Annual Report 2020

Empa
Materials Science and Technology

Our Vision.
Materials and Technologies for a Sustainable Future.

Cover Photo: researchers from Empa and ETH Zurich have been able to produce a nanostructured material that functions as a luminous solar concentrator and can be applied to textiles. This will help, e.g. jackets to harvest solar energy, for instance to charge smartphones and the likes in your pocket.

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An enormous impact – despite Corona

Last year, hardly anything went as planned – and certainly nothing stayed the same: Right at the beginning Corona challenged us and kept us on our toes throughout the rest of the year. From the outset it was clear to us at Empa that we had to protect our employees in order to be able to carry out our tasks in the best and most efficient way. A complete shutdown as a result of the threat from the SARS-CoV-2 virus was never an option. Instead, we immediately introduced an effective protection concept and a comprehensive training for all our employees.

Initially, the numerous inquiries about protective masks were quite a challenge, as much was still unclear. Detailed test procedures that were quickly developed and transferred to private labs were the beginning, cooperations with numerous industry partners and within the framework of the COVID-19 Task Force the consistent next steps. Many Swiss companies develop innovations within EU- and Innosuisse-funded projects, but also in direct collaboration with Empa. As a result, we were able, in 2020, to set a new record with respect to the number industry collaborations. Likewise, the number of scientific publications by our researchers has also risen to a new all-time high of over 850. Empa has thus fired up its "innovation engine" once again.

In this context, an increased focus on data science in deepening the atomic understanding of materials, as well as in the area of machine learning and digital twins, has opened up further important dimensions for us. Well over 20 percent of our researchers are working on concepts like these – and are attracting increasing interest from our external partners.

Unfortunately, we had to cancel our open lab days to celebrate Empa's 140th anniversary last year; however, we were able to successfully finish a long-cherished book project: "Beyond Materials – A brief history of Empa" vividly illustrates our transition to a modern, top-notch research institute, but at the same time is a kind of stopover on the way to the future.

A future that we have developed and defined in our Development Plan for the next four years together with our numerous key players. In addition to research into sustainable, resilient materials and technologies with a human-centric focus, this includes the development of a forward-looking Empa campus in Dübendorf with 'net zero' CO_2 emissions as a lighthouse project for the climate and energy transition. This year, the first stage will start with a new laboratory and a multifunctional building. So that we can continue to advance our technologies with the next generation of Empa researchers – at full speed and for the benefit of Switzerland.

Prof. Dr Gian-Luca Bona *Director*

Year at a Glance

Three ERC grants for Empa researchers
A grand total of three Empa researchers, two of them women, were awarded ERC Grants from the European Research Council in the past year. Dorina Opris (right) received one of the sought-after Consolidator Grants. Thanks to the award, which is endowed with around 2 million euros, she will be able to further expand her research group in the field of novel polymers for energy conversion over the next five years. Marianne Liebi and Bruno Schuler each received a Starting Grant for especially talented young researchers to build up their own research areas in the coming years. Schuler investigates the fundamental building blocks of quantum information technology. Liebi is developing a new method to examine the nanostructures of materials without having to look at them directly.

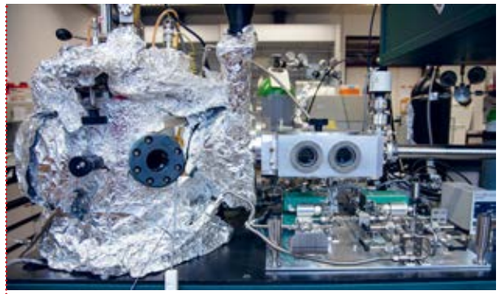
Aerogel – the micro-building material of the future
Aerogel is an excellent thermal insulator. To date, it has mainly been used on a large scale, for example in environmental technology, in physical experiments or in industrial catalysis. Researchers at Empa, ETH Zurich and the Paul Scherrer Institute (PSI) have succeeded in making aerogels for applications in microelectronics and precision engineering: using 3D printing, researchers were able to manufacture tiny parts made of silica aerogels and silica composite materials with high precision. This opens up numerous new application possibilities in the high-tech industry, for example in microelectronics, robotics, biotechnology and sensor technology.

Stuttgart rail bridge hangs on Swiss carbon ropes
Another milestone for an extremely versatile material with Swiss roots: in May 2020, a 127-meter-long railway bridge was pushed over the A8 highway near Stuttgart, its 72 suspension cables consisting entirely of carbon fiber-reinforced polymer (CFRP). This ultralight, yet extremely stable material was developed largely at Empa and has since been used in more and more structures worldwide.

Urban heat islands – every tree counts
Summer heatwaves are becoming more frequent and are leading to increased urban heat islands. Is it possible to create cool zones to counter this trend? Empa researchers have developed a simulation program that can make detailed predictions about which pavement and which type of vegetation would achieve the best results. Using the Münsterhof square in Zurich – a classic heat island – as an example, they have run a model simulation. Their calculations show that temperatures on the Münsterhof would be significantly lower if the square was not paved but covered with soil and grass. This would cause the ground to cool down more overnight and store less heat during the day. Planting vegetation, as was done in an art project in the summer of 2019, could be the solution to the increasing temperatures in cities. Image: Peter Baracchi

Platinum catalyst keeps fruit fresh for longer
If vegetables are stored together with fruit, they affect each other in the ripening process. This is due to ethylene, which is emitted by some types of fruit and vegetables and accelerates ripening. To prevent accelerated decay, researchers at Empa and ETH Zurich developed a catalyst that breaks down the plant hormone ethylene into water and carbon dioxide. The concept is based on a delignified wood structure enriched with a platinum-based catalyst that is dispersed at an atomic level. When ethylene flows through this porous structure, it repeatedly collides with catalytically active platinum particles. The team demonstrated that, at room temperature, the catalyst decomposes virtually all of the ethylene emitted. Larger catalysts could be installed in refrigerators and cold stores to slow down the ripening process of fruits and vegetables.

Detecting environmental damage with drones
It's no easy task to keep an eye on the ecological balance in forests. A research team from Empa and Imperial College London developed drones that attach sensors to trees to detect environmental damage. The drones are equipped with cameras and a launching device for sensor darts. The darts can be launched in a controlled manner thanks to metals with shape memory-materials that react to heat, change their shape and then revert to their original structure. Additionally, the drones can collect data independently. The researchers have already tested the drones' capabilities in flight experiments at Empa. The drones are currently controlled by people. The next step is to make the drones autonomous so that they can carry out their functions in remote locations.

