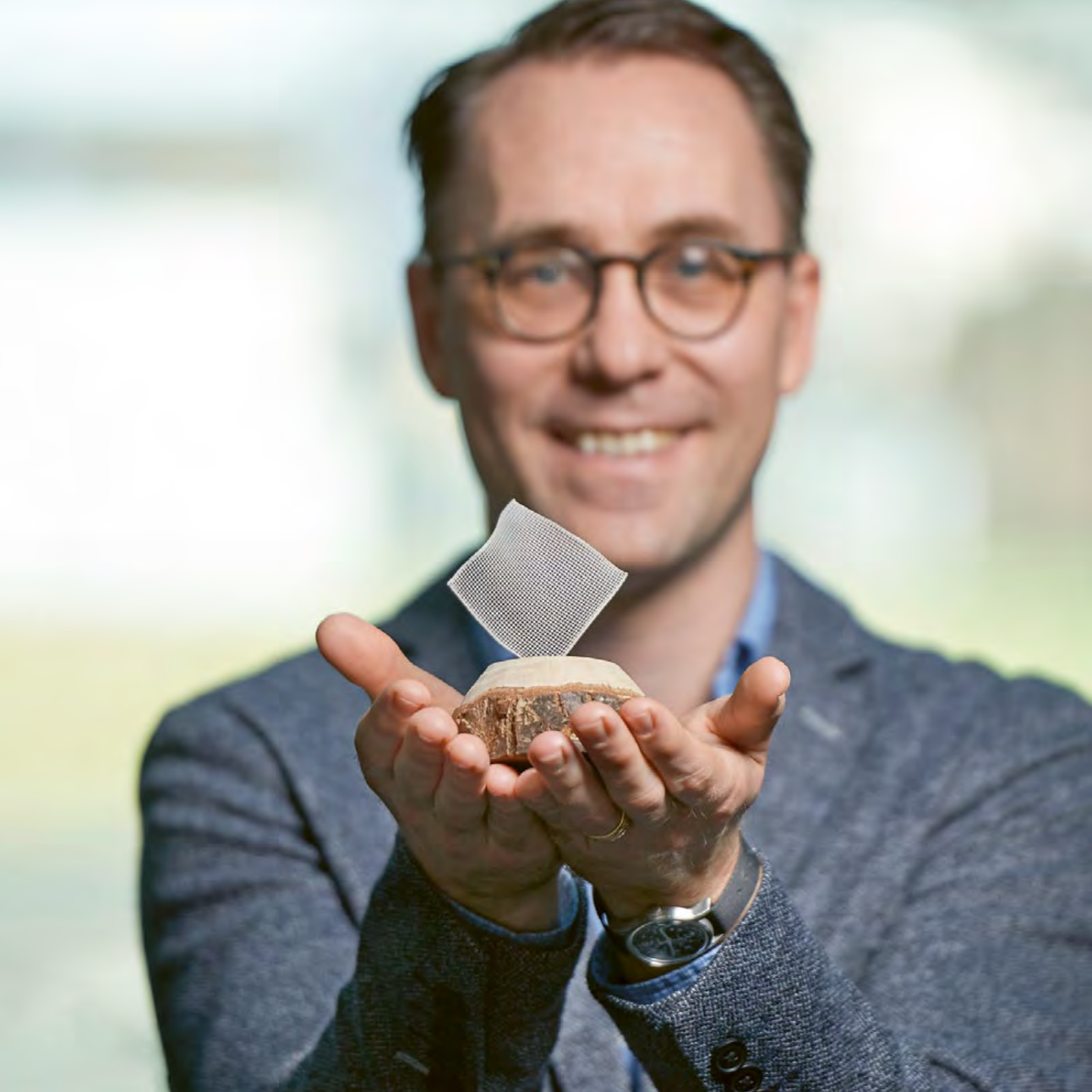
Automated vehicles have the potential to make road traffic safer, more efficient and more comfortable. Lexus and Empa started a collaboration to improve sensor technology for automated vehicles. Sensor systems play a crucial role in automated driving. By sensing the vehicle's environment, they provide the information that is required to guide the vehicle safely through traffic. In real-life applications, however, these sensors are exposed to a wide variety of weather and environmental influences as well as mechanical stress. As part of the collaboration, Lexus has made a test vehicle available to Empa, where it is now being equipped with various sensors and a data acquisition system in order to investigate the behavior of the sensors in detail under real driving conditions.

The beauty of science

The beauty of scientific results is sometimes only revealed to experts. For the art and science exhibition "ArtSci 2019" at ETH Zurich, however, researchers made the magic of the natural sciences tangible and visible to a wide audience. Empa researchers presented no less than three works of art – which showed that excellent research and creativity can certainly benefit from each other. "Frozen clouds", one of the three works, shows a colored bio-aerogel. This is such an incredibly light solid that it could also go by the name of "frozen cloud".

Coveniently to (simulated) Mars

"Serenity" is the name of the new Mars suit prototype, which the Austrian Space Forum is currently developing together with Empa researchers. It is to be used in 2020 in the simulation of an international Mars mission in Israel's Negev desert. The two partners signed a cooperation agreement for the development of the prototype. The cooperation focuses on optimizing the wear comfort and the thermal regulation system of "Serenity" based on body models developed at Empa. Image: ÖWF



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.

Faster and cheaper way to new types of solar cells

Dr Frank Nüesch, frank.nueesch@empa.ch
Dr Jakob Heier, jakob.heier@empa.ch
Anand Verma, anand.verma@empa.ch

The semiconductor perovskite is seen as a new hope to push the production price for solar cells below that of silicon used so far. Empa is developing new manufacturing processes to make perovskite solar cells not only cheaper, but also faster to produce and fit for industrial use. To this end, Empa has collaborated with the Vaud-based company Solaronix SA in the "UPero" project funded by the Swiss Federal Office of Energy. Together they produced a functional perovskite cell on a laboratory scale of 10 × 10 cm using a more efficient process.

Slot die instead of screen printing

For the production of this novel perovskite cell, the so-called slot die process is used. In this process, the material layer is applied on a glass substrate and structuring is done by removing excess materials by laser scribing. The new coating process not only enables researchers to coat faster, but also to adjust the thickness of the individual layers more flexibly. In the future, coating will be easy and quick using the slot die process. The increased coating speed is also the central element in a possible industrialization of perovskite cell production.

A total of five layers of different materials, including titanium oxide, zirconia and graphite, are required for such a cell. Whereas in the previous screen printing process the layers have to be dried and sintered (i.e. compacted) individually, which takes a lot of time and energy. In the slot die process all layers can be applied directly one after the other and sintered together. The perovskite solar cell gets its final touch by applying the perovskite absorber by means of ink-jet printing in Empa's "Coating Competence Center" – the so-called infiltration. Here the perovskite is no longer applied to the substrate as a solid layer, but seeps through all porous sub-layers of the solar cell to the bottom.

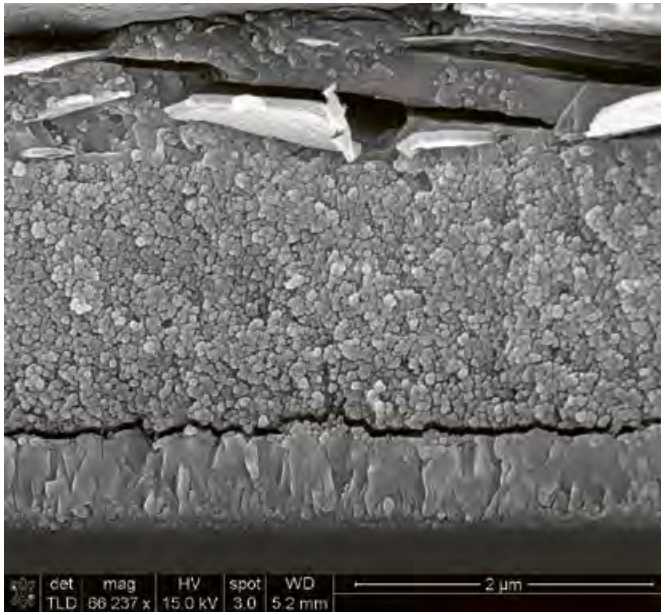
A successful cooperation

In developing the new process, the Empa team worked closely with Solaronix experts. They are the source of the "inks" – nanoscale conductors, semiconductors and insulators – for printing the individual, wafer-thin layers of the solar cell. The difficulty for the Empa researchers was to prepare this ink in such a way that it was suitable for the slot die process. They recently succeeded in doing just that.

A further advantage of the perovskite solar cells produced by this novel process is a longer lifetime in comparison with previous perovskite cells. The next step will be field testing: at the end of 2020, a perovskite panel will be mounted on the roof of the NEST building on the Empa campus in Dübendorf, where the cells will have to prove themselves in everyday use. //

1
Cross section through the individual layers of the perovskite solar cell seen through the scanning electron microscope: The individual layers are wafer-thin, and the porous materials have been "filled" with perovskite in the final step.

2
The slot die applies a carbon layer to the substrate. This allows all five layers of the solar cell to be applied one after the other and sintered together. With the conventional screen printing process, each layer had to be dried and sintered separately for at least one hour.



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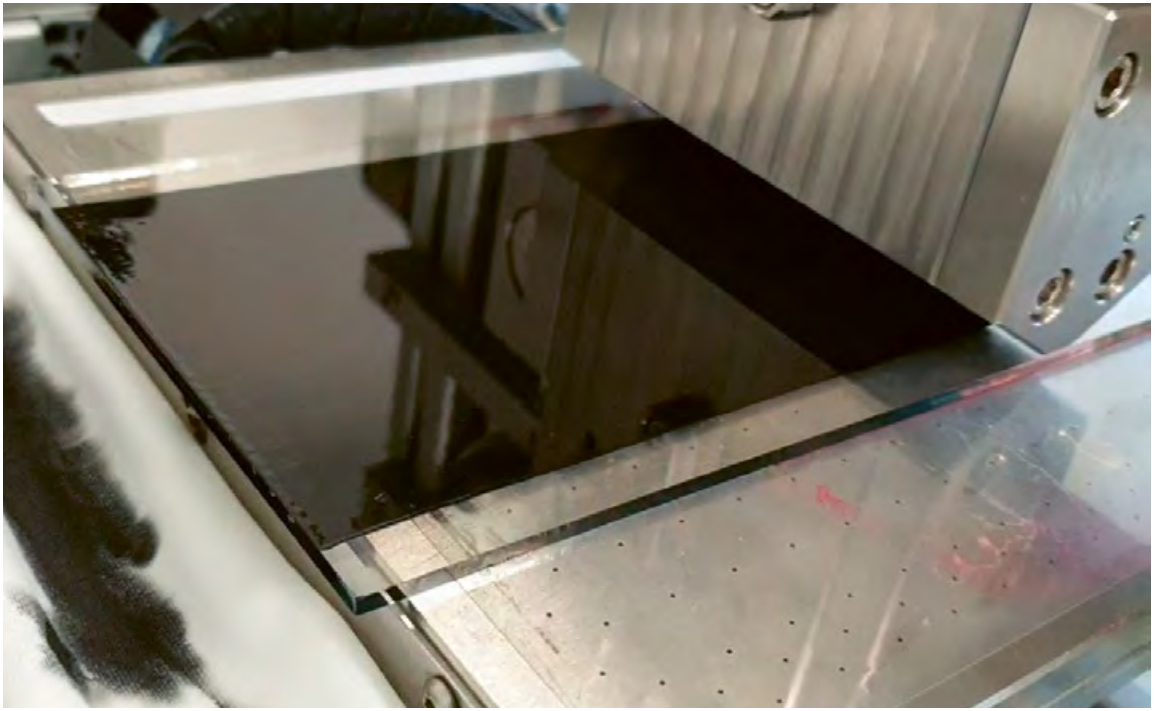
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What is the best treatment for a herniated disc?

Dr Ameet Aiyangar, ameet.aiyangar@empa.ch

A herniated disc is painful – and one of the most common reasons for surgery on the spine. If the herniated disc does not shrink again on its own with the help of medication, two types of surgery may be considered: One is a "Decompression" to surgically decompress the affected nerve roots. The second is to fuse the affected vertebrae. However, fusion is a more invasive intervention with more associated complications – and sometimes the problem only shifts: the discs below and above could be subjected to greater stress and also eventually fail. In order to decide which intervention is necessary, doctors usually rely on the comparison of two static X-rays – in an upright and in a forward-bent position. If the affected vertebrae shift strongly towards each other or even twist, a fusion is indicated – if not, decompression, i.e. removal of the disc mass, may be adequate.

Studies have shown, however, that this is often not sufficient as a basis for a decision: up to a third of patients who receive the simpler operation have to be re-operated. Conversely, it can be assumed that not all patients who had their vertebrae stiffened really required this operation. The problem is that the images only show the initial and final state of the vertebrae position – but not what happens during the movement itself.

Dynamic movement patterns are crucial

Researchers from Empa's Mechanical Systems Engineering Laboratory and the Department of Orthopedic Surgery at the University of Pittsburgh were able to show that the vertebrae do not shift linearly during movement. On the contrary: depending on the patient, very different patterns of movement were observed. For the study, the researchers took continuous, dynamic X-rays of volunteers while they slowly tilted their upper bodies forward. Based on the images, the researchers then calculated how the vertebrae were moving.

It could have been expected that rotation and displacement of the vertebrae would increase evenly during the movement. In some of the test persons, however, the instability of the vertebrae during movement was up to eleven times higher than the comparison between the initial and final position would have suggested.

Technology is not yet part of everyday clinical practice

This shows that a dynamic assessment of the damage is necessary to select the best possible treatment. However, there are only a few imaging devices with the technology required for dynamic images – "Dynamic Stereo X-Ray" (DSX) – worldwide, and the calculations of the movement patterns are extremely complex. At the moment, the technology is therefore only being used in research. However, until it becomes clinical practice, it may make sense to create and compare several X-ray images in different states of movement instead of just two images in the end positions. //

In case of a herniated disc, there are basically two types of surgery that can be considered. But which is the better one? Image: iStockfoto

Foam protects against scarring

Dr Markus Rottmar, markus.rottmar@empa.ch

Poorly healing wounds and severe scarring can significantly impair a person's mobility and health. And although millions of people are affected, the complex process of wound healing is still not fully understood, let alone controllable. With the research project "Scar-avoid", supported by the Gebert Rüf Foundation, scientists now aim to better understand and support the natural healing process. For this purpose, Empa researchers have developed a polymer foam, which optimizes the natural self-healing potential of wounds.

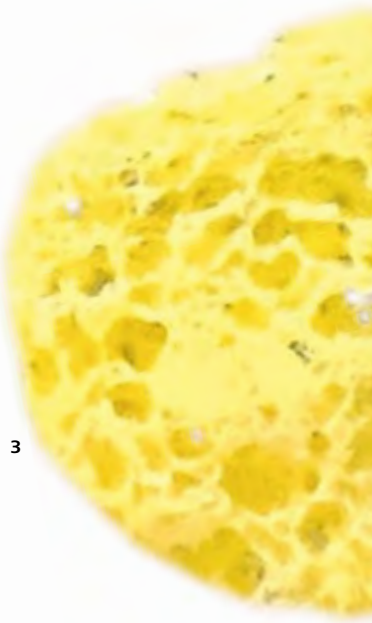
Inviting architecture

The basis for the "wound foam" is a polymer already approved for medical applications. The biopolymer is foamed in a high-pressure reactor using supercritical carbon dioxide, whereby the pore size can be precisely adjusted by variations in pressure and/or temperature. Once placed onto an injury, the polymer structure intervenes in the wound healing cascade at several stages: With its open-pored architecture, it offers incoming cells a suitable scaffold for settling down. Since the scaffold is biodegradable, the cells can then remodel the polymer structure and create a new, functional tissue.

Turmeric controls cell functions

In order to avoid the formation of unwanted scar tissue, the polymer structure is also equipped with a bioactive substance that inhibits scar formation. To this end, the researchers made use of a substance that is more familiar from the kitchen than from the hospital: curcumin. The powder, a component of the turmeric root, also known as turmeric, is a food additive that gives color to certain foodstuffs and contributes to the aroma in curry powder. Curcumin is interesting as a pharmacological component because of its anti-inflammatory properties. Empa researchers added curcumin to cell cultures and found that biomarkers typically found in scars are significantly reduced.

In the foam, curcumin is incorporated within the scaffold and is released gradually. It controls the activity and function of the cells that migrate into the structure, thus supporting the natural balance of wound healing. What is currently being analyzed in laboratory tests in the form of small polymer samples will hopefully be used in clinical applications in the form of larger polymer membranes in future. The membranes are intended to optimize wound healing, particularly in cases of serious injuries, such as after traffic accidents or severe burns. //



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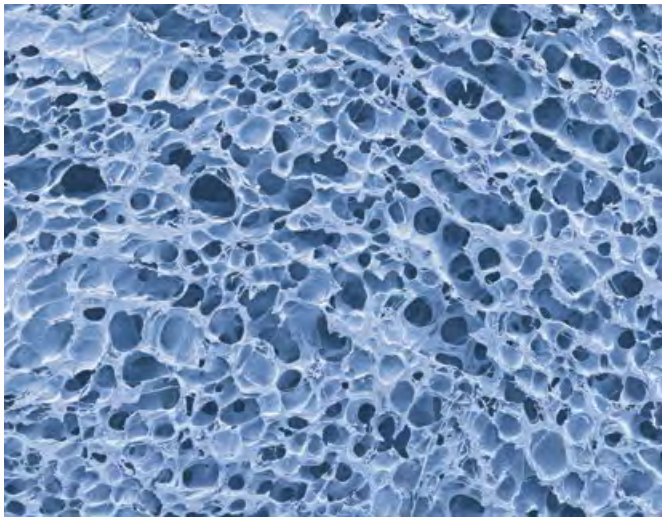

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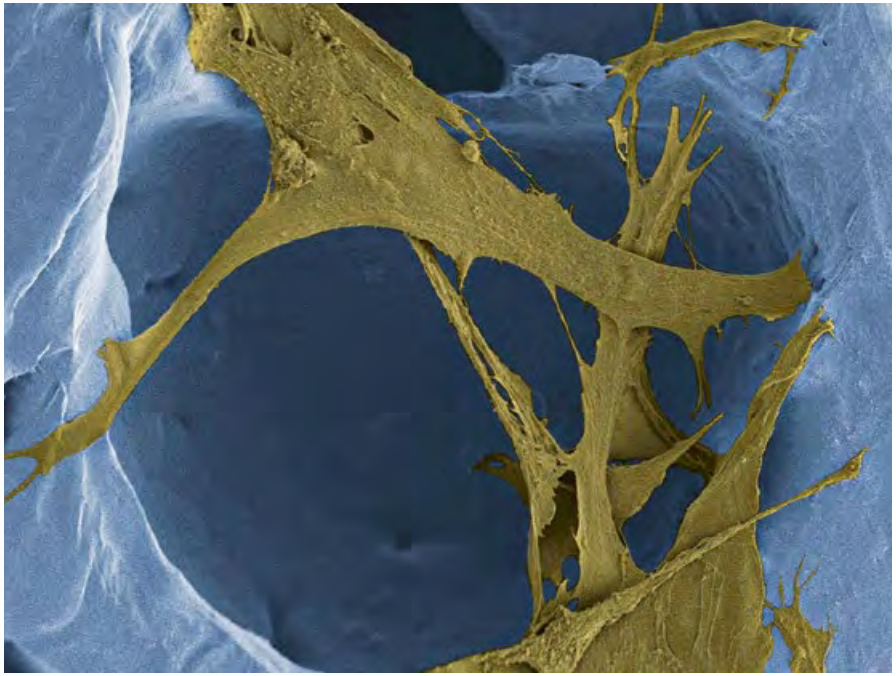
1
For "Scaravoid" a biopolymer is treated with supercritical carbon dioxide. Colored SEM image, 30x magnification.

2
Within the polymer foam, cells like these fibroblasts (brownish) can attach in order to build up new, functional skin tissue. Colored SEM image, 1200x magnification.

3
The polymer foam can be placed into a skin wound and optimizes the natural healing process. It is equipped with curcumin, which regulates cellular functions.



2

Innovative valve train saves fuel

Dr Patrik Soltic, patrik.soltic@empa.ch

The valve train is the "respiratory organ" of combustion engines; it manages the aspiration of fresh air and the discharge of exhaust gases, which is referred to as "gas exchange". Today, only mechanically driven camshafts are used in series production for this purpose, often equipped with an additional mechanism, some of which are quite complex. This allows modifying a valve movement pattern given by the camshaft, but it also causes extra friction. At the same time, flexibility is not given to the desired extent.

A team at Empa's Automotive Powertrain Technologies laboratory together with an external partner developed an electrohydraulic valve train that is significantly more flexible than today's series production technology. The valves are actuated hydraulically and controlled electrically via a solenoid coil. As soon as a control current flows, a specially designed hydraulic valve opens, allowing hydraulic fluid to open the gas exchange valve to the desired extent in milliseconds against a spring. When the current is switched off, the gas exchange valve is closed by the spring force and recuperates a large part of the hydraulic energy required for opening. The system, called "Flex-Work", is significantly more fuel-efficient over a wide range of operating conditions than conventional camshaft-driven systems using a throttle for load control. In the low load range typical for passenger cars the fuel consumption is lowered by as much as 20 percent.

Adaptable to renewable fuels

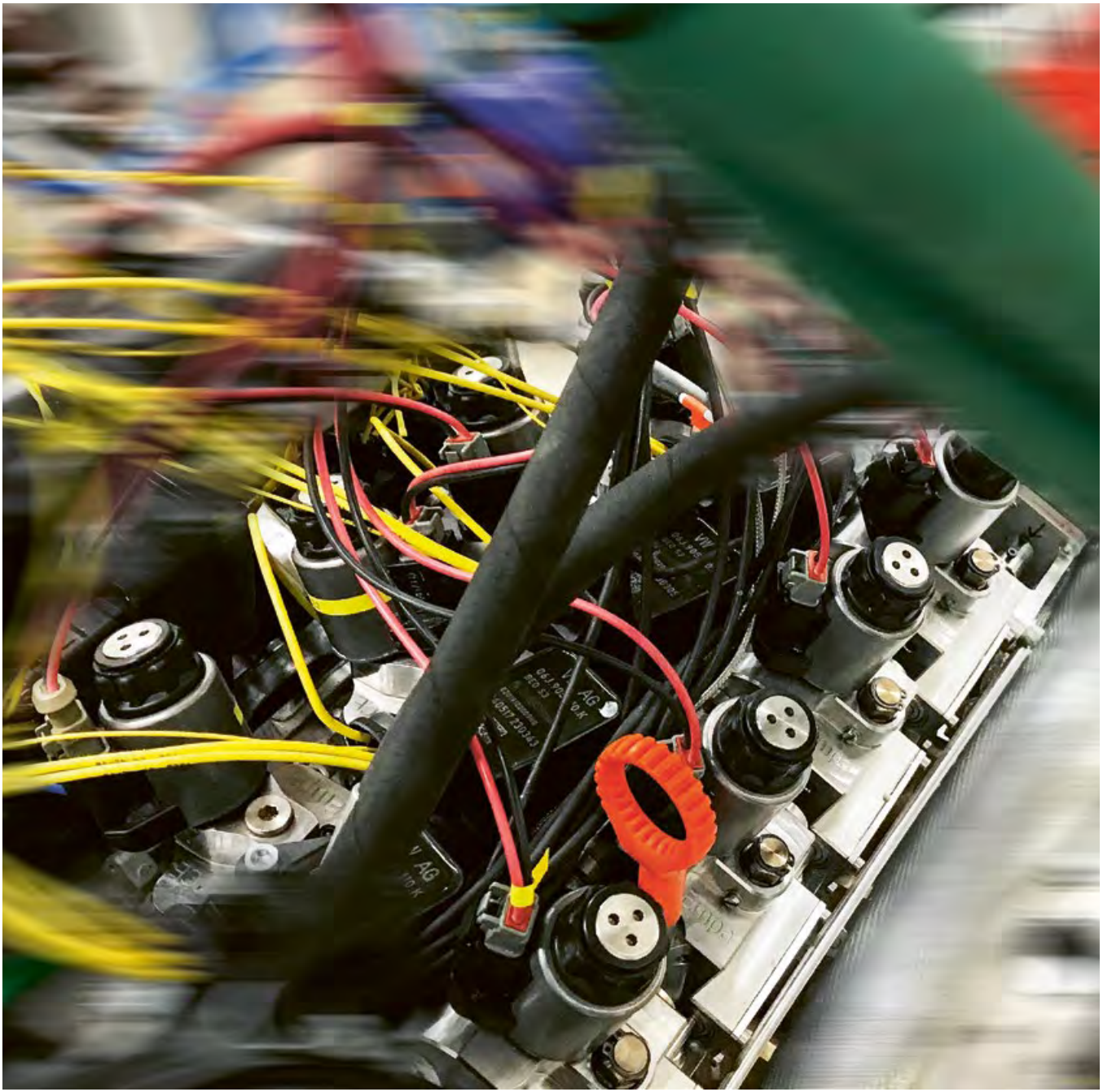
The opening and closing times as well as the valve lift for each cylinder can be chosen freely. This means that the condition inside the combustion chamber can be adapted from cycle to cycle. This makes the engine highly dynamic – and also adaptable to renewable fuels: oxygen-containing fuels such as methanol or ethanol, for example, allow more residual gas to remain in the cylinder. Natural gas, biogas and syngas generated from wind and solar power offer increased anti-knock properties, and the valve train can react flexibly to this as well.

Cylinder head without oil

Another added benefit of the system set up at Empa is the choice of hydraulic fluid: instead of using oil as usual, a water-glycol mixture, i.e. engine cooling water, is used. This makes the cylinder head completely oil-free, which allows the use of a cheaper engine oil with extended change intervals and less catalyst-poisoning components.

As part of the "FlexWork" project funded by the Swiss Federal Office of Energy (SFOE), the new valve train was put into operation in a VW 1.4l TSI engine. Running on an Empa's engine test bench for several months the valve train has already flawlessly survived many millions of cycles.

Moreover, the valve train is suitable not only for combustion engines, but also for other "breathing machines", such as compressors or expansion machines, which become more flexible and efficient. //



Empa has developed an innovative, electrohydraulically actuated valve train for internal combustion engines, which enables completely free adjustment of stroke and timing, while at the same time being robust and cost-effective. The new technology saves up to 20 percent fuel.

Medical sensors made of nanocellulose

Dr Gilberto De Freitas Siqueira, gilberto.siqueira@empa.ch

Empa researchers, together with colleagues from the Simon Fraser University in Canada, are developing flexible, biocompatible sensors made of nanocellulose, which can be applied to the skin. The 3D-printed analysis chips made from renewable resources will monitor health parameters such as the concentration of ions including calcium, potassium and ammonium.

A wood-based gel

Nanocellulose is a cheap, renewable raw material that can be obtained in form of crystals and fibers, for instance from wood. However, the gelatinous nanosubstance no longer bears any resemblance to the original appearance of a tree. Other sources for the novel material are bacteria and algae as well as residues from food production. This means that nanocellulose is not only easy and sustainable to extract, it also exhibits mechanical properties that make the gel very interesting for materials scientists to develop new composite materials. And because the material is biocompatible, it is particularly suitable for biomedical research.

To produce chemical sensors, nanocellulose is used as an "ink" in a 3D printing process. The sensors are electrically conductive, as the ink is mixed with silver nanowires to form a three-dimensional network. To enable further analysis of the recorded data, the sensor sends them to a computer for processing. Altogether, the tiny "biochemistry lab" is just half a millimeter thin.