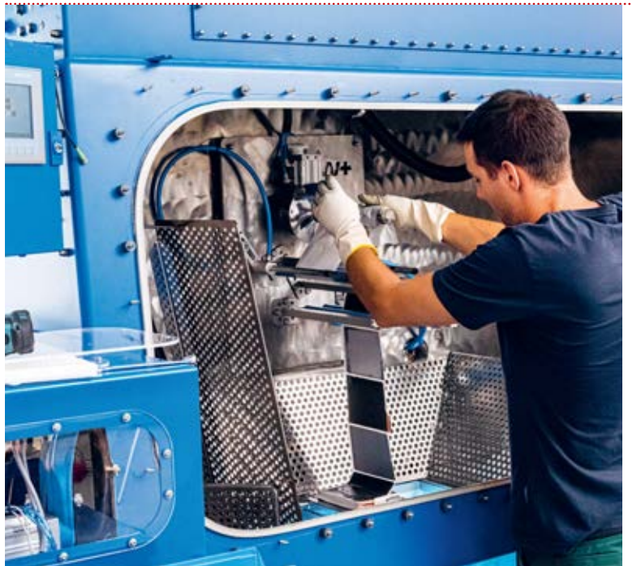


Making large strides with small spinning particles
Skyrmions are magnetic objects that could revolutionize the data storage industry and enable new computer architectures. However, before they can be utilized in technical applications, there are still a number of challenges to overcome. A team of Empa researchers has now succeeded for the first time in producing a complex multilayer system in which two different types of skyrmions – the future bits for 0 and 1 – can exist at room temperature. Using a magnetic force microscope, individual layers were compared with each other to determine which layers contain which type of skyrmions. In addition, micromagnetic computer simulations confirmed the experimental results. The researchers are convinced that they have made large strides towards practical applications, as the multilayers produced with sputtering technology can in principle also be manufactured on an industrial scale.

Turning streetwear into solar concentrators
Researchers at Empa and ETH Zurich have successfully developed a material that works like a luminescent solar concentrator and can be applied to textiles without the textile becoming brittle and susceptible to cracking or accumulating water vapor in the form of sweat. The luminescent materials capture a much wider spectrum of light than is possible with conventional photovoltaics. Solar concentrators worn on the body are immensely useful with regard to the ever-increasing demand for energy, especially for portable devices.

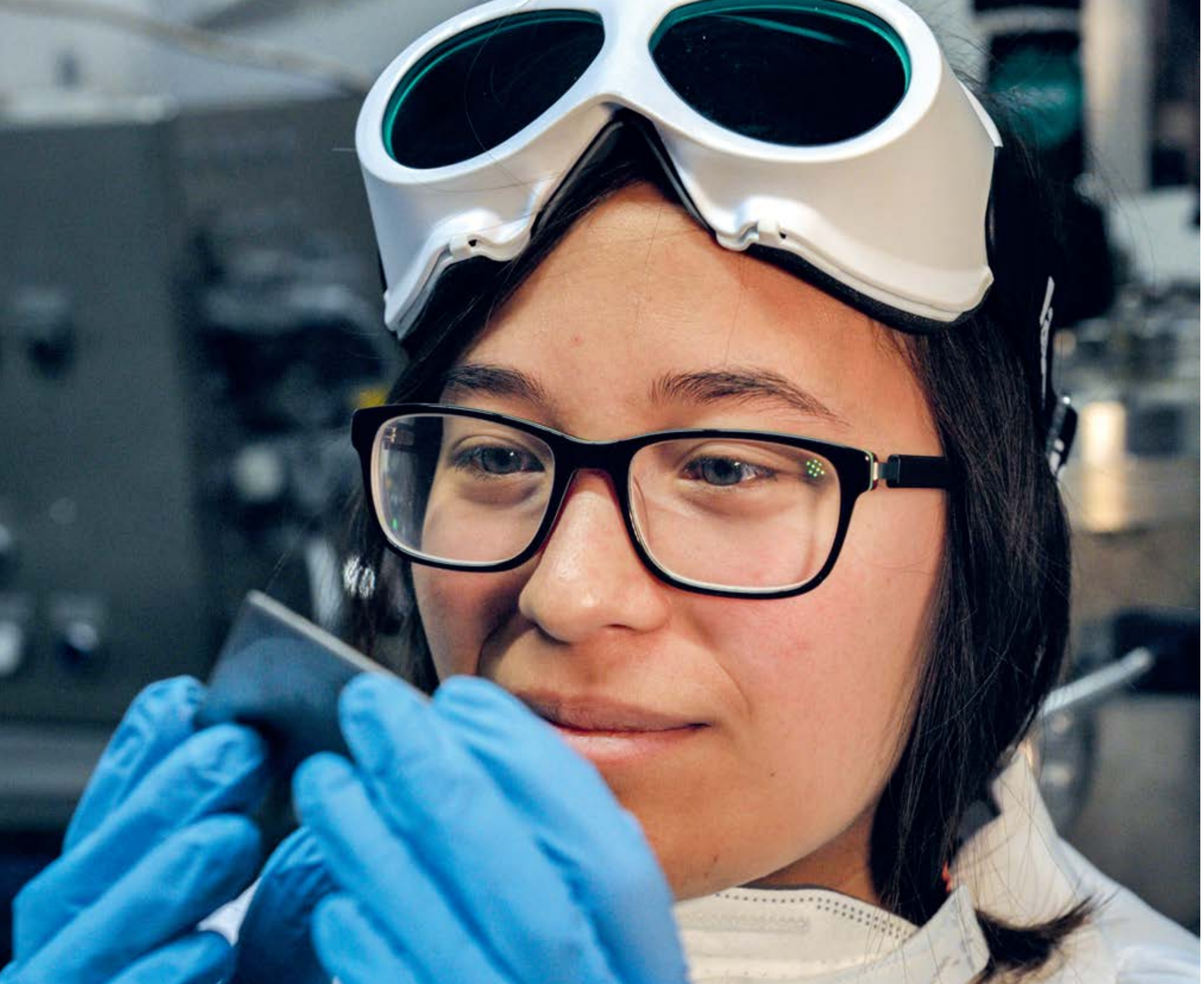
Safe diagnostics for mother and child
Pre-eclampsia is a particularly dreaded pregnancy complication that threatens the lives of both mother and child. Currently, arriving at the correct diagnosis is a time-consuming and often inaccurate process. It is based on two physical changes, which are both consequences of pre-eclampsia: the mother's blood pressure and certain proteins in her urine. However, the two symptoms are not necessarily proof of pre-eclampsia, which can lead to unnecessary hospitalizations or even malpractice. The Empa spin-off MOMM Diagnostics has developed a fast and precise test that saves health care costs by providing certainty early on. The test analyses two specific biomarkers in the maternal blood. What's ingenious about the test is that a tiny biosensor is printed on a paper strip. A drop of blood from the mother's finger is enough to detect the molecules.