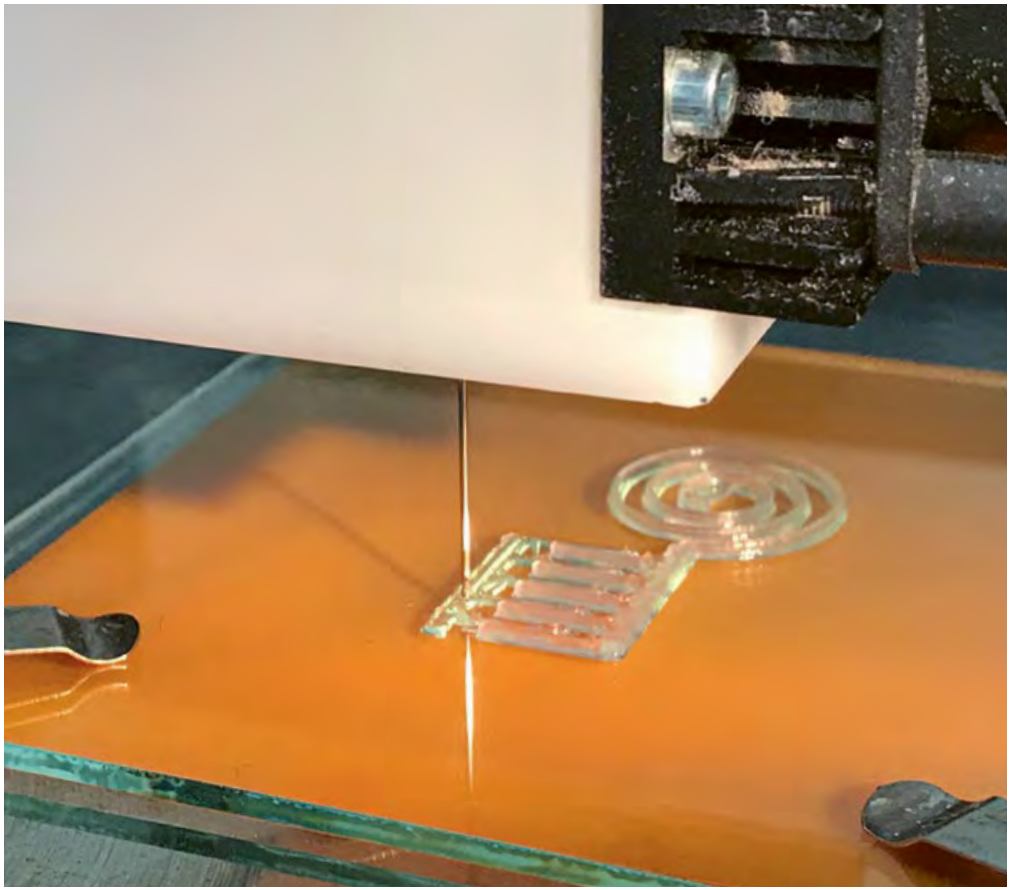
While the current sensor specifically and reliably measures ion concentrations, the researchers are already working on version 2.0. To ensure that the sensor is not only biocompatible, but also biodegradable, the silver particles are to be replaced by another conductive material, say, on the basis of carbon compounds.

A flexible motion sensor

Another nanocellulose-based sensor that can be worn as an insole in shoes is being developed in parallel. Within the D-Sense project, Empa is collaborating with researchers from EPFL, ETH Zurich, the Centre Suisse d'Electronique et de Microtechnique (CSEM) and the Centre hospitalier universitaire vaudois (CHUV). D-Sense is one of the projects funded within the ETH Domain's Strategic Focus Area "Advanced Manufacturing". The aim is a 3D-printed, multi-layered wearable sensor that sits snugly on the skin. Among other things, the foot sensor measures mechanical parameters such as load, pressure and the effect of force, which can be used to precisely analyze the movements of joints. //

1
A 3D printer is used to apply the nanocellulose "ink" to a carrier substrate. Silver particles make sure the material is electrically conductive.

2
Empa researcher Gilberto Siqueira demonstrates a nanocellulose circuit fresh out of the 3D printer. After drying the material can be further processed.



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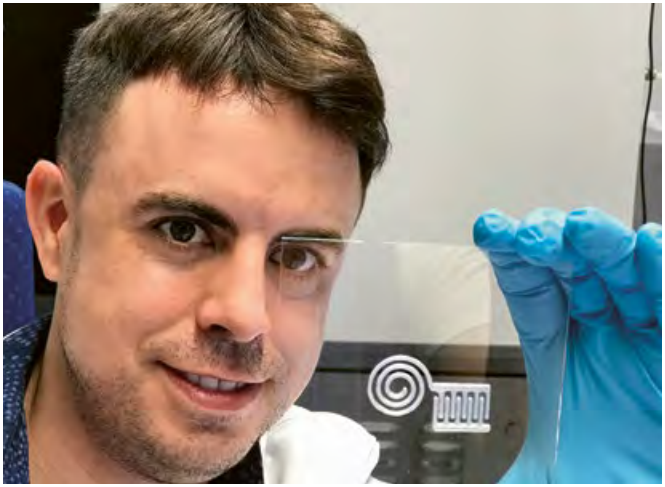


2

More added value thanks to new production technologies

Dr Lars Sommerhäuser, lars.sommerhaeuser@empa.ch

Jobs in industry account for a good 20 percent of the value creation and thus of Switzerland's prosperity. On average, a person working in industry generates almost CHF 100,000 in added value per year, which is about twice as much as a person working in the rapidly growing service sectors. To ensure that our average income and purchasing power do not fall, we thus have to preserve jobs in industry in Switzerland.

Use it – or lose it!

Moreover, we are constantly developing new and innovative technologies for manufacturing products in Switzerland. However, we can only maintain our technological leadership if we apply these newly developed technologies ourselves, i.e. within Swiss industry. This is because, as a rule of thumb, manufacturing technologies are developed further at those places where they are being used. This is another reason why we need jobs in industry in our country.

True to its motto "Empa – The Place where Innovation Starts", Empa develops materials and processes that are needed for new and innovative manufacturing technologies; but the institute goes even further: together with partners from industry, it wants to demonstrate that new technologies not only work in the laboratory, but can also be upscaled and successfully used in industrial production. Technology transfer centers take central stage in this. They install and operate pilot plants, which, although they only churn out small quantities, already use industrial production processes and standards in contrast to their lab-scale predecessors. Empa's Coating Competence Center in Dübendorf, in operation since 2016, is one such technology transfer center. But it takes more than just one center in Switzerland.

A center for 3D printing of implants

In 2019, Empa launched an initiative on behalf of the Swiss government to establish a network of Advanced Manufacturing Technology Transfer Centers (AM-TTC) throughout Switzerland. As part of the initiative, two new technology transfer centers have already been opened in 2019 as public-private partnerships with financial support from the ETH Board. One of these, the Swiss m4m Center for 3D-printed medical implants in Bettlach in the canton of Solothurn, was founded by Empa together with three partners from science and industry. In the meantime, more than 30 additional partners have joined. With financial support, in-kind services and know-how, they are helping to set up a pilot production facility for medical implants at the Swiss m4m Center.

The Center and its partners want to take 3D printing to a level where patient-specific, innovative implants can be developed and manufactured quickly and cost-effectively. The aim is to improve patient treatment and care without compromising on quality or reliability. Therefore, the center will qualify and validate all development and manufacturing steps and integrate them into a quality management system certified according to ISO 13485.

At the same time, the center has the task of making 3D printing technology accessible not only to large medtech companies but also to SMEs. This is an important factor for Switzerland as an industrial site with its numerous SMEs in the field of medical technology in order to ensure that Swiss companies can remain competitive in the future. //

A 3D-printed reinforcement plate to hold an artificial acetabulum cup in case of complex pelvic fractures. (Photo: Swiss m4m Center)

A beacon for the way into the future

Reto Largo, reto.largo@empa.ch

NEST has received another groundbreaking addition in 2019: like a gigantic sky lantern, the latest unit DFAB HOUSE floats on the top floor of the modular research and innovation building. In NEST, researchers and companies work together to realize new ideas in real construction projects. New types of construction processes are applied, new technologies and materials are used – for the construction of apartments and offices, which will be inhabited and used on a daily basis once they are installed in NEST.

DFAB HOUSE was inaugurated at the end of February 2019 in the presence of Federal Councillor Guy Parmelin and embodies the digital change in the building sector. The three-story "house" was not only planned completely digitally, but also – with robots and 3D printers – built largely digitally. For the construction of the unit, researchers from eight chairs at ETH Zurich – who joined forces within the framework of the National Center of Competence in Research (NCCR) "Digital Fabrication" – and their industrial partners transferred several digital construction technologies from the laboratory to real-world applications for the very first time. Digital technologies aim to make planning and building not only more efficient but also more sustainable.

New possibilities in lightweight construction

In the summer of 2019, construction of the seventh NEST unit began: HiLo aims to demonstrate the possibilities of lightweight construction. ETH Zurich is once again on board as a research partner. New formwork concepts, new lightweight flooring concepts and adaptive facade elements will be used.

At ehub (page 28) and dhub (page 30), several projects could be completed last year; they dealt with, among other things, the use of artificial intelligence (AI) in the control and regulation of building technologies as well as with combining live data and digital models to improve the planning process. At the Water Hub, Eawag researchers worked intensively on activated carbon filters as a second treatment stage in greywater treatment. The aim is to remove organic matter. In addition, a first copy of the new NoMix toilet "Save!" was installed at NEST in late 2019. This allows urine to be collected and treated separately.

Focus on know-how transfer

Besides work on the new units and numerous research projects therein, the transfer of know-how as well as networking again played a major role in 2019. Well over 10,000 visitors were inspired by NEST on guided tours or at events. At expert seminars – for instance, on the subject of circular economy – construction experts learned how the ideas implemented at NEST could also find their way into their own everyday working experience. A number of new partners joined NEST who are involved in existing units as well as in upcoming ones. The concept of the "Solar Fitness & Wellness" unit, for example, met with the interest of several large hotel and wellness operators with whom cooperation agreements are currently being set up.

Three (further) awards

In 2019, NEST was awarded three prizes. At the beginning of the year, the Swiss Federal Office of Energy (SFOE) awarded NEST the special "Transition" prize at the Watt d'Or awards ceremony. This was followed in June by the Building Award in the R&D category. And finally, the NEST unit Urban Mining & Recycling was among the winners of the international competition "beyond bauhaus – prototyping the future". The concept of closing materials cycles in the construction sector prevailed against around 1,500 applications from 50 countries. //

The NEST unit DFAB HOUSE at night. Photo: Roman Keller

Step by step to more hydrogen filling stations

Adrian Gonzalez, adrian.gonzalez@empa.ch

Hydrogen mobility in Switzerland is picking up speed. An important milestone for this was laid by Empa's mobility demonstrator, move, which opened in Dübendorf a good four years ago with the support of the Swiss Federal Office of Energy (SFOE) and various industrial partners, and has been continuously developing ever since. The aim is nothing less than the decarbonization of mobility – thanks to renewable electricity, hydrogen and synthetic fuels such as methane.

Supported by the SFOE, H2 Energy and Hyundai, the first two 700-bar hydrogen fueling stations for passenger cars in Switzerland have been built in recent years; the first one at move at the end of 2016, followed shortly thereafter by the second one in Hunzenschwil in the canton of Aargau, built by Coop and H2 Energy.

Goal: a nationwide network of hydrogen gas stations

The construction and pioneering operation of these two hydrogen-fueling stations were followed by various initiatives to expand hydrogen mobility in Switzerland. Hyundai, for example, announced that it would deliver a total of 1,000 fuel cell trucks to Switzerland in the coming years. Moreover, the "H2 Mobility Switzerland" association was founded, which is advised by H2 Energy. Its goal is a comprehensive network of hydrogen fueling stations throughout Switzerland. The findings from the first years of operation of the two hydrogen filling stations are of great benefit for the development of this network. Questions have arisen at national and international level regarding the calibration and quality measurement of hydrogen fueling stations. As part of a European project, the Swiss Federal Institute of Metrology (METAS) has, therefore, developed a new calibration device and tested it at the H_2 fueling station of move. In parallel, Empa has carried out detailed investigations of the flow behavior and temperature distribution during refueling of compressed H_2 gas cylinders. The results will help to further optimize the refueling process.

Guidelines for approval procedures

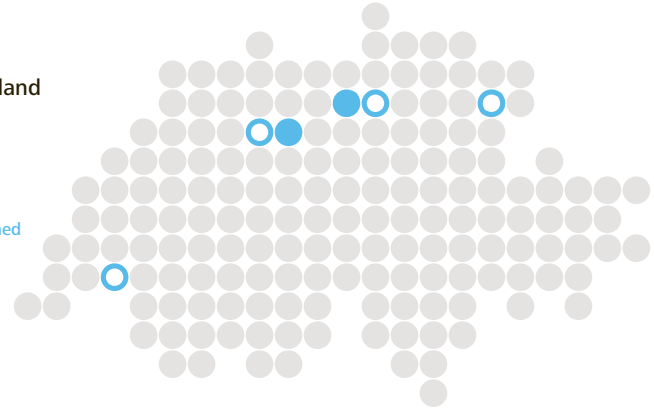
The approval process for hydrogen fueling stations is highly complex, and there is little experience in Switzerland to date – both on the part of plant planners as well as regulatory authorities. Therefore, Empa, together with the relevant expert bodies and regulatory authorities, has drawn up a guideline for the construction of hydrogen fueling stations, which was recently published by the Swiss Standards Association (SNV) as "Swiss Guideline SNG 10000:2019". The guideline provides a step-by-step breakdown of which authorities and organizations are to be involved in the approval process in Switzerland and what needs to be taken into account during planning and construction. It also provides an overview of the relevant national and international laws, guidelines and standards. //

In move at Empa in Dübendorf, a hydrogen fueling station is in operation since 2015.

H_2 FILLING STATIONS in Switzerland

● FILLING STATIONS in operation
Coop, Hunzenschwil (AG)
Empa, Dübendorf (ZH)

○ FILLING STATIONS currently beeing planned
Agrola, Zofingen (AG)
Avia, St.Gallen (SG)
Coop, Crissier (VD)
Coop, Dietlikon (ZH)



Source: Association pro H_2 mobility Switzerland, October 2019

Cross-linking energy flows

Philipp Heer, philipp.heer@empa.ch

The energy system in Switzerland and throughout Europe is undergoing radical change. The political and social boundary conditions are changing rapidly, and at the same time, intensive research is being carried out into new technologies for supplying, storing and converting energy. Digitalization is making a significant contribution to bringing sectors that previously functioned independently of each other closer together and to making data available to optimize the energy performance of buildings, neighborhoods, cities and entire countries. The goal is nothing less than the decarbonization of our energy supply.

At Empa, the Energy Hub – or ehub for short – is dedicated to this goal. ehub is a research platform for energy management at a district level. It uses the Empa demonstrators NEST (page 24) and move (page 26) to couple and optimize energy flows in and between buildings with energy flows in mobility. With each new NEST unit, ehub receives a new "building" that will be integrated into the overall energy system.

But there is more: together with ETH Zurich and the Paul Scherrer Institute (PSI), the ehub team has launched the ReMaP project in 2019. ReMaP stands for "Renewable Management and Real-Time Control Platform" and is intended to bring together the existing demonstration projects of the participating institutions.

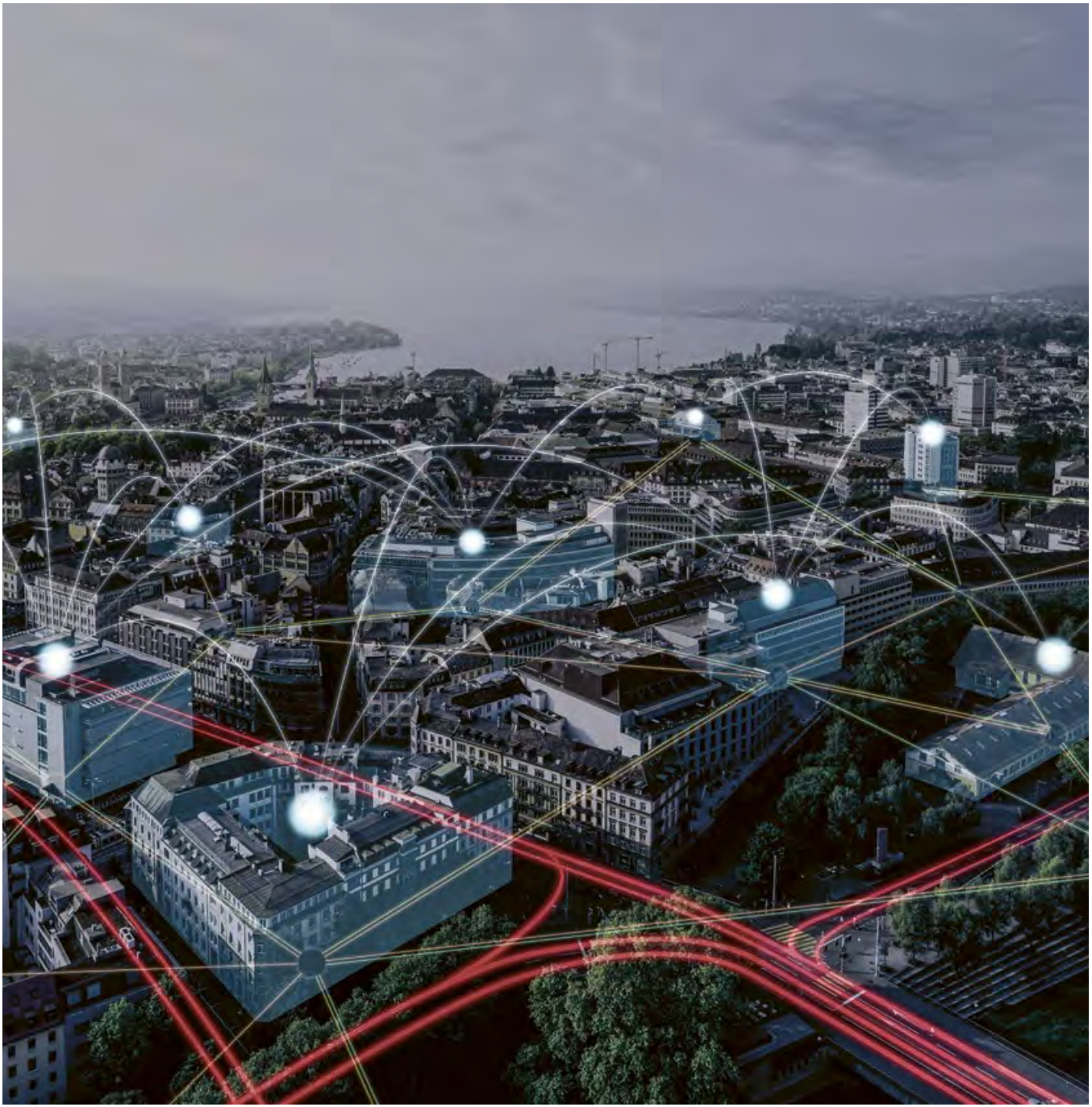
Less energy consumption thanks to AI

Several research projects at ehub could be completed in 2019. Among other things, the ehub team was able to demonstrate that the use of machine learning to control building technologies can lead to significant energy savings – an area of research that is also part of Empa's Digital Hub (dhub; page 30). More specifically, the researchers have developed a predictive cooling and heating control algorithm, which was first used in the NEST unit Urban Mining & Recycling in the summer of 2019. The apartment has two identical bedrooms. The temperature in both rooms should not exceed 25 °C during the day and 23 °C at night. A conventional thermostatic valve provided cooling in one room, while the experimental AI-based control system was at work in the other. The AI was fed with data from the previous ten months – and it knew the current weather forecast from MeteoSwiss. The result was extremely clear: The intelligent heating and cooling control system adhered much more precisely to the comfort specifications – and required around a quarter less energy.

In a next trial, this novel control system will now be used in an apartment building. At the same time, further development is underway: the heating controller will be coupled with the battery of an electric vehicle, which will act as a flexible storage unit. The ehub team is also looking into the question of how the various energy requirements can be coordinated with each other in other projects. Together with the start-up Aliunid, the researchers are investigating how flexibly a neighborhood can deal with fluctuating energy in order to serve the entire energy network.

Exchange between research and industry

In addition to regulatory changes, the transformation of our energy system will depend heavily on how new technologies and systems are accepted by industry and brought to market. The ehub team considered this fact in 2019 by organizing the symposium "Decarbonization of the energy system". Around 120 experts from industry met with Empa's energy researchers in July. //



The energy system of the future interconnects technologies, energy sources and sectors. Image: iconaut

Understanding digital transformation together

Reto Largo, reto.largo@empa.ch

The Digital Hub (dhub) is the latest demonstration platform on the Empa campus in Dübendorf. It represents the digital level of the other demonstrators, NEST (page 24), move (page 26) and ehub (page 28), and virtually links buildings, mobility and the energy system. The data from the three areas will be available cross-sectorally and in real time and provide the basis for developing and validating new products and services for smart cities and communities.

Like the other demonstrators on the Empa campus, dhub is to be seen as a platform, on which companies, together with academic researchers, can implement and further develop new digital ideas for the first time in a real-world environment and without risk. Autodesk Research, for instance, used this opportunity last year to take its Dasher 360 product further. The software links 3D models with live data, which, in the NEST example, is generated by more than 700 sensors and actuators. This provides the building operator with a better basis for decision-making and enables him to take more targeted measures to optimize the system controls or to maintain the building. Autodesk integrated NEST into the globally available demo version of Dasher 360 and presented it at numerous national and international conferences.

Consistent language and methodology

The "Building Digital Switzerland" initiative also uses the digital NEST model. The aim is to establish a common methodology for the digital planning and operation of buildings based on specific application scenarios. The primary aim is to achieve a uniform understanding of the processes and a common language throughout the entire construction and real estate industry. The 3D model will also be used for the construction of future or the conversion of existing NEST units. In the case of the HiLo unit, construction of which started in summer 2019, all line pipes will be prefabricated using the new model for the first time. This allows a faster and more cost-effective construction process. Bouygues Energies & Services Switzerland is a partner in this area.

With the same partner, another major challenge in the construction sector is being addressed using the example of the HiLo construction site: cooperation in decentralized teams. With a so-called BIM Room (Building Information Modelling) near the construction site and other digital aids directly on the construction site, seamless digital planning and execution should be made possible.

Optimizing operations through machine learning

Many projects in dhub are closely intertwined with activities in ehub (page 28). Digitization opens up completely new possibilities, particularly in the control of energy flows. The constant availability of both historical and current data and the use of AI, for example, pave the way for adaptive control systems. Using the ehub infrastructure, Empa researchers have carried out several projects in recent years to successfully optimize operations using machine learning. //

Live data in a 3D model: in the virtual NEST, the data from over 700 sensors and actuators are available in real time. Image: Dasher 360

© Marco Zanoni

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.

eMaterials science at the nanoscale: the fascination of the limit

Dr Pierangelo Gröning, pierangelo.groening@empa.ch

One nanometer – the 0.000,000,001th part of a meter or just the length of six carbon-carbon bonds – is the scale, on which modern materials science looks for new physical effects or strives to understand, shape and improve the properties of materials in more detail. Eventually, research in the nanometer range means working with atomic precision, whether in synthesis or in characterizing the structure of materials.

Superfluorescence – made possible thanks to structural perfection

Fluorescent materials spontaneously emit light upon excitation by an external light source such as a laser. Superfluorescence is the term used to describe the behavior when different fluorescent emitters can be synchronized, resulting in a significantly stronger light emission. In order for this effect to occur, however, the emitters must meet certain requirements. In particular, the wavelength of the emission must be virtually identical; moreover, additionally a high coupling strength is necessary. Nanocrystals present ideal building blocks for superfluorescent materials. In physical terms, these are quantum dots and therefore fluoresce at a very specific wavelength – which depends on the size and shape of the nanocrystals. In order for superfluorescence to emerge, the nanocrystal assembly needs to be highly monodisperse, i.e. exhibit a very small variation in size, and to be strongly optically coupled too. This is exactly what a team of researchers at Empa and ETH Zurich led by Maksym Kovalenko in collaboration with the IBM research lab in Rüschlikon has achieved. They synthesized perovskite nanocrystals with an edge length of 9.5 nm and a mean deviation of less than 5 percent (i.e. less than half a nanometer!). By means of self-organization, they assembled the nanocrystals into a mesoscopic "crystal", on which superfluorescent behavior could be observed for the first time in a solid. The controlled generation of superfluorescence and the corresponding quantum properties of the generated light could open up new possibilities in quantum informatics, quantum sensor technology and quantum-encoded communication.

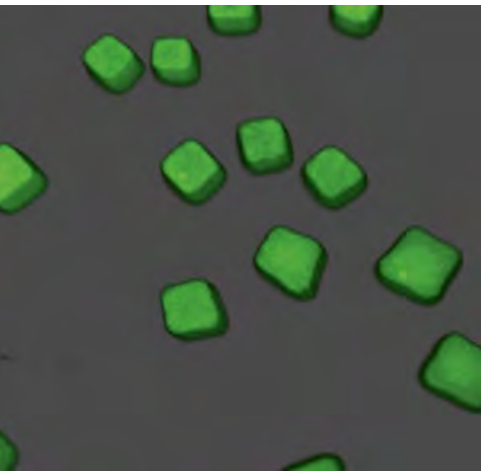
Ferroelectricity: when 20 picometers make the difference...

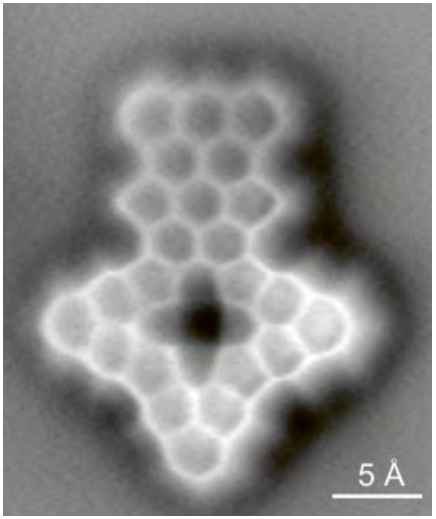
Ferroelectric materials exhibit spontaneous electrical polarization even without an external electric field. However, external electric fields can be used to manipulate and control the direction of the spontaneous polarization. Ferroelectrics generally have a high to very high relative permittivity (ϵ_r), which is why they are also of interest as thin films in semiconductor technology as so-called FeRAM (ferroelectric random access memory). In contrast to the DRAMs (dynamic RAM) widely used today, FeRAMs do not require permanent refreshing of their memory state. A special class among the many ferroelectric materials are the so-called 'unusual' ferroelectrics, in which secondary effects such as lattice distortions influence the primary ordering parameters of polarization. These secondary effects can strengthen and stabilize the ferroelectric state. Hexagonal yttrium manganese oxide ($YMnO_3$) is such an unusual ferroelectric material whose secondary effects are caused by small geometric effects in the crystal lattice. An Empa team led by Marta Rossel, together with Nicola Spaldin's group at ETH Zurich, has investigated the ferroelectric behavior of $YMnO_3$ thin films and found that the phase transition temperature is strongly dependent on film thickness. While it is 986 °C for the bulk material, it is lowered to between 250 °C and 670 °C for layers of 10 to 100 nm thickness. The phase transition temperature, which decreases with decreasing layer thickness, can be attributed to the mechanical stresses in the layer

1

1
Superfluorescent crystals of perovskite nanocrystals ($CsPbBr_3$) excited with violet light at 405 nm wavelength. Figure: 3D confocal microscopic photoluminescence image (ETH Zurich; ScopeM)

2
Non-contact Atomic Force Microscope (nc-AFM) image of a porphyrin-nanographene hybrid structure ($C_{38}H_{18}$): an AFM tip that had been functionalized with a single CO molecule can drastically increase resolution – and renders not only individual carbon atoms but also atomic bonds visible. (5Å = 0.5nm)





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induced by the deposition process. In the context of this finding, which is important for technological applications, the researchers have also investigated the structural changes during the phase transition. Using high-resolution transmission electron microscopy (TEM), they were able to prove that the phase transition from ferroelectric to paraelectric is caused by a (very) small disorder effect of the yttrium atoms. In the paraelectric phase, the yttrium atoms are no longer ordered at their lattice points, but are shifted stochastically by 20 picometers (= 0.02 nanometers) in the direction of the polarization. This observation of the order-disorder transition is an important step towards a better understanding of the behavior of unusual ferroelectrics.

A CO molecule for higher resolution

By entering the nanoscale in materials research, analytical methods for the chemical and structural characterization of materials have been developed further with the aim of achieving atomic resolution. Particularly in imaging methods such as TEM and AFM (Atomic Force Microscopy), further major progress has been made in the last decade. As described above, the latest generation of TEMs can be used to detect structural effects in the range of 20 picometers. In AFM, in addition to the continuous development of the instrument, it was a trick, first applied by researcher of the IBM research center in Rüschlikon, that led to a drastic improvement in resolution. The trick was to functionalize the already very sharp AFM tip with an individual CO molecule. Besides having an extremely well defined tip apex, thereby also the sensitivity of the tip to structural features could be strongly enhanced. With organic molecules as well as with graphene nanostructures, this "trick" works so well that it allows not only to image individual atoms but also atomic bonds, which leads to a breathtaking resolution. An AFM image of a porphyrin-nanographene hybrid structure can hardly be distinguished from a skeletal structure drawing used by chemists or generated in programs such as ChemDraw. Although they consist exclusively of carbon, such graphene nanostructures can even be magnetic, their electronic and magnetic properties however can dramatically vary by a single "misplaced" atom or bond. Currently, an Empa team is developing "carbon-only"-magnetic systems, where the use bond-resolving nc-AFM is indispensable to elucidate accurately the structure-magnetism relationship of these novel materials. //

Increasing the safety and comfort of our built environment

Dr Tanja Zimmermann, tanja.zimmermann@empa.ch
Dr Moslem Shahverdi, moslem.shahverdi@empa.ch
Dr Christoph Czaderski, christoph.czaderski@empa.ch
Dr Armin Zemp, armin.zemp@empa.ch

At Empa, research on the built environment ranges from developing new functional materials to the design of advanced systems and their integration into buildings and structures. Key issues at all levels are the minimization of the environmental footprint while still guaranteeing the same or better comfort and safety for the users, as the following examples illustrate.