How dangerous are burning electric cars?
Empa researchers and tunnel safety experts joined forces to set fire to the battery cells of electric cars in a test tunnel. The experiment examined three realistic scenarios: in a closed space, in a space with sprinklers and in a tunnel with a ventilation system. They then analyzed the distribution of soot and smoke gases and the chemical residues in the firefighting water. They concluded that, with regard to heat development, a burning electric car is no more hazardous than a conventional vehicle. The firefighting water poses a larger problem, however, as analyses showed that its chemical contamination far exceeded the Swiss legal limits. In any case, this highly contaminated water must be treated professionally before it is discharged into the sewage system. The cleanup after the fire is also a job for professionals wearing protective suits. Image: istockphoto, trikolor



Recycling 91 percent of lithium-ion batteries
In 2020, the Swiss electric vehicle manufacturer Kyburz put a recycling plant into operation that can reclaim most of the materials from lithium-ion batteries. The plant was designed and constructed in close cooperation with the experts at Empa. It was important to develop an efficient, environmentally friendly and safe recycling process. The project's long-term objective is to deconstruct all the LiFePO4 batteries ever installed by Kyburz. Approximately 4,000 cells per year are intended to be processed during the first expansion phase. After completion, the plant will achieve a capacity of up to 24,000 cells per year, which corresponds to annual production of 3,000 vehicles. Image: Werner Hauser

Nanosafety research without animal testing
Many animal experiments in research can be avoided by using cell cultures and microorganisms. In order to further reduce their number, researchers are seeking alternative methods. However, this poses a challenge if the safety of substances that have hardly been studied is to be ensured. This applies in particular for nanomaterials. At Empa, a team of researchers is developing methods to ensure nanomaterial safety by combining test tube experiments with computer modelling.



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.

The smallest motor in the world

Dr Oliver Gröning, oliver.groening@empa.ch

A research team from Empa and EPFL has developed a molecular motor, which consists of only 16 atoms and rotates reliably in one direction. It could allow energy harvesting at the atomic level. The special feature of the motor is that it moves exactly at the boundary between classical motion and quantum tunneling – and has revealed puzzling phenomena to researchers in the quantum realm.

Like a large-scale motor, the 16-atom motor consists of a stator and a rotor, i.e. a fixed and a moving part. The rotor rotates on the surface of the stator, where it can change between six different positions. For a motor to actually do useful work, it is essential that the stator constrains the rotor to move in just one direction.

The opposite of a ratchet

The 16-atom motor operates in a manner exactly opposite to a ratchet in the macroscopic world with its asymmetrically serrated gear wheel: while the pawl on a ratchet moves up the easy slope and locks in the direction of the steep slope, conversely the atomic variant requires less energy to move up the steep slope of the gear wheel than along the easy slope. Movement in the usual "locking direction" is therefore preferred and movement in the "running direction" is much less likely. So movement is virtually only possible in one direction.

The motor has directional stability of 99 percent, which distinguishes it from other similar molecular motors. In this way, the molecular motor opens up a way for energy harvesting at the atomic level.

From classical physics to the quantum world

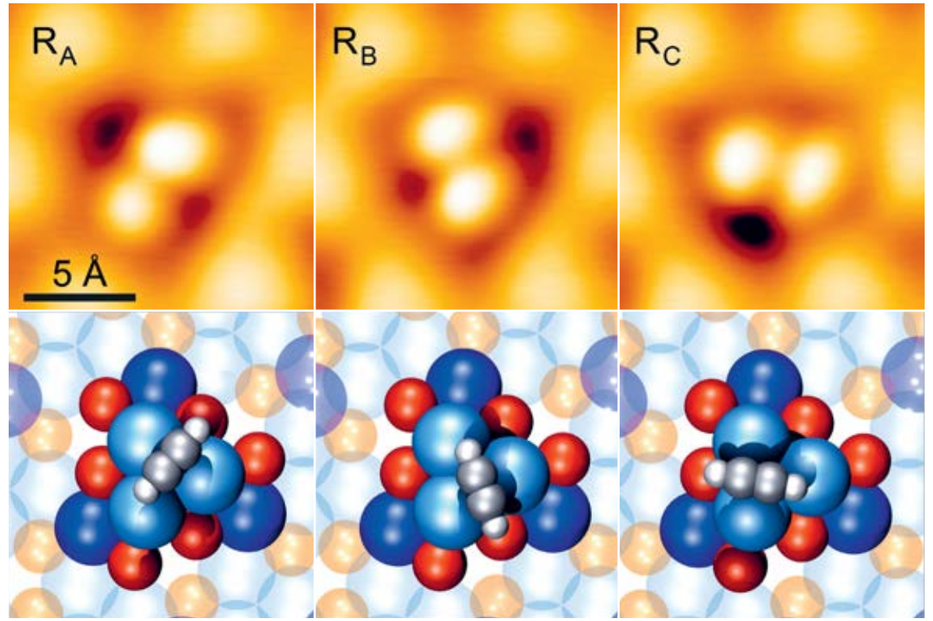
According to the laws of classical physics, a minimum amount of energy is required to set the rotor in motion against the resistance of the ratchet; if the supplied electrical or thermal energy is not sufficient, the rotor has to stop. Surprisingly, the researchers were able to observe an intrinsic, constant rotation frequency in one direction even below this limit, at temperatures below 17 Kelvin (–256 °C) or an applied voltage of less than 30 millivolts.

Findings in the field of quantum physics

At this point, we have reached the threshold between classical physics and quantum physics. According to the rules of the latter, particles can "tunnel", meaning that the rotor can cross the "ratchet teeth" even if its kinetic energy is insufficient in the classical sense. This tunneling motion normally occurs without any loss of energy.

The second law of thermodynamics states that entropy in a closed system can never decrease. In other words: if no energy is lost in the tunneling event, the motor's direction of rotation should be completely random. Surprisingly, however, the 16-atom motor still turns in the same direction in 99 percent of the time. The fact that the motor still rotates almost exclusively in one direction therefore indicates that energy is also lost during tunnel movement – where the atomistic details of this process are not yet fully elucidated.

So, the Empa researchers haven't just developed a toy for molecular tinkering. The motor could enable the study of energy dissipation in quantum tunneling processes. //



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Scanning tunneling microscopy image (magnified by about 50 million) of a dumbbell-shaped acetylene-rotor molecule in three different rotation states. The to-scale atomic structure of the stator (blue-red) and the acetylene-rotor (grey-white) are shown schematically below.

Frozen smoke for construction and microtechnology

Dr Wim Malfait, wim.malfait@empa.ch

Aerogels are breathtaking: even though they are solids, they consist almost exclusively of pores. Their nickname “frozen smoke” aptly describes the fact that aerogels look like mere wisps of material. Researchers are not only intrigued by their bizarre beauty, but also by their useful properties such as very low thermal conductivity. Together with Fixit, a manufacturer of building materials, the experts at Empa developed an aerogel insulating plaster with high energy-saving potential, which netted them a Swiss Green Business Award in the category “Innovation” a few years ago.

In addition to their success in the construction sector, aerogel materials are also conquering microtechnology. In the past year, Empa researchers and their colleagues at ETH Zurich and the Paul Scherrer Institute (PSI) demonstrated how to produce 3D-printed components made of silica aerogel and silica composite materials in an article in the journal “Nature”.

Post-processing possible

The problem is that in practice, such materials are brittle, which is why they are usually reinforced with fibres or polymers for large-scale applications. Due to its fracture behavior, it is not possible to saw or mill small pieces out of a larger aerogel block. It is also not possible to solidify aerogels in miniaturized moulds as this method is not reliable and results in high scrap rates.

However, using a 3D printer, the Empa team was able to create stable microstructures made of silica aerogel that were as thin as a tenth of a millimetre. These displayed thermal conductivity of just under 16 mW/(m*K) – only half that of polystyrene and significantly less than that of a non-moving layer of air.

At the same time, the 3D printed aerogel has even better mechanical properties and can even be drilled and milled. This opens up new possibilities for the post-processing of 3D printed aerogel mouldings. With this method, it is now possible to adjust the flow and solidification properties of the silica ink from which the aerogel is later produced so that both self-supporting structures and wafer-thin membranes can be printed. Such structures offer the possibility to insulate even the smallest electronic components from each other. One possible application is the shielding of heat sources inside medical implants, which should not exceed a surface temperature of 37 °C in order to protect body tissue.

In addition to small-scale technologies, Empa experts are also driving forward applications in the construction industry. Several years ago, Empa researchers developed a paste containing aerogel particles which was filled into the cavities of the bricks. The result was thermal insulation equivalent to a filling made of the volcanic stone perlite, which allows significantly thinner walls. This results in a space gain, and is a worthwhile idea overall that is currently being pursued further.

Aerogel Architecture Award

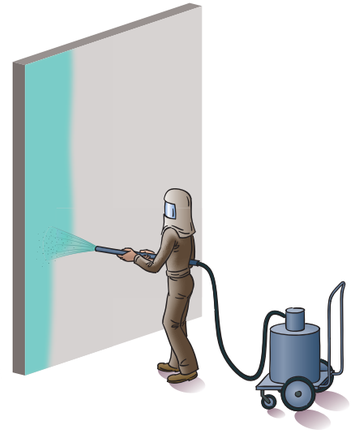
In timber construction, where prefabricated elements are being used more and more frequently, an intended application of the high-performance insulating material is to facilitate slimmer designs. Empa researchers are contributing to the design of such structures, which should also be suitable for adding storeys to existing buildings.

In order to promote the energy-efficient and climate-friendly use of aerogels, Empa has initiated the Aerogel Architecture Award. The winning projects will receive awards in summer 2021 at a fitting venue: NEST on the Empa campus in Dübendorf. //

1

1
As an example of overhanging structures made of silica aerogel, the researchers printed the leaves and blossoms of a lotus flower.

2
Aerogel high-performance insulating plaster in practice: the plaster is sprayed on with a plastering machine and subsequently smoothed out.



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Improving therapy with digital twins

Prof. Dr Thijs Defraeye, thijs.defraeye@empa.ch

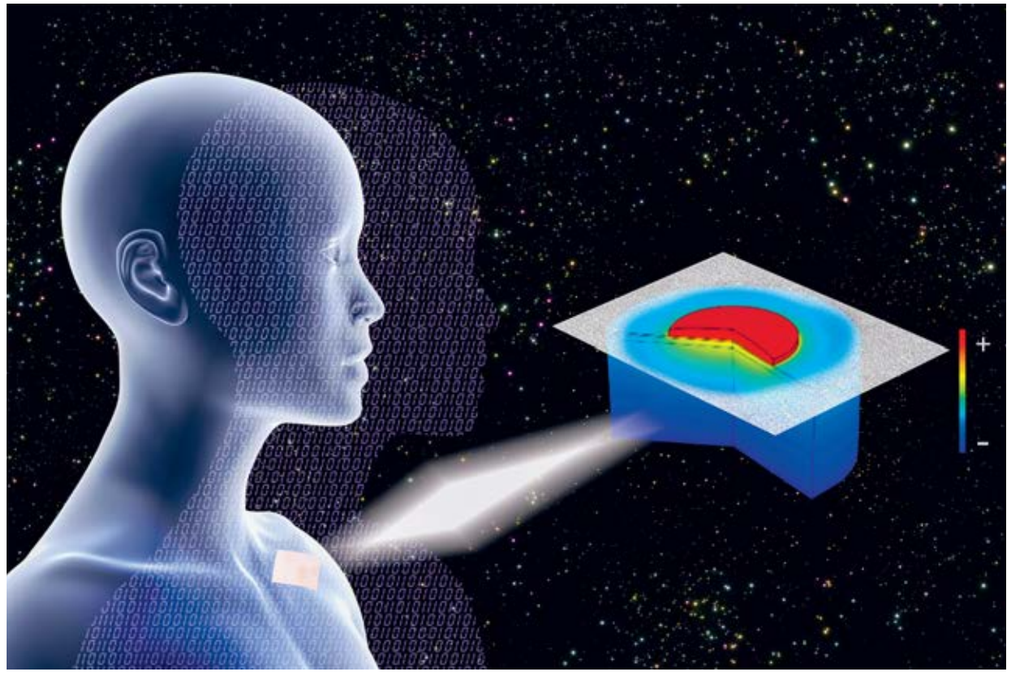
Major advances in modern medicine allow us to provide patients with an improved quality of life even during severe illnesses. Synthetic opiates, for example, can be used to control even severe pain in the event of cancer. The exact dosage, however, is a challenge. Painkillers such as fentanyl must be dosed very precisely to be effective but not harm patients, sometimes with life-threatening side effects. Researchers have hit upon the innovative research field of computer and data sciences to ensure that individual dosages can be determined and kept constant in future in line with personalized medicine. A team at Empa is developing a digital twin of the body that will enable real-time modelling to control and predict the course of treatment.

Several hundred avatars treated

The complex digital doppelganger is based on mathematical models where researchers incorporate several variables from real people, such as age and lifestyle. A painkiller's effectiveness is influenced by a host of physical parameters that can vary widely from person to person. Therefore, data on how the drug is metabolized in the body and how much of it ultimately arrives in the brain's pain center must also be included. To ensure that the dosage is not only safe but also achieves the desired effect on the patient, the in-silico twin also receives physiological and psychological feedback from the real person. In this way, the therapy can be dynamically adjusted and its course can even be predicted. Several hundred of these personalized avatars have been created and personalized therapy procedures have been tested virtually in test phases so far. The plan is to optimize further therapies, for example for diabetes, by using digital twins in cooperation with clinics and hospitals.

Digitalization against food waste

Recently, the team was awarded one of data.org's Inclusive Growth and Recovery Challenge prizes for a related project. The highly endowed award is sponsored by the Rockefeller Foundation and the Mastercard Center for Inclusive Growth. The aim of the joint project with the BASE Foundation (Basel Agency for Sustainable Energy) is to use computer models and mobile apps to promote sustainable agriculture and improve the ecological and economic situation for small farms in developing countries. The large-scale project also provides an excellent basis for Empa researchers to further develop the field of computer and data science, and digital twins in particular, for diverse applications. //



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1
Painkillers, insulin or other medicines can be dispensed precisely and with anticipation thanks to a digital twin.