"memory-steel" – Extending the life span of buildings

Buildings and bridges are in need of strengthening if their functionality changes, e.g. due to higher traffic loads, or if the structures are in bad conditions, e.g. due to corrosion. In several research projects, scientists at Empa's Structural Engineering laboratory, together with the Empa spin-off re-fer AG, developed a new strengthening method for reinforced concrete structures by using a new material called "memory-steel".

In the framework of an Innosuisse project, "memory-steel" reinforcements were used for shear strengthening of real-scale concrete T-beams. Results showed that the new strengthening method has a very high efficiency to strengthen existing structures. An important milestone for future market implementation was the first on-site application of the system by re-fer and SikaBau in the summer of 2019: reinforced concrete beams in the Kurtheater Baden were strengthened with U-shaped ribbed "memory-steel" bars embedded in a mortar layer (Figure 1).

In an ongoing SNF project, the bond behavior of ribbed "memory-steel" bars in cement-based mortar grout is investigated. The results could already be used for a unique strengthening application at the Jungfraujoch in the Bernese Alps. At an elevation of 3,466 meters above sea level, the Jungfraujoch connects the two 4,000 + meter peaks of Jungfrau and Mönch. Since 1912, the Jungfraujoch has been accessible to the public by the Jungfrau Railway. Due to an extension of the platform access, the existing vault needed strengthening in flexure in longitudinal direction. In late 2019, in collaborations with re-fer, WaltGalmarini AG, and B + S Ingenieure, ribbed "memory-steel"

Strengthening of a tunnel vault with ribbed "memory-steel" bars at the Jungfraujoch Railway: the bars are pre-stressed by heat. After the pre-stressing, the "memory-steel" bars are embedded in shotcrete mortar. Picture: re-fer, iStockphoto

bars were embedded in a sprayed mortar layer to strengthen a vault.

Less noisy freight trains thanks to novel FRP wheelsets

Fiber-reinforced polymers (FRP) show a significant higher strength-to-weight ratio (in fiber direction) resulting in superior mechanical properties compared to conventional materials in a wide range of applications. Railway noise is often an important source of annoyance for people living near railway tracks. The constantly growing demand in transport leads to an increasing number of people affected by traffic noise, both during the day and at night. In a project funded by the Swiss Federal Office for the Environment (FOEN) and carried out in cooperation with PROSE, Carbo-Link, and SBB Cargo, the feasibility of using FRP composite materials to manufacture a train wheelset, which potentially generates less noise, was studied. In addition to noise reduction, such an FRP wheelset would lead to weight savings, which brings associated benefits, e.g. high-speed, reduced power consumption, lower inertia, less track wear and the ability to carry greater payloads.

3D finite element models were developed to analyze the structural integrity of an FRP wheelset. In parallel to the structural assessment of the wheelset, the acoustic emission of the designed FRP wheelset was compared to a conventional steel wheelset. The results showed that the designed FRP wheelset was able to withstand maximum permissible mechanical stresses, is about 40 percent lighter than the conventional steel wheelset and could reduce rolling noise by about 2.8 dB(A) in comparison with a conventional steel wheelset. //

Sensor development for a sustainable future

Dr Brigitte Buchmann, brigitte.buchmann@empa.ch

1
A quantum-cascade laser spectrometer for sensing methane, mounted on a drone. This high-precision instrument is light, sensitive and fast enough to detect, quantify and distinguish greenhouse gas emissions from natural and man-made sources.

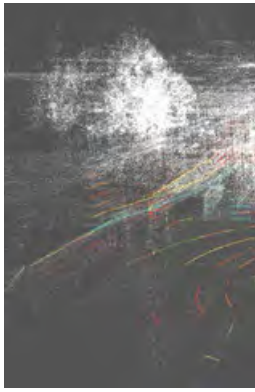
2
Visualization of the sensor data of an autonomous vehicle: this is how the car "sees" its surroundings on the Empa campus.

In order to achieve the 2 °C target of the Paris Climate Convention, we have to significantly reduce our greenhouse gas emissions. This requires completely new concepts and strategies. For instance, selective and extremely precise sensors, mounted on drones, can detect unknown, diffuse emissions and trigger appropriate technical and political reduction measures. Reliable sensors are also essential for future autonomous vehicles, on the one hand to ensure their safety, but also to reduce emissions. Empa researchers are providing the technical basis with innovative measurement technology, sensor systems and comprehensive data analysis.

Detecting methane sources

The use of unmanned aerial vehicles (UAV) as mobile platforms for the measurement of atmospheric trace gases provides valuable information on spatial and temporal variability at a level of detail that cannot be achieved by traditional, stationary measurement networks. Methane is of particular interest because it is the second most abundant anthropogenic greenhouse gas and plays a crucial role in the chemistry of the Earth's atmosphere.

Empa researchers developed a lightweight and robust laser spectrometer for the highly precise measurement of atmospheric methane concentrations. The analytical instrument is based on a quantum cascade laser and a circular, segmented multi-path cell with a total optical path length of ten meters. This innovative cell design is extremely compact, achieves minimal optical noise and guarantees excellent mechanical stability. Compared to traditional laser spectroscopy of trace gases in the mid-infrared, the dimensions, weight and power consumption of this sensor have been reduced by almost two orders of magnitude. The instrument weighs less than two kilograms and still achieves a precision of less than one ppb (at typical methane concentrations in ambient air of about 2,000 ppb). State-of-the-art electronics allow the determination of several thousand high-resolution absorption spectra per second, wireless data transmission and real-time visualization of the measured data. The instrument has already been used in numerous field experiments on a commercial drone in various European countries, illustrating the potential of this unique instrument for identification, characterization and quantification of natural and anthropogenic methane sources.



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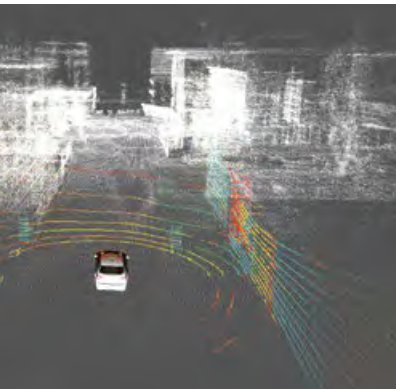


Making self-propelled cars safer and more sustainable

Self-propelled automated vehicles could provide a better and more sustainable urban mobility system and help to prevent or reduce serious road accidents. Besides the actual motion planning of the vehicles, sensor technology plays a crucial role. In self-propelled cars, they take over the function of the driver's eyes. Like the human eye, sensors are influenced by external conditions such as backlighting, darkness, materials, surfaces and weather, but are also subject to technical influences such as dirt, malfunctions, aging or damage. Finally, (intentional) manipulation by third parties should also be prevented.

In collaboration with a number of partners – the Swiss Federal Roads Office (FEDRO), the Swiss Competence Center for Energy Research (SCCER) Mobility, Innosuisse, ETH Zurich, the Swiss Federal Institute of Metrology (METAS), the Touring Club Switzerland (TCS) and the companies AXA Versicherungen, Orthotec and Embotech, a start-up of ETH Zurich – Empa researchers have successfully carried out initial field trials on the Empa campus using a Lexus. The car is equipped with a radar, a lidar, a GPS, a digital camera and a data acquisition system – which allows investigations of the real-world behavior of all sensors, especially under rapidly changing environmental conditions. The use of new digital data evaluation methods enabled an efficient analysis of large amounts of data. The Empa team intends to use these field tests to develop the requirements for sensors for self-propelled cars. //

Energy research – only facts lead to viable solutions

Dr Peter Richner, peter.richner@empa.ch
Urs Elber, urs.elber@empa.ch

Climate change is becoming increasingly obvious. This also raises public awareness about the fact that our energy system has to change. A system that has developed and consolidated over decades – and now needs to be fundamentally redesigned. This is a gigantic task, as there are sometimes conflicting information and opinions in circulation that make decision-making difficult.

This is where research has to provide reliable facts. However, these facts must first be elaborated. The energy system is so complex that, in addition to the development of new materials, technologies and methods, it also requires systemic analyses. The facts-based conclusions must then be communicated through various channels to science, politics, business and, last but not least, the general public in order to involve all societal stakeholders.

Knowledge exchange between research and industry

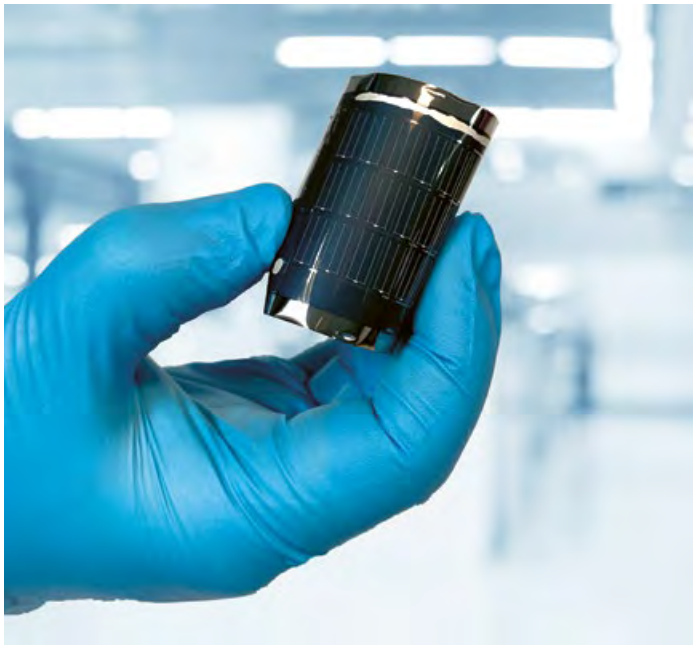
Empa has undertaken a great deal in this direction in 2019. In numerous public lectures, presentations, workshops and courses and at many external events, Empa researchers communicated research results and their implications far beyond the realm of academic research, thus making a significant contribution to the dissemination of these findings. A special event was the Empa symposium "Energy and Decarbonization" in July. Lectures from industry and research and joint workshops made a significant contribution to the transfer of research results to industry. Conversely, feedback from the business world helps Empa to make the creativity of its researchers available to society.

A systemic analysis published last year, in which the effects of an increasing electrification of building heating and mobility were investigated, showed the consequences of replacing fossil fuels with electricity-based technologies. Based on real-world data, it shows that a pure transformation from fossil fuels to electricity alone will only slightly reduce our CO_2 emissions. It also shows that an increased use of photovoltaics will mean that large amounts of electricity have to be imported and exported. The study was based on the assumption that 50 percent of possible roof areas in Switzerland would be equipped with solar cells. A follow-up study is now underway to analyze the effects of a smart consumption, grid and storage management in light of the expected

1

1
A recent Empa study assumes that 50 percent of the possible roof surfaces in Switzerland will be equipped with solar cells.

2
Flexible solar cells with unprecedented efficiency: Empa's Laboratory for Thin Films and Photovoltaics has – once again – broken its own world record.



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surplus energy production and consumption – and to show what new options, if any, this will open up.

World records from Empa's labs

One thing is clear, though: without solar energy, the transition cannot succeed. Thus, developing technologies to harvest this energy is essential. In 2019, an Empa team achieved (yet another) success and further improved its previous record for energy conversion efficiency. The researchers improved the energy conversion efficiency of flexible so-called CIGS solar cells to 20.8 percent, 0.4 percent above their previous record value. The technology of choice is copper indium gallium diselenide (CIGS), which enables the production of flexible, extremely lightweight solar cells on polymer films. Light, cheap, efficient – this should make our solar future a great deal more real. //

Health solutions for growing societal demands

Prof. Dr Alex Dommann, alex.dommann@empa.ch

Excellence in materials science and technology leverages novel materials and systems for health and performance, which is meeting a growing need of our society. Novel materials can be beneficial for a plethora of health and health care innovations in and on the human body. Novel precision medicine concepts are increasingly integrated into clinical routine and will shape medical device development in the future. Within its Research Focus Area "Health and Performance" and with strong links to clinical partners, Empa develops and carries out cutting-edge research on new materials and systems to protect and support the human body under different environmental settings and in various health conditions. To achieve this, scientists need to understand and steer materials-biology interactions on the level of biomolecules, bacteria, human cells and tissues from nano- to macroscale using state-of-the art and specifically designed analytical equipment.

All activities rely on a comprehensive and holistic view, from single molecules to complex body functions, and share a common view and expertise in material synthesis, material processing, bioanalytics, computational modeling and simulations, bioinformatics, imaging and life science.

Wearable diagnostics

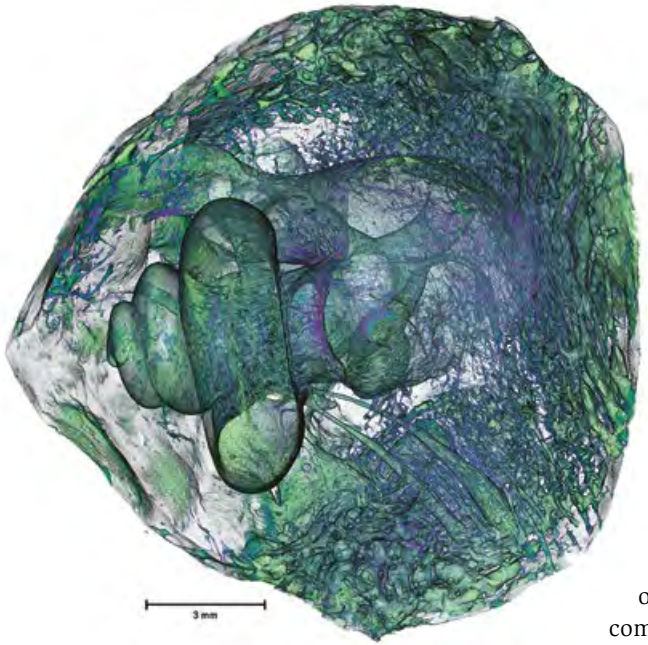
Long-term monitoring is a promising approach for the early diagnosis or even prediction of future health problems. However, the acceptance of new sensor systems by patients is highly dependent on ease of use and wear comfort. Moreover, the perceived usefulness of such devices and thus the accuracy of the diagnosis are also key elements for patients' acceptance. Therefore, sensing systems have to meet clinical-grade accuracy. Empa researchers are developing wearable systems for long-term and non-invasive monitoring of different physiological functions in collaboration with clinicians and health professionals.