2
Empa researcher Seraina Schudel and the "fruit spy": using real biophysical twins with sensors in the form of artificial fruit, complementary data can be generated for the development of digital twins in food research.

Carbon dioxide tracking in space

Dr Gerrit Kuhlmann, gerrit.kuhlmann@empa.ch

CO_2-concentrations in the air continue to rise rapidly, and the swift reduction of man-made emissions is becoming increasingly important in order to prevent catastrophic climate change. In order to assess the effectiveness of political measures, timely and reliable emission levels are needed. Although the current network of ground stations is useful for tracking the increase in CO_2 in the atmosphere, it is not yet dense enough to provide reliable information on the emissions of individual countries or even individual regions or cities. Current emissions estimates are based on statistics and activity data from transport, industry, heating and energy production. The evaluation of these data is complex and the results are only available with a long delay. Estimates are also uncertain, as precise figures are often not available and simplified assumptions must be made – for example, in the case of heating.

Researchers working on improved emission determination

For this reason, the EU, together with the European Space Agency ESA, is developing a system for monitoring CO_2 emissions. A key component of this is the CO_2M satellite mission ("Copernicus Carbon Dioxide Monitoring"). Starting in 2025, the first CO_2M satellites are to be sent into orbit to produce global maps of atmospheric CO_2 concentrations using spectroscopic measurements. This will make it possible to determine where and how much CO_2 is emitted by industrial plants, cities and countries. These measurements will reduce the current uncertainties in estimating CO_2 emissions from the combustion of fossil fuels.

ESA relies on Empa's expertise to design the satellites. The challenge in determining CO_2 emissions is distinguishing between anthropogenic (i.e. man-made) and biological signals, as the respiration of vegetation causes strong fluctuations in the distribution of CO_2. The satellite must therefore be able to separate these from man-made emissions. The idea behind this is that nitrogen dioxide (NO_2) must additionally be measured, as it is produced by the combustion of coal, oil and gas but not by biosphere respiration. An additional NO_2 instrument should therefore be able to identify anthropogenic CO_2 signals.

Empa simulates satellite measurements

In order to test the feasibility of this idea, Empa researchers simulated the distribution of CO_2 and NO_2 concentrations for the year 2015 with an unprecedented spatial resolution. Analyzing the simulations showed that the combination of CO_2 and NO_2 measurements can determine anthropogenic CO_2 emissions more accurately and reliably than a single CO_2 measuring device installed on the satellite. Based on the work of Empa researchers, the CO_2M satellites will therefore be equipped with an additional instrument for measuring NO_2. //

Satellite images from Empa researchers' simulations: in areas where high NO_2 values (right) coincide with high CO_2 values (left), the high levels of CO_2 are man-made. The emissions of the city of Berlin and several coal-fired power plants are clearly visible. The aim of the EU and ESA is to detect CO_2 emissions almost in real time in order to be able to reliably and promptly determine greenhouse gas emissions worldwide in the future. Image: Unsplash/NASA

Researching next-generation batteries

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In early 2020, the two large European battery research projects SeNSE and SOLiDIFY were launched, in which Empa is involved. These projects are part of a large-scale European research initiative with the goal of establishing Europe as the leader of the swiftly growing battery market. The SeNSE project coordinated by Empa focuses on batteries for electric cars. The demand for these batteries will see a sharp increase in the coming years.

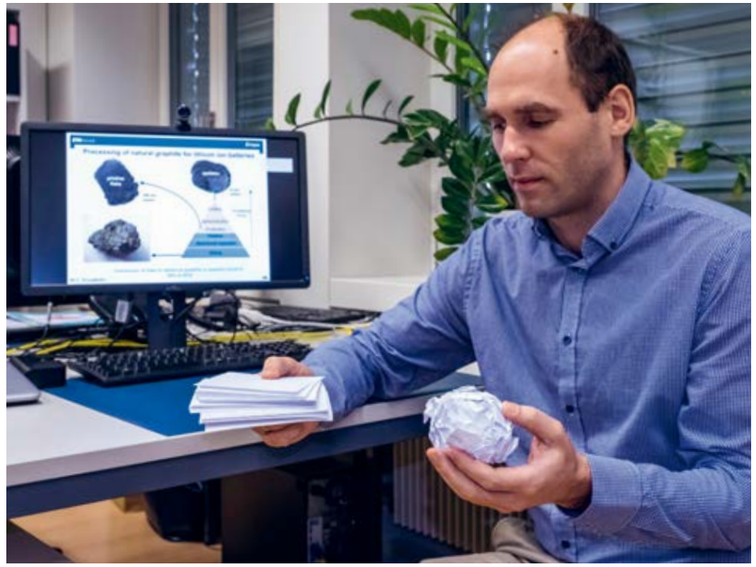
Generation 3b lithium-ion batteries
The eleven research partners of SeNSE are developing "generation 3b" lithium-ion batteries. The objectives for these batteries are higher energy density, improved cell chemistry and enhanced battery management. The percentage of cobalt is to be further reduced. Sensors inside the battery cells are intended to improve service life and fast charging capability.

Solid-state batteries – generation 4b
The second European research project in which Empa is involved is called SOLiDIFY. This project deals with future-generation batteries, the so-called solid-state lithium-metal batteries. These batteries will no longer contain any liquid, flammable components. They are therefore safer and more heat resistant, provide more battery power and can be charged and discharged faster. In addition, Empa has formed a strategic allegiance with the Fraunhofer Institut in Würzburg (Germany) where both institutions perform joint research on solid-state batteries. The Swiss industry is also taking an increasing interest in solid-state batteries, which is why several Innosuisse projects with Swiss industry partners were launched this year.

Sodium and aluminium graphite batteries
Using lithium-ion batteries for stationary applications of any size (homes, energy suppliers, major consumers) is still too expensive. Additionally, the raw material supply chain for lithium-ion batteries is under immense pressure. This is due on the one hand to the rapidly increasing production of electric cars and on the other to the world's cobalt, nickel and lithium reserves, which are unevenly distributed and sometimes located in politically unstable regions.

This is why there is an urgent need for new large-scale battery technologies that use only inexpensive components and elements abundantly available in nature. Over the past two decades, a spate of articles have been published about lithium-ion-free batteries. One possible approach would be to replace lithium with sodium. Sodium chloride occurs in seawater and is available all over the world.

Aluminum is also available in large quantities, non-toxic and inexpensive. However, due to their cell chemistry, aluminum graphite dual-ion batteries are considerably larger and about five times heavier than lithium-ion batteries with comparable storage capacity. Consequently, there are still several obstacles to overcome in the development of inexpensive, environmentally friendly alternatives to lithium-ion batteries. //



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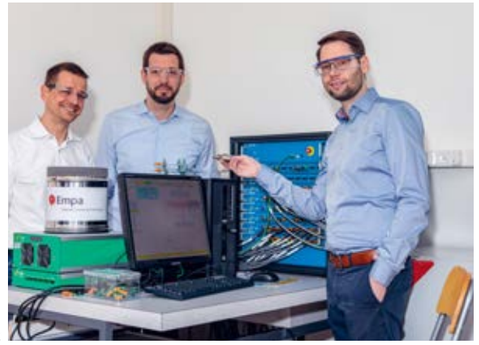
Kostiantyn Kravchyk explains the chemical structure of an aluminum graphite battery.



2
Stephan Fahlbusch, Corsin Battaglia and Ruben-Simon Kühnel (from left) at the Empa test system for experimental battery cells.

FOXIP or the joy of synergy

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Empa deals with technology. According to Wikipedia, technology is defined as the sum of techniques, skills, methods and processes used in the production of goods. What does it take to make products in the first place? You need the four Ms: manpower, materials, methods and machines. A good product results from the perfect synergy of these four Ms. New materials, new methods and new machines in turn make new products and thus innovations possible. For product innovations, we humans must therefore not only develop new materials, but also be familiar with and further develop the methods and machines, as well as testing how products are created from these materials. At Empa, this takes place e.g. in the "Coating Competence Center" (CCC) and in the projects funded by the ETH Domain's "Strategic Focus Area Advanced Manufacturing" (SFA-AM).

Unique high-precision printer

In the SFA-AM-funded project "FOXIP – Functional OXIdes Printed on Polymers and Paper", a consortium of scientists from Empa, EPFL and the Paul Scherrer Institute (PSI) is working with industrial partners to develop electronic components with circuits printed on flexible substrates such as plastic films or paper. To do this, the scientists have to develop new materials, such as inks containing graphene or metal oxides. They also need to develop and test methods and machines for applying these inks to the flexible substrates. For this purpose, the FOXIP project team uses various printing techniques such as gravure, flexographic, screen and inkjet printing. The machine used is a high-precision printer developed specifically by Norbert Schläfli AG for the production of printed electronics and currently only available at Empa's CCC.

Flash lighting for ink

The conductor paths, which are printed with metal oxide inks, must be heated to a high temperature in a second step so that the connections become conductive. However, the flexible substrate must not be damaged by excessively high temperatures during this sintering process. The FOXIP team therefore uses the photonic curing method to sinter the inks, where the printed conductor paths are illuminated in short pulses for a fraction of a millisecond with an extremely powerful flash lamp. In this process, the ink is heated to a high temperature while the printed substrate, e.g. a PET film, is only heated slightly and thus not damaged.

The FOXIP team has demonstrated that electronic circuits can be printed onto polymer films. Touch sensors can also be printed in this way. However, the printed conductor paths must be transparent in order for these films to be usable in touchscreens. The team uses transparent conductive oxides (TCO) for this purpose. Scientists at Empa printed invisible buttons using these TCO inks to demonstrate their function. If you touch certain points on an object printed in this way, you can enter an access code for a door, for example. Besides invisible buttons, there are many other ideas on how to use this new technology. Because everything in the FOXIP project fits together: manpower, materials, methods and machines. //

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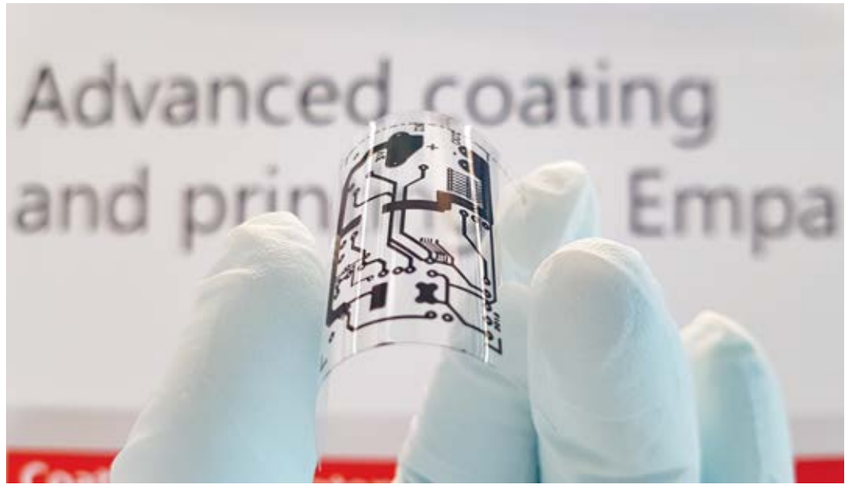
Conductor paths made of graphene inks printed on film using flexographic printing.

2
Sensors that respond to touch can also be printed on plastic films. For invisible control elements, the printed conductor paths must be transparent.



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Reality check for new construction methods

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The guiding principle behind NEST, the modular building for research and innovation by Empa and Eawag is “Exploring the Future of Buildings”. Despite the adverse circumstances caused by the COVID-19 pandemic, NEST managed to live up to this motto in the past year. The distinctive roof shell with double curvature was completed at the construction site of the new NEST unit “HiLo”. The concrete sandwich construction was not built using conventional formwork but with a textile that was placed on a reusable cable network. Thanks to newly developed design and planning algorithms, researchers from ETH Zurich, together with partners from the construction industry, were able to implement a concrete roof of this level of complexity for the first time in an actual construction project.

Two new units in the planning

At the same time, another new unit was being planned. “STEP2” – as it is called – combines innovations in the areas of circular economy, industrial and digital fabrication as well as building envelope and energy systems. It will focus on the marketability of new solutions and processes. Accordingly, all innovations will be developed from the very beginning along the entire value chain in an open innovation approach. The two-storey unit is due to be completed in the summer of 2022. The main partner in this project is BASF, a company with which Empa maintains a strategic innovation partnership.

At the end of 2020, the need for individual workplaces that comply with COVID-19 regulations prompted Empa researchers to search for ideas for yet another unit. A new office unit named “Sprint” that allows for flexible interior design is to be integrated into NEST as fast as possible. And as if that weren’t enough, the new unit is to be constructed almost exclusively with reused materials and components. In this manner, the project team, made up of Empa scientists and reuse experts, is demonstrating to what extent the concept of reuse can be realized and can make a contribution to circular construction.

Energy networking

In the past year, NEST provided valuable infrastructure for both the Energy Hub (ehub, see page 28) and the Digital Hub (dhub). NEST serves as a real-world district where energy flows can be optimized, in some cases incorporating artificial intelligence (AI).

New partnerships

The NEST partner network once more grew significantly in the past year. In this respect, NEST’s cooperation with the Innovation Park Central Switzerland is of particular note. As does NEST, the Innovation Park unites several companies and organizations committed to jointly promoting innovation in the construction sector. The close collaboration of both networks, which has already resulted in multiple joint events and topical workshops, has the aim of increasing synergies in order to create implementable projects at NEST.