In cooperation with the Kantonsspital St.Gallen, Empa researchers have, for instance, clinically validated a textile ECG sensor on 240 patients and showed that patients can also use this system conveniently at their homes for the diagnosis of sleep apnea. Several industrial partners are currently commercializing the system, including Nahtlos, an Empa spin-off. The company will bring the ECG sensor system to market for the monitoring and diagnosis of cardio-vascular problems, thanks to financial support of the Startfeld Foundation.

Empa also explores various sensor architectures enabling a direct monitoring of physiologically relevant analytes. For instance, potentiometric sensors and dedicated electronics have been developed to support the early detection of pre-eclampsia in pregnant women. This technology is currently implemented by MOMM Diagnostics, another Empa spin-off, to develop a point-of-care diagnosis for an improved and much more precise monitoring of high-risk pregnancies with the potential to avoid unnecessary hospitalization.

Individualized health solutions

In order to develop individualized health solutions, Empa researchers are anticipating transformative material designs and concepts by combining in-depth expertise in materials science with new trends in biomedical research such as omics, sensing and imaging analysis for a comprehensive and holistic understanding of the interactions of cells, tissues or the entire human body with novel materials intended for biomedical applications. Current activities in nanomedicine include theranostic magnetic blood purification for the treatment of sepsis and nanoparticles-based tissue glues for an integrative wound treatment.



The otic capsule containing the cochlea, the human inner ear responsible for converting sounds from mechanical vibrations into electrical signals that are carried to the brain by the vestibulocochlear nerve. The anatomy is reconstructed in a 3D model from micro-tomographic sections acquired with a nominal resolution of 12µm.

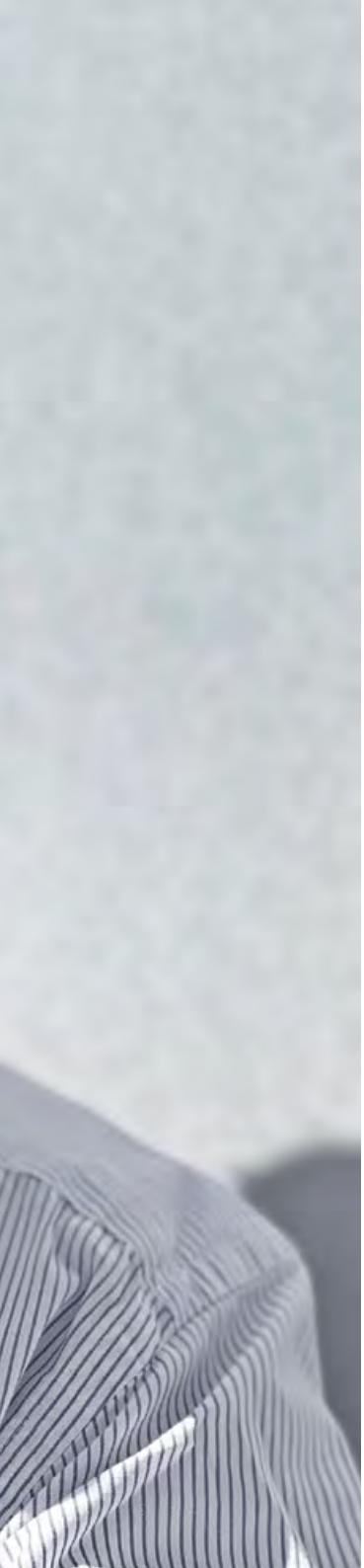
Implants and biointerfaces

Materials that steer the response of tissues and cells for regeneration or the replacement of tissue function (as known for many implants), or which can prevent the infection of implants or devices are another focus of Empa's research activities. The need for instructive material concepts for medical therapies are manifold, and Empa's activities range from materials for bone or cartilage repair and regeneration, patient-specific implants fabricated through 3D printing and other Advanced Manufacturing (AM) technologies, materials for soft tissue integration or regeneration all the way to materials that steer and accelerate wound healing. The highly interdisciplinary research teams leverage the expertise from all fields of materials science and combine it with biological competence to further the understanding of responses at the interface of materials and biology. The biointerface of any medial material in contact with body fluids, human cells or tissues as well as the mechanical properties of materials determine its fate, efficacy and success.

Monitoring treatment response

Analytical and imaging techniques, combined with advanced ICT tools, allow the collection and analysis of large amounts of health-related data and will optimize the medical care by steering therapeutic decisions, monitoring disease progression and/or the response to a certain treatment, which is the ultimate goal of precision medicine. To this end, Empa develops innovative multi-scale analytical and imaging techniques for diagnostics and monitoring that can be transferred to clinical practice and integrated into the clinical workflow.

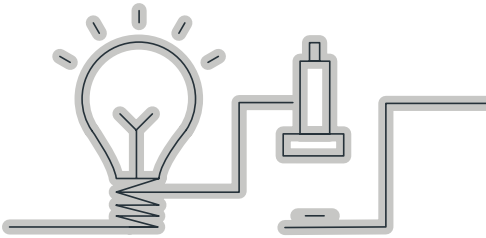
In placenta research, the localization and the nanostructural characteristics of the mineral deposits in placental tissues are studied at unprecedented resolution, which paves the way for investigations focused on the identification of potential markers for disease risks in a clinical setting based on atypical mineral fingerprints in placental tissue. //



From Research to Innovation

Top-flight 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 concrete problems or bringing technical specialists up to the state of the art – with almost 600 highly qualified scientists and top-class infrastructure, Empa is the place to be.

Innovation that matters



Marlen Müller, marlen.mueller@empa.ch

In a rapidly changing economic and social environment, innovative strength and flexibility are crucial for both SMEs and larger companies. Empa supports its industrial partners in the development of innovative and sustainable solutions, materials and systems in order to successfully cope with technological change and an increasingly tougher international competition. An efficient technology transfer helps to ensure that research results are available to industry as fast as possible and can be applied commercially.

In 2019 Empa has launched around 200 new research projects with partners from industry. In addition, it has filed patent applications for twelve inventions and concluded twelve new license and technology transfer agreements with industrial partners.

Insulation with waste paper

In a project funded by Innosuisse, Empa scientists, together with Isofloc AG, have developed an insulating material based on waste paper, which is suitable for prefabricated wooden building elements, even in multi-story wooden houses, and which provides effective protection against fire. The new insulation material contains little chemistry, but all the more technical know-how; the binder is a cellulose flake structure that is harmless to humans, animals and the environment. The waste paper fibers are automatically blown into a cavity until it is completely filled. Isofloc estimates that the new insulation will be on the market in a year's time, together with the appropriate injection machines. Mountains of waste paper will then be turned into a valuable insulation material that not only helps to save large amounts of fossil fuels during production and use, but can also be used industrially as the only loose insulation material that is effective in protecting against fire.

Native "tropical wood"

Like many tropical woods, ebony is one of the endangered species, the use of which, for instance in instrument making, is problematic. Despite strict trade regulations, ebony stocks are declining rapidly. The start-up company "Swiss Wood Solutions (SWS)", founded by researchers from Empa and ETH Zurich, is developing processes for modifying Swiss woods in such a way that they exhibit the properties of threatened tropical woods such as ebony or grenadilla. In this process, native sycamore maple from sustainable forestry is cut, soaked in an

2

1

1
A raw material made from waste paper is turned into a solid, fireproof insulating material using an environmentally friendly binder.

2
Jazz guitar with fretboard (fingerboard), hand rest and bridge made of Sonowood maple, built by Mauro Bodio Guitars. Picture source: bodio-guitars.com

aqueous solution, dried and compressed using hot-pressing techniques. Wood compressed in this way now exhibits properties that are essential to instrument making and has already been used successfully for violins, guitars and clarinets, as well as for training swords for the Asian martial art of Budo. Now trial production is to be expanded. In November 2019, SWS put into operation the first industrial press in Empa's business incubator glaTec in Dübendorf. In close cooperation with Empa, SWS is now optimizing the production process for wood modification with the aid of neural networks and machine learning as part of a joint Innosuisse project.

High-performance sleepwear

As part of an Innosuisse project with the Lucerne University of Applied Sciences and Arts (HSLU) and the start-up company Dagsmejan, Empa researchers have investigated textiles for pyjamas in order to improve sleep comfort and thus enhance sleep quality. The main focus is on thermoregulation of the human body during sleep. If the body core temperature, which drops by up to 1 °C during the night, is affected by external thermal factors, this has a major impact on sleep quality and thus on physical and mental recovery. As part of the project, the researchers initially identified optimal textile combinations, yarn technologies and knitting techniques and used these to develop various pyjamas that take into account the individual preferences ("warm or cold sleepers") of potential customers. In 2018, Dagsmejan successfully launched the new sleepwear on the online market; the company now has a large distribution network and customers in over 40 countries. //

New technologies with an economic impact

Mario Jenni, mario.jenni@empa.ch
Peter Frischknecht, peter.frischknecht@empa.ch

In Empa's Business Incubators, a total of 50 start-ups with 334 employees were supported last year from the initial business idea all the way through to market entry.

Drone kites harvesting wind energy

In 2019, 14 start-ups were hosted in the Business Incubator glaTec, including the Empa spin-off MIRO Analytical Technologies, which was included in the business incubation program of the European Space Agency (ESA) and was also nominated for the pioneer prize of the Zürcher Kantonalbank (ZKB).

The early-stage project Sympheny successfully mastered the first two rounds of Venture Kick, Switzerland's largest start-up support program, which awards up to CHF 150,000 in three rounds.

Swiss Wood Solutions, a spin-off of Empa and ETH Zurich, has put a new 30-tonne wood press into operation at glaTec to convert wood from local forests into high-density wood – urgently needed for the manufacture of musical instruments to replace endangered tropical wood.

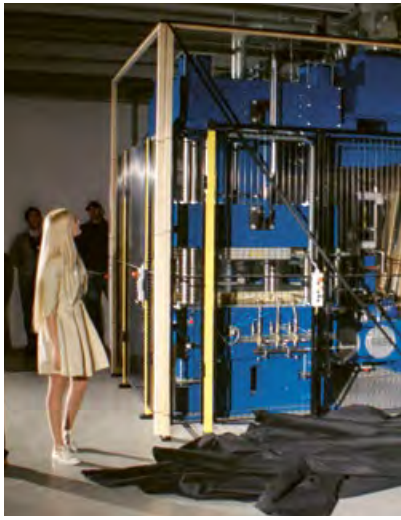
Wind turbines are not necessarily needed to harvest wind energy – the drone kite of Empa's spin-off TwingTec manages this task much more elegantly by "harvesting" wind energy at high altitudes. Last fall it succeeded for the first time in taking off automatically, generating electrical energy during flight and landing again.

Successful company launches

St.Gallen-based Business Incubator Startfeld offered its 1,000th consultation for neo-entrepreneurs in 2019. The joint incubator of Empa, the University of St. Gallen and the University of Applied Sciences St. Gallen was launched in 2010. Altogether, these consultations resulted in a total of 100 funded projects. Startfeld itself invested around CHF 4.1 million in these start-ups in the form of seed money; more than CHF 55 million was chipped in by private investors. This created more than 650 jobs.

The Empa spin-off Seamless was selected as a participant in the national Kickstart Accelerator Program in the Health category, and MycoSolutions, another Empa spin-off, was a finalist in the Startfeld Diamond competition 2019.

The partnership between Empa and the Cantonal Hospital St. Gallen (KSSG) is also developing extremely well. In May 2019 the KSSG spin-off Stromal Therapeutics received funding from Startfeld. The start-up company develops drugs to improve diagnosis, treatment and prevention of various types of cancer as well as chronic inflammatory diseases by manipulating so-called stromal cells. //



2

1
Together with the Kantonsspital St. Gallen Empa researchers have clinically validated a textile EKG sensor on 240 patients. It has been shown that patients can use this system conveniently at home for the diagnosis of sleep apnea.

2
Oliver Kläusler, CEO of Swiss Wood Solutions, unveils the 30-tonne press that transforms wood from domestic forests into high-density wood – urgently needed for the manufacture of musical instruments as a substitute for endangered tropical wood. The Violinist Anastasiya Petryshak (left) played for this occasion on a violin, where the fingerboard and tailpiece are made of Sonowood.

Empa Zukunftsfonds – research for the world of tomorrow

Gabriele Dobenecker, gabriele.dobenecker@empa.ch

Through its "Empa Zukunftsfonds", Empa is funding research projects and promising talents who do not yet receive funding elsewhere: forward-looking ideas, which, once realized, can make a significant contribution to a more sustainable world. The Empa Zukunftsfonds allocates funds entrusted to it by companies, foundations, charities and individuals as donations and endowments. Empa has thus been able to initiate a number of research projects with these funds and with its own resources.

A wood-based glue for the restoration of art and cultural goods

If something is broken, it can be glued. It is as simple as that – at least in everyday life for "normal" materials and with the appropriate adhesive at hand. With artwork and cultural goods made of wood, things look quite different though. Countless wooden sculptures, panel paintings and altars in churches and castles around the world show cracks and fractures due to their age and their rather suboptimal storage conditions; all of these would have to be glued for restoration purposes.

Wood glues wood – this is the simple idea that should lead to optimized adhesives for the restoration of wooden artefacts. Cellulose structures, organized into fibrils and fibers by chemical forces, are the stable basic structure of every tree and plant. The aim of the project is the development, optimization and targeted use of these cellulose structures as aqueous adhesive suspensions for the gluing of wood artifacts. The interdisciplinary project, in which restorers from the Bern University of the Arts are working together with experts from Empa, was launched in early 2019 and is supported by the Gebert Rüf Foundation.

Tailor-made damping of vibrations and noise

It was a high-risk project the Empa Zukunftsfonds kick-started with an initial funding: are there materials, which have a high mechanical load-bearing capacity and at the same time, thanks to their internal structure, can dampen noise and vibrations? Without foam rubber, springs and shock absorbers?