While visitor numbers at NEST remained at a very high level in the previous years, in 2020, significantly fewer visitors were able to visit and tour the premises due to the COVID-19 pandemic. To provide news despite the restrictions, Peter Richner, Deputy CEO of Empa, has been airing a new podcast directly from NEST regularly since mid-2020. It will also soon be possible to tour NEST virtually: starting directly from the website, interested parties will then be able to take virtual walks through NEST, meet participating researchers and experience the modular building’s fascination through virtual reality. //

Concrete was sprayed on a textile shell for the roof of the “HiLo” unit. Image: Roman Keller

Saving the climate with synthetic fuels

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The mobility demonstrator move is an example of what a future without fossil fuels might look like. It focuses on electromobility and hydrogen mobility as well as synthetic fuels for hybrid vehicles. These three mobility paths are investigated at move with regard to greenhouse gas emissions as well as energy, technical, operational and economic aspects.

Renewable energy fort he winter

2020 was dedicated to the move-MEGA expansion project that aims to add a methanation facility to move. This facility produces synthetic methane by converting hydrogen and CO_2 (from the atmosphere). Fuels produced with renewable energy, also called synfuel or syngas, can be produced in small and medium-sized facilities in Switzerland as well as large facilities in desert regions and offshore wind farms. From there, they can be transported using existing transport infrastructures and trading mechanisms. Syngas and synfuel are particularly suited for converting long-distance and heavy traffic to the use of renewable energy sources and supplying Switzerland with renewable fuels even in winter.

The novel move-MEGA methanation facility is based on a sorption-enhanced basic catalytic process, in which the water produced by the chemical conversion is continuously absorbed by a highly porous zeolite material and thus removed from the gas mixture. This results in methane that can be fed directly into the grid, which means that the new process does not require subsequent gas treatment as in conventional methanation processes. Together with the lower level of pressure, this means a tangible gain in efficiency compared to regular facilities. Last year, Empa researchers developed the basis for constructing the move-MEGA facility. They determined the required parameters in test facilities, and defined the facility concept at the end of 2020, which is now being evaluated with move's industrial partners.

Clever heat management

While the hydrogen required for methanation is already being produced at move, a CO_2 collector facility from the ETH spin-off Climeworks is to be installed directly on site to supply CO_2 from ambient air. Atmospheric CO_2 is of great importance, especially for larger methanation facilities; on the one hand, this makes the facility location-independent, and on the other, CO_2 transports are no longer necessary. Finally, the extracted CO_2 is pure and does not have to be purified in a subsequent step. However, atmospheric CO_2 extraction requires very high temperatures (about 100 °C). In the move-MEGA project, a large proportion of the required heat is to be covered by waste heat from water electrolysis and the methanation facility.

In addition to technological issues, the team is also looking at the economic viability of such facilities. Investment and operating cost models allowing analyses of methane production costs were developed based on literature data and interviews with industrial partners. These show that the production costs are significantly higher than the supply of fossil fuels, especially at the beginning. Hence, Empa researchers also developed a cost allocation model that shows a comparatively cost-effective switch from fossil fuels to renewable synthetic fuels by 2050. This can massively reduce CO_2 emissions from applications that cannot be electrified at all or not fast enough.

move-MEGA is supported by the canton of Zurich, the ETH Board, Avenergy Suisse, Migros, Lidl Switzerland, Glattwerk, Armasuisse, Swisspower and Seitz AG. //

By 2030, the retailer Lidl Switzerland will switch from fossil diesel to liquefied renewable gas to operate its trucks. Image: Lidl Switzerland

Towards a sustainable and flexible energy system

Philipp Heer, philipp.heer@empa.ch

A stronger network of technologies, energy sources and sectors, a decentralized power grid and increasing digitalisation of the energy system: the transformation to a more sustainable energy system involves major changes as well as huge challenges. To overcome them, energy must be converted more flexibly and stored more efficiently. At Empa, the "Energy Hub" (ehub) is one of the facilities dealing with these topics. The research platform uses the two demonstrators NEST (see page 24) and move (see page 26) to optimize energy management for the entire building complex and simultaneously link the energy flows in the buildings with mobility.

Networked research infrastructures across locations and institutes

To work towards a future energy system, possible technologies must be viewed and analyzed not in isolation but in interaction with each other. For this reason, Empa partnered with ETH Zurich and the Paul Scherrer Institute (PSI) at the end of 2018 to launch the ReMaP Platform (Renewable Management and Real-Time Control Platform) that allows various locations to be flexibly combined. In 2020, the researchers integrated the infrastructures of the ehub at Empa and of the ESI Platform at the PSI into the ReMaP Platform and can now use them jointly for research projects. The project team presented a live demo of the platform to a virtual audience for the first time in December 2020.

Optimization through flexibility

Several research projects of the ehub team in the past year had the aim of making the energy system more flexible. A joint project with the start-up aliunid, for example, explored how energy suppliers can use components in residential buildings more flexibly to increase energy efficiency and reduce emissions. This project examined combinations of various systems such as photovoltaic systems, air-heating pumps, heat storage systems and electric vehicles. Simulations showed that more flexible energy systems could reduce costs by up to 25 and emissions by up to 21 percent for the building complex.

Learning-based control system

In a further project, Empa researchers designed a control system to optimize energy management in buildings using artificial intelligence (AI). In a computer simulation, this system first had to meet certain specifications with regard to room temperature and the charging of an electric vehicle, as well as taking into account two different electricity tariffs. The self-learning algorithm used weather data and room temperatures from previous years. The Empa demonstrator "Digital Hub" provided the data basis. The researchers then subjected their control system to a practical test at NEST. The result was that in the span of one week, the AI control was able to save 27 percent of heating energy compared to a conventional control system.

Progress in the team, projects and exchanges of ideas

Last year saw growth not only of the number of new projects launched with research and business partners, but also of the ehub team itself. A total of four new employees joined ehub in 2020.

In summer, Empa held a webinar in which it explored the following questions with representatives of agencies, regulatory authorities, associations and innovative start-ups: What framework conditions are inhibiting or accelerating the shift to renewable energy? The presentations and discussions further promoted the exchange between research, economy and politics and the mutual understanding on this topic. //

Empa researcher Philipp Heer at an Energy Hub (ehub) terminal. Its infrastructure is designed such that partners from research and industry can remotely control the system via defined interfaces. In this manner, they can gain important findings for their research questions and product development.

Empa activities … … regarding COVID-19

COVID-19 Task Force: Swiss researchers join forces

In order to manage the crisis, experts from relevant fields have joined forces to form the "COVID-19 Task Force" to support Swiss federal agencies as an advisory body. In addition to advising decision-makers, the task force focuses on the development of technologies to help in the fight against SARS-CoV-2, as well as on research into the pathogen and suitable control measures. *Image: iStockfoto*

EmpAIR indicates when rooms need to be ventilated

This Empa development could help to limit the spread of the coronavirus. In addition to humidity, temperature and air pressure, the system also measures the CO_2 concentration in a room and indicates, via an app, when the room needs to be ventilated to supply fresh air. The device operates on the principle that CO_2 concentration is a good proxy of the air exchange in indoor spaces.

Optical biosensor for COVID-19

A team of researchers from Empa, ETH Zurich and Zurich University Hospital has succeeded in developing a novel sensor for detecting coronaviruses. In future, it could be used to measure the concentration of the virus in the environment – for example in places where there are many people or in hospital ventilation systems.