In 2016, after three years of research, the proof was at hand: such materials do indeed exist. Thanks to model structures made of an aluminum alloy, which were produced for the first time using 3D printing, the researchers have since been able to further refine their method of damping noise and vibrations. In 2019, they were able to equip the crystals with additional properties they did not possess initially; the researchers incorporated small, rotating plates into the crystal structures, which are capable of converting oscillations along the longitudinal axis into torsional movements.

In the meantime, a first prototype has been developed in the lab that shows a possible application of these so-called phononic crystals: a window made of two Plexiglas plates, in which rotating discs in syndiotactic arrangement had been integrated. The size of the discs is tuned to the frequency of human speech. The idea behind it: if certain frequencies are filtered out, the spoken content becomes incomprehensible to any listener; the human brain can no longer assemble the acoustic information into a meaningful message. First tests in Empa's acoustics lab showed the potential of the idea: one can clearly see the speaking persons and also hear them in a muffled way – without understanding a single word. //

1
A functional model of chiral, phononic crystals is used for the measurement of vibrations. One possible application of phononic crystals is a "cryptography window" that distorts speech purely mechanically – without electronics or electricity.

2
Fire painting on lime tree with a continuous crack along the grain; fragment, artist and dating unknown, probably 19th century; currently at the Bern University of the Arts. Dimensions: 30 × 30 cm. Photo: Karolina Soppa.

1

2

All over the world

Prof. Dr Gian-Luca Bona, gian-luca.bona@empa.ch

Many research projects are international by nature; usually teams from numerous countries and with different scientific backgrounds work together in an interdisciplinary way. These days the lonely scholar, who follows a flash of inspiration in his chamber and revolutionizes science, is rather the exception. Thus Empa's network is spanning the globe and includes partnerships with researchers from almost 100 countries.

Empa attaches great importance to major projects and consortia funded by the EU; last year Empa researchers were involved in more than 70 EU projects, and only recently the "SeNSE" project, led by researchers at Empa, was launched, which is intended to develop the next generation of lithium-ion batteries. Empa is also the Swiss partner in the "SUNRISE" consortium, in which 20 institutions from research and industry from 13 European countries are involved with the aim of developing sustainable alternatives to fossil-based, energy-intensive production of fuels and basic products for the chemical industry, based solely on solar energy and generally available raw materials. At the beginning of 2019, SUNRISE was selected as one of only six project outlines to develop the basis for a new European large-scale research initiative similar to the previous flagship projects.

Pan-European networking also took place in the NEST research and innovation building (page 24), which has recently joined the European Network of Living Labs with more than 150 members. At the OpenLivingLab Days in Thessaloniki in September, NEST was formally welcomed to the network along with 19 other newcomers.

Institutional partnerships

In 2019, Empa has continuously expanded its network at the bilateral level and further intensified existing contacts. For instance, in July at the Europe-Korea Conference on Science and Technology in Vienna, Empa signed a Memorandum of Understanding (MoU) with the Korean Institute of Civil Engineering and Building Technology (KICT) with the intention of launching joint research projects in the field of intelligent buildings and sustainable use of natural resources and energy. Researchers from both institutes have already developed initial project ideas at a first workshop held during the conference.

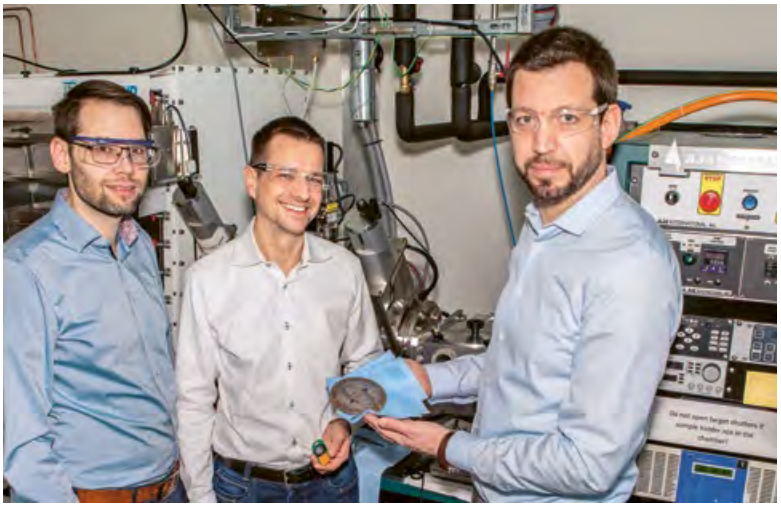
In October, Empa CEO Gian-Luca Bona was a guest at Empa's Japanese "sister institute", the National Institute for Materials Science (NIMS) in Tsukuba on the occasion of the annual NIMS Week. The conference also included an anniversary symposium at the University of Tokyo to mark the 20th anniversary of the open access journal Science and Technology of Advanced Materials (STAM), which Empa has published jointly with NIMS since 2014.

An international group of guests

Conversely, many foreign visitor groups found their way to one of the three Empa sites. In May, for example, a delegation from the cultural and creative industries in Hesse, led by Hesse's Minister of Economics, Tarek Al-Wazir, visited NEST and discussed with Empa Deputy CEO Peter Richner topics such as building in closed material cycles and how to reduce the consumption of resources in the construction sector.

In August a group from the Chinese electronics and mobile communications giant Huawei discussed with Empa CEO Gian-Luca Bona the possibilities of research cooperation in the field of sensors as well as the possibility of establishing a corporate research center in the greater Zurich area. There were also groups of visitors from Italy – such as

high-tech companies and start-ups from Calabria as part of the local "Calabria Valley" innovation initiative – and from South Tyrol. //



1
The EU-funded "SeNSE" project is coordinated by Ruben-Simon Kühnel, Stephan Fahlbusch and Corsin Battaglia (right). Battaglia is head of the Materials for Energy Conversion lab at Empa.

2
Tanja Zimmermann, member of Empa's Board of Directors, and KICT President Seung Heon Han with the signed Memorandum of Understanding (MoU), surrounded by representatives of both institutions. Photo: KICT

Doing science – and talking about it

Dr Michael Hagmann, michael.hagmann@empa.ch

Excellent science and innovative technological developments needs to be communicated. This is the only way knowledge and technology can be transferred from research labs to society, i.e. the general public and politicians. And it is only through a lively exchange and an open dialog with the researchers it is funding that society can ultimately judge whether the taxpayers' money is used in a meaningful way. Especially for a research institute such as Empa, this exchange is crucial, since it has set itself the goal of using its research to contribute to solving societal challenges, for instance in the energy and health sectors.

Demonstration platforms in the focus of public attention

Fortunately, interest in Empa among its stakeholders appears to be undiminished; thus Empa was once again able to welcome more than 15,000 visitors last year, whether on guided tours of the various Empa labs, at one of the numerous events at the Empa Academy, or at NEST and in Empa's other lighthouse projects (page 24 ff.). In addition to some high-ranking international delegations (page 52), the visitors again included numerous Swiss institutions, companies and associations, such as the Swiss textile industry, a delegation from the Swiss Army, the FDP women, the Swiss section of the Association of German Engineers and – at the opening of the NEST unit DFAB HOUSE – Federal Councillor Guy Parmelin (page 24).

Empa on the road

At the same time, however, Empa is also repeatedly reaching out to discuss topics such as a sustainable energy supply, innovative mobility concepts or resource-saving construction technologies. For example, Empa was present at the annual meeting of the Swiss car dealers association, at the General Assembly of the Swiss Gas Industry Association (VSG) and at Swissbau, which attracted close to 100,000 experts from the construction industry to Basel. Together with its partners at "Swissbau Focus", Empa organized several well-attended events on topics such as construction technologies for a circular economy, the use of drones in the maintenance of buildings and intelligent control of energy flows in future cities and districts.

Moreover, Empa CEO Gian-Luca Bona and his deputy Peter Richner were able to discuss the economic benefits of alumni from the ETH Domain's institutions, for example in the form of spin-offs, with some 60 representatives of Swiss politics at the World Economic Forum (WEF) in Davos. Among the interested guests at the WSL Institute for Snow and Avalanche Research (SLF) were Federal Councillor Parmelin, the State Secretary for Education and Research, Martina Hirayama, and the newly elected President of the ETH Board, Michael Hengartner.

Increased media coverage

The fact that Empa's research activities are of social relevance was also mirrored by the enormous interest shown by the media last year: close to 7,500 media articles in 34 languages reported on Empa's research activities, including almost 1,750 in print media and more than 230 radio and TV reports – more than ever before and a renewed (and surprisingly significant) increase over the previous year. //

1
Federal Councillor Guy Parmelin inaugurates the latest NEST unit, DFAB HOUSE.

2
Empa at Swissbau: Enrico Marchesi highlights the importance of building in the circular economy.

3
Peter Richner, Deputy CEO of Empa, talks about how to extend the lifetime of buildings and infrastructure at the WEF in Davos.

Successful women at Empa

Dr Marianne Senn, marianne.senn@empa.ch

Empa researchers receied some 30 awards and appointments in 2019. 15 of these – exactly half – went to women. This is well above the overall proportion of women at Empa, which reach 30 percent in 2019. Female scientists at Empa are thus extremely motivated and extremely successful. And according to official figures, the proportion of women among Empa staff has also developed positively over the past year: it has risen by almost one percent, and now stands at more than 17 percent in the middle and top management.

Equal pay for men and women

In recent years, the issue of gender pay equality has been a focus of attention in the public sector. The Federal Administration has held several events on this topic. In 2016, Federal Councillor Alain Berset launched a charter for equal pay in the public sector, which to date has been signed by 16 cantons and 80 municipalities. Recently, state-affiliated institutions at federal, cantonal and municipal level were also given the opportunity to join the charter. Empa, together with the other institutions of the ETH Domain, therefore joined the initiative on 28 November 2019 in the presence of Federal Councillor Alain Berset and other political leaders.

Promotion of young female scientists

Particularly striking is the promotion of women within the framework of the EU "COFUND" program for the hiring of postdoctoral fellows. The proportion of women among the successful candidates in the last two calls was between 35 and 40 percent.

The ETH Domain's "Fix the leaky pipeline" program continued to support numerous young women on their career path in 2019; four of them from Empa took part in the FLP mentoring program. Five participants were admitted to the ETH Domain's "CONNECT" program, enabling them to make initial contacts for a successful career in industry.

Research for the young and a family-friendly childcare

During the summer, as has been the case for some years now, Empa held a one-week summer camp for children of its staff in Dübendorf. And in November more than 100 kids visited the Dübendorf and St. Gallen sites as part of the National Future Day, including a group of 30 girls from the national programs "Mädchen-Technik-los" and "Mädchen-Informatik-los".

The 25th anniversary of the Empa and Eawag Children's Pavilion in Dübendorf also took place in the summer. This is the home of the joint day nursery run by the two research institutes, where more than 30 children are looked after while their parents conduct research at Empa and Eawag. //

2

1
Federal Councillor Alain Berset with the heads of Human Resources of the ETH Domain institutions (from left to right): Lukas Vonesch (ETH Zurich), Karsten Bugmann (PSI), Alain Berset, Beatrice Lamprecht (Eawag), Susanne Jost (WSL) and André Schmid (Empa).

2
Impressions from the 25th anniversary of the Empa and Eawag Children's Pavilion, the joint day nursery in Dübendorf.

Reducing greenhouse gas emissions

Marcel Gauch, marcel.gauch@empa.ch

In its measures to protect the climate, the Swiss government has required all federal institutions to reduce their CO_2 emissions by at least 50 percent by 2030 compared to the reference year 2006, either by boosting efficiency, substituting fossil fuels with renewable energy sources or producing renewable energy themselves. The remainder of the reductions not achieved by the institution's "in-house" efforts must be offset by CO_2 compensation. Taken together, this means that Empa, along with the entire federal administration, is on the way to achieving zero CO_2 emissions by 2030. Thanks to far-sighted planning, particularly for the Empa-Eawag campus in Dübendorf, Empa is well prepared for this path and Empa serves as a role model for the rest of Switzerland within the framework of the federal Energy Strategy 2050.

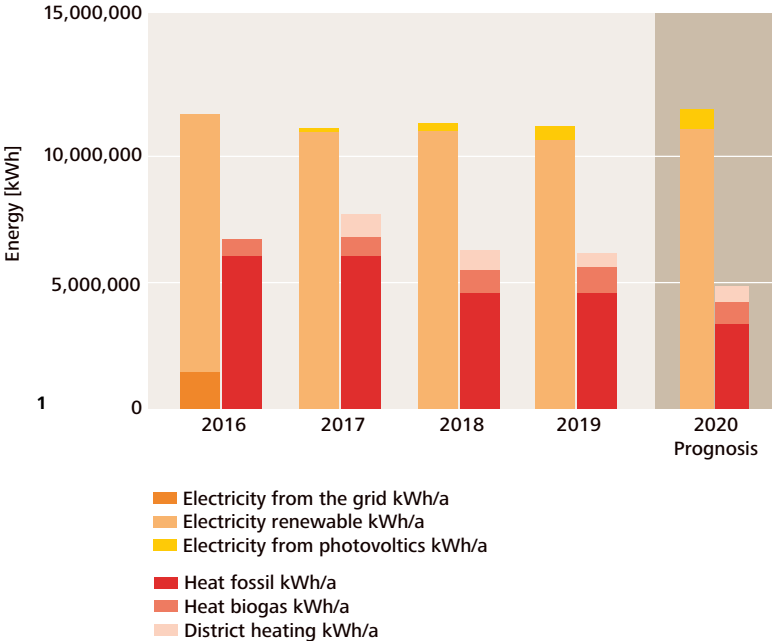
Ring pipeline closed

A surplus of energy arises at one place, but energy is needed at another place. A basic prerequisite for an intelligent exchange is the spatial connection of supply and demand. In the energy concept for the Empa-Eawag campus, this connection is based on a ring pipeline, which was closed in 2019. Waste heat from research infrastructures and from refrigeration machines can now be collected in a medium-temperature heat network at 38 °C and made available to other processes. In particular, this new system is able to meet the heating and cooling needs of all renovated and newly planned buildings on the campus. Processes with higher temperature requirements will in future be supplied with heat pumps that raise the energy from the medium-temperature range (38/28 °C) to a high-temperature level of 65 °C using electricity from renewable sources. This means that in future the gas boiler will only be needed to cover peak demand.

A big step in the expansion of photovoltaics

Empa's largest PV system to date was put into operation on the roof of the laboratory building. The result is not only impressive because of the almost three times greater amount of self-produced renewable energy, but also because of the visually successful integration into the building. As a major contribution to achieving the objectives of the Swiss government's climate measures, PV will be continuously expanded over the next few years to a total area of around 5,000 square meters. //

3

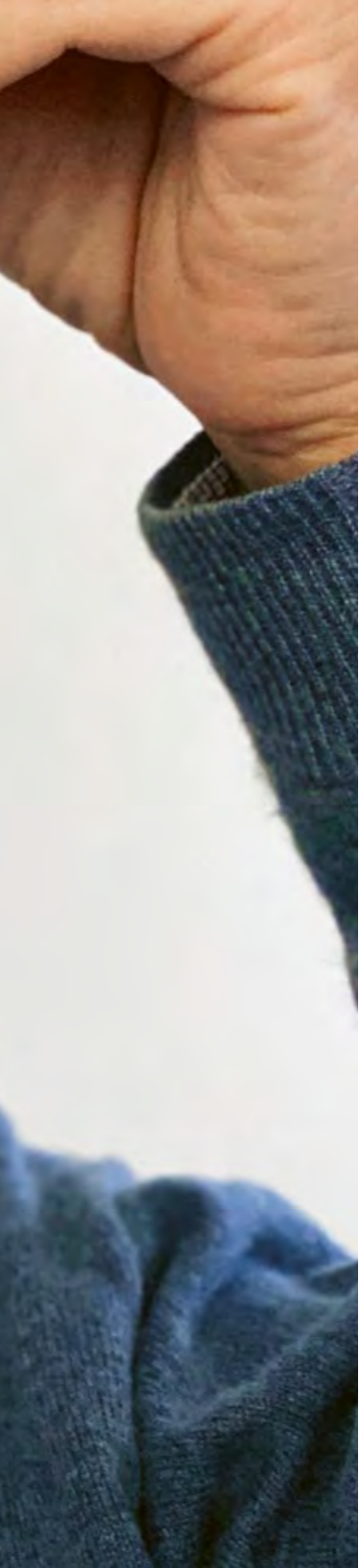


1
Empa's energy consumption: Thermal energy needs were maintained at last year's level, while electricity demand fell slightly. In the future, the use of heat pumps is expected to lead to an increased demand for electrical energy, but also to a significant decrease in thermal energy demand, resulting in significant CO_2 reductions.

2
Photovoltaic system on the Empa laboratory building in Dübendorf.

3
Energy is fed into and released from the energy network of the Empa-Eawag campus at various locations.


Tensor:
Transformations are used to
SYMMETRIES
with respect to
principal direction of anisotropy
"Mirror reflection"



Facts and Figures

Researchers like measuring, including their own performance: in 2019, Empa researchers and engineers published 718 academic papers and filed patent applications for 12 developments. At the end of the year, 105 projects funded by the Swiss National Science Foundation (SNSF), 89 projects backed by Innosuisse and 72 EU projects were underway at Empa. Together with other start-ups in Empa's two business incubators, the 27 spin-offs employed a total of 956 people.

Empa's annual financial statement has been compiled, as at all institutions in the ETH Domain, based on IPSAS (International Public Sector Accounting Standards). It is available at *www.empa.ch/web/s604/annual-reports.*

Risk management

Stefan Hösli, stefan.hoesli@empa.ch

The objective of risk management is to identify potential risks for Empa and its employees at an early stage, to analyze them, to take measures to mitigate them, and to evaluate the effectiveness of these measures. This system leads to a safety culture and thus to a constantly improving safety situation at Empa.

Principles for dealing with risks

Empa has based its regulations in this area on the risk management guidelines for the ETH Domain and the Swiss Confederation. Its safety and risk policy lays down binding rules for the homogeneous, systematic and consistent handling of the wide range of risks. The top priority of all measures is the protection of the lives of employees, guests and all persons within Empa's sphere of influence. Further objectives are the protection of the environment from negative impacts, the protection of know-how and intellectual property, and the protection of Empa's reputation. The focus of these efforts is on prevention.

Risk management follows a standardized process, which starts with a periodic inventory of risks. Each risk is evaluated according to its possible impact and probability of occurrence, and assessed in the dimensions of financial and reputational risk. Finally, measures to contain the risks are defined and implemented. In risk controlling, the risk management process is regularly reviewed and – if deemed necessary – adjusted.

Focus on security issues

Employee awareness of security issues has further improved over the past year. This is reflected, once again, in a significant increase in the number of enquiries about safety-related topics such as drone flights on campus or in buildings, explosion protection or the safety of chemical reactions and laser systems.

A central aspect of prevention is the training of staff. With between 450 and 500 new entries a year, this is a Herculean task. Risk management has once again expanded its training courses and now offers a wide range of courses in the fields of chemical, nanotechnology, laser safety, etc. for different user levels. The course calendar is published at the beginning of each year.

Measures have also been taken to further professionalize the team for fire and chemical incidents. This is being done through training in tactical and technical areas, but above all through intensified exercises. In 2019, joined regular exercises were introduced for Empa's rescue service and the team responsible for chemical incidents. Joint analyses have led to a more efficient interaction between the intervention teams and with technical experts. Successful evacuation exercises were conducted under this premise at the Dübendorf and St. Gallen sites in 2019.

Due to social and technical developments, the topic of IT security is becoming increasingly important. However, not all employees are yet fully aware of the fact that this goes far beyond the everyday work of an ICT department, and that the way in which each and every employee is working and handling information is crucial. Important topics such as cloud computing are being addressed in project teams with the aim of developing guidelines and raising awareness. Data security is also being addressed comprehensively within the framework of a cross-institutional working group within the ETH Domain, and cooperation in sub-areas is being intensified.

A particular challenge for risk management was the investigation of the up-to-50-tonne debris from the collapsed Morandi Bridge at the beginning of 2019. With minimal advance warning, both the physical safety of the bridge parts as well as the data security and the integrity of the results had to be guaranteed over an extended period of time. At the same time, international media interest led to a substantial reputational risk for Empa. Therefore, measures of a hitherto unknown magnitude were developed and successfully implemented by the risk management team with the involvement of IT security specialists and together with scientists from various disciplines. //

Human resources development

(previous year's figures in brackets)

André Schmid, andre.schmid@empa.ch

At the end of 2019, 1033 (994) people, including trainees, were working at Empa. This corresponds to a full-time equivalent (FTE) of 967.5 (928.6) positions, due to numerous part-time employments.

The number of scientific personnel, including PhD and postdoctoral students, is 593 (558). Of these, 103 (108) are Senior Scientists. Technical/administrative staff amounted to 398 (396) persons in the year under review. The proportion of women, 30.4 (28.9) percent, reflects the gender distribution among graduates from Swiss universities and the two ETH in the scientific disciplines represented at Empa.

The proportion of foreign citizens was 468 (436), or 45.3 (43.9) percent of the total staff. The EU accounts for 287 (281) persons, or 61.3 (64.4) percent of all foreign employees. Empa offers vocational training for a number of professions and currently employs 42 (40) trainees. As in previous years, all Empa trainees successfully passed their final exams last year.

STAFF END OF 2019

	2018	2019
Scientific staff	**558**	**593**
Technical and administrative staff	**396**	**398**
apprentices	40	42
Total	**994**	**1033**

Key figures

SCIENTIFIC OUTPUT

	2018	2019
ISI publications	**700**	**718**
Conference contributions	**1,372**	**1,250**
Doctoral studies completed	**45**	**37**
Doctoral studies in progress	**191**	**208**
Teaching activities (in hours)	**4,423**	**4,406**
Prizes and awards	**81**	**81**

MEDIA EXPOSURE

	2018	2019
Radio	72	169
TV	56	63
Print	1,250	1,730
Online	3,850	5,500
Total	**5,250**	**7,462**
Languages	32	34

EMPA ACADEMY

	2018	2019
Empa events	**96**	**92**
Participants	5,931	5,070
Scientific conferences	17	10
Events for industry	24	20

KNOWLEDGE DISSEMINATION & TECHNOLOGY TRANSFER

	2018	2019
New R&D agreements	208	193
Active exploitation contracts	68	66
New exploitation contracs	16	12
New patent applications	14	12

SPIN-OFFS & START-UPS (tebo & glaTec)

	2018	2019
Companies total	**94**	**104**
thereof spin-offs	26	27
Employees total	**784**	**956**
thereof employees of spin-offs	131	136

CURRENT PROJECTS

	2018	2019
Swiss National Science Foundation (SNSF)	122	105
Innosuisse	95	89
EU projects	69	72

Bodies of Empa

ETH Board

The ETH Board has overall responsibility 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).

CHAIRMAN
Michael O. Hengartner Prof. Dr

VICE-CHAIRWOMAN
Beth Krasna Dipl. Ing. ETH, independent supervisory board member

MEMBERS
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Gian-Luca Bona Prof. Dr, Empa
Marc Bürki Dipl. El.-Ing., Swissquote
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Susan Gasser Prof. Dr, Dr h. c. mult., Universität Basel
Barbara Haering Dr Dr h. c., Econcept AG, Zurich
Christiane Leister Leister AG, Kägiswil
Joël Mesot Prof. Dr, ETH Zurich
Martin Vetterli Prof. Dr, EPF Lausanne

Industrial Advisory Board

A body of leading personalities which advises the Empa management on fundamental concerns.

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Burkhard Böckem Dr, Hexagon, Heerbrugg
Robert Frigg Prof. Dr mult. h. c., 41 medical, Bettlach
Andreas Hafner Dr, BASF, Basel
Markus Hofer Dr, Bühler, Uzwil
Urs Mäder Dr, SATW, Zurich
Andreas Schreiner Dr, Novartis, Basel

Research Commission

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
Urs T. Dürig Dr, SwissLitho AG, Zurich
Rik Eggen Prof. Dr, Eawag, Dübendorf
Thomas Egli Prof. em. Dr, Feldmeilen
Marcus Textor Prof. Dr, ETH Zurich
Alexander Wokaun Prof. em. Dr, Endingen

Organizational chart

as of May 2019

RESEARCH FOCUS AREAS
(Research priorities)

Nanostructured Materials
Dr Pierangelo Gröning

Sustainable Built Environment
Dr Tanja Zimmermann
Prof. Dr Giovanni Terrasi

Health and Performance
Prof. Dr Alex Dommann

Natural Resources and Pollutants
Dr Brigitte Buchmann

Energy
Dr Peter Richner
Dr Björn Niesen

BOARD OF DIRECTORS

Director	Deputy	Members of the Board
Prof. Dr Gian-Luca Bona	Dr Peter Richner	Dr Brigitte Buchmann, Prof. Dr Alex Dommann, Dr Pierangelo Gröning, Dr Urs Leemann, Dr Tanja Zimmermann

DEPARTMENTS

Advanced Materials and Surfaces
Dr Pierangelo Gröning

Electron Microscopy Center
Dr Rolf Erni

Engineering Sciences
Dr Peter Richner

Center for Synergetic Structures
Dr Cédric Galliot

Materials Meet Life
Prof. Dr Alex Dommann

Center for X-ray Analytics
Prof. Dr Antonia Neels

LABORATORIES

Joining Technologies and Corrosion
Dr Lars Jeurgens

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

Surface Science and Coating Technologies
Dr Lars Sommerhäuser a.i.

Functional Polymers
Prof. Dr Frank Nüesch

Structural Engineering
Prof. Dr Masoud Motavalli

Mechanical Systems Engineering
Prof. Dr Giovanni Terrasi

Multiscale Studies in Building Physics
Dr Ivan Fabrizio Lunati

Experimental Continuum Mechanics
Prof. Dr Edoardo Mazza

Urban Energy Systems
Dr Kristina Orehounig

Magnetic and Functional Thin Films
Prof. Dr Hans Josef Hug

Biomimetic Membranes and Textiles
Prof. Dr René Rossi

Particles-Biology Interactions
Dr Peter Wick

Biointerfaces
Prof. Dr Katharina Maniura

Transport at Nanoscale Interfaces
Prof. Dr Michel Calame

RESEARCH, KNOWLEDGE AND TECHNOLOGY TRANSFER PLATFORMS

NEST/dhub
Reto Largo

move
Dr Brigitte Buchmann

ehub
Philipp Heer

Coating Competence Center
Dr Lars Sommerhäuser

Empa Academy
Claudia Gonzalez

Business Incubators
glaTec
Mario Jenni
Startfeld
Peter Frischknecht

International Research Cooperations
Prof. Dr Gian-Luca Bona

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

Mobility, Energy and Environment

Dr Brigitte Buchmann

Materials for Energy Conversion
Dr Corsin Battaglia

Advanced Analytical Technologies
PD Dr Davide Bleiner

Air Pollution / Environmental Technology
Dr Lukas Emmenegger

Automotive Powertrain Technologies
Christian Bach

Materials for Renewable Energy
Prof. Dr Andreas Züttel (Antenne Sion)

Technology and Society
Dr Patrick Wäger

Acoustics / Noise Control
Dr Jean Marc Wunderli

Functional Materials

Dr Tanja Zimmermann

Materials and Technology Center of Robotics
Dr Mirko Kovac

High Performance Ceramics
Prof. Dr Thomas Graule

Cellulose & Wood Materials
Dr Gustav Nyström

Concrete and Asphalt
Prof. Dr Pietro Lura

Building Energy Materials and Components
Dr Matthias Koebel

Advanced Fibers
Prof. Dr Manfred Heuberger

Corporate Services

Dr Urs Leemann

Library (Lib4RI)
Dr Lothar Nunnenmacher

Fundrising / Entrepreneurship / Industry Relations
Gabriele Dobenecker

ICT Services
Stephan Koch

Mechanical Engineering / Workshop
Stefan Hösli

Finances / Controlling / Purchasing
Heidi Leutwyler

Communication
Dr Michael Hagmann

Human Resources
André Schmid

Knowledge and Technology Transfer / Legal
Marlen Müller

Real Estate Management
Hannes Pichler

Empa – The Place where Innovation Starts

Empa
www.empa.ch

CH-8600 Dübendorf
Überlandstrasse 129
Phone +41 58 765 11 11
Telefax +41 58 765 11 22

CH-9014 St. Gallen
Lerchenfeldstrasse 5
Phone +41 58 765 74 74
Telefax +41 58 765 74 99

CH-3602 Thun
Feuerwerkerstrasse 39
Phone +41 58 765 11 33
Telefax +41 58 765 69 90