Photo: CDC/Unsplash

Developing better protective equipment against the virus

In order to meet Switzerland's need for protective equipment, researchers from Empa, ETH Zurich, EPFL and the Spiez Laboratory, together with health care and industry partners, have launched the ReMask project. Its objectives are technologies to reuse masks, the domestic production of efficient protective equipment and developing alternative masks to trap and kill viruses.

HelloMask – the first transparent surgical mask

HelloMask, a transparent surgical mask developed by researchers at Empa and EPFL, can be manufactured on an industrial scale. The start-up HMCARE, which was founded for this purpose, has raised 1 million Swiss francs. HelloMask was designed primarily to improve the contact between caregivers and patients. Illustration: EPFL

Life cycle assessments of facemasks

If you want to protect yourself and others from COVID-19, wear a mask. But what about the environmental impact of this mass product? Empa researchers have investigated this issue through life cycle analyses. The calculations show that cotton masks perform better than disposable surgical masks in terms of energy consumption and greenhouse gas emissions. In contrast, surgical masks perform better in terms of water consumption and overall environmental impact. Image: Matthias Heyde/Unsplash

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.

Nanomaterials: driving innovation for future technologies

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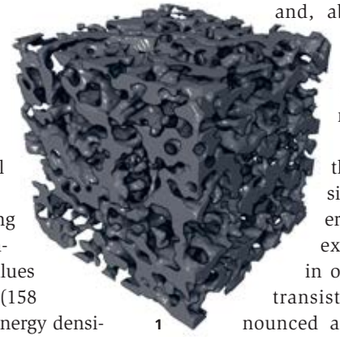
Climate change and the associated necessary reduction of CO_2 emissions, a sustainable energy supply and digitalization are the major social challenges of our time. Overcoming these challenges in an economically feasible way is not possible without technological progress, which generally stems from new materials. Today, material development is mainly based on nanotechnological approaches which focus either on a nanostructure that improves or optimizes material properties or on nanoscale materials with completely novel quantum physical properties.

Printing synaptic transistors, solar cells and supercapacitors

Printing in any form is the most important processing technology for nanomaterials. How to print electronic components and circuits as cheaply as newspapers has become an important research question in recent years. This includes developing processes for the production and preparation of nanomaterials as well as turning them into ink formulations to be used in various printing techniques. Empa researchers achieved a technological breakthrough for the production of printing inks with 2D materials. Thanks to two newly developed and patented processes, one for the efficient and gentle exfoliation of 2D materials and the other for ink production, they can turn any 2D material into inks of any viscosity. This is achieved without using additives, which always generate disruptive effects in printing applications. In accordance with its physical behavior, this group of inks was named "Van der Waals Ink". In an impressive demonstration, the researchers displayed the enormous technological potential of these novel inks for printing electronic components using the example of supercapacitors with record values in surface capacitance (158 mF/cm²) and surface energy density (164°µWh/cm²).



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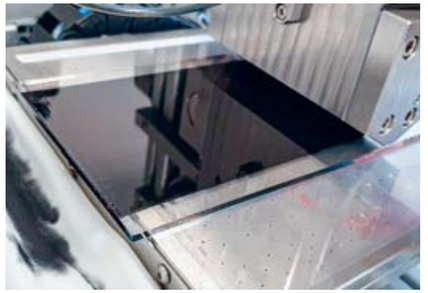
In addition to printing passive electronic components such as capacitors, resistors and conductors, Empa researchers have for years also been developing printing technologies for the production of active electronic components such as transistors, light-emitting diodes and solar cells. The major challenge here is the sintering process, which is necessary to transform the ink into a crystalline solid with the desired electronic properties without damaging the temperature-sensitive polymer or paper substrate. Current developments include printing perovskite solar cells and transistors with oxide semiconductor materials. The latter have significantly better switching characteristics than printed organic transistors and, above all, are much more stable, which is why complex encapsulation is no longer necessary.

While studying the printed oxide transistors, Empa researchers came across an unexpected peculiarity: in operation, the printed transistors exhibit a pronounced and extremely stable hysteresis in turn-on and turn-off behavior. This gives the transistor a memory effect. Its output signal no longer depends only on the intensity of the input signal, but also on its frequency – the transistor's operating principle resembles that of a biological synapse, which is why it is referred to as a synaptic transistor. These transistors are the basis for artificial nervous systems and novel neuromorphic computers, which are modelled after the human brain. The researchers have recently succeeded in printing transistors with synaptic function up to a frequency of 100 kHz, which is two decades higher than all printed synaptic transistors published to date.

Magnetic graphene – there's nothing carbon can't do

The metalloid graphene consists of a two-dimensional honeycomb structure made of carbon atoms, with a thickness of only one atom. In the form of ribbons only a few nanometres in width, the electronic properties of graphene can be adjusted at will, from insulating to semiconducting to metallic, via the width and topology of the edges. Having proven that the "simple" material graphene, in the form of nanoribbons, is equally suitable for nanoelectronics, spintronics and quantum computing, an Empa team has now also succeeded in making graphene nanostructures magnetic. In this process, they initially synthesized triangulene dimers and showed that the magnetic moments of the triangulene molecules in the dimers form a "quantum-entangled" state. Furthermore, they proved that the dimer can be excited from the antiferromagnetic state (spin = 0) to the ferromagnetic state (spin = 1) with an energy of 14 meV. Shantanu Mishra's doctoral thesis, on which these results were based, received the annual award in Condensed Matter Physics from the Swiss Physical Society (SPS) in 2020. //



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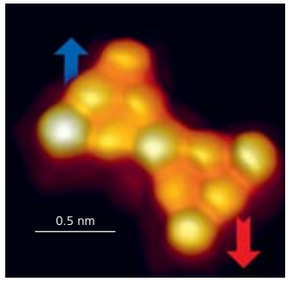

3

1
X-ray tomography image of a graphene gel ink. Edge length: 100 µm

2
In a project funded by the Swiss Federal Office of Energy (SFOE), Empa researchers are working with Solaronix to develop a slot process for the inexpensive production of perovskite solar cells. The process is seven times faster than conventional screen printing.

3
Graphically enhanced atomic force microscope image of a triangulene dimer. The arrows show the antiferromagnetic spin orientation (spin = 0).

Additive manufacturing for a sustainable built environment

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Research in and development of novel materials along with the corresponding manufacturing processes for a sustainable built environment has a long-standing and successful tradition at Empa. A prime example of a novel research activity in this area is Additive Manufacturing (AM). This technology, until recently limited mainly to polymers, now offers new opportunities also for the traditional and most widely used building and construction materials: concrete and asphalt.

Alternative strategies for prestressing 3D printed concrete

3D printing of concrete in the layered extrusion process can open new paths for the application of concrete in the building industry. The ultimate goal of improved sustainability can be reached thanks to enhancing the efficiency and precision of the fabrication process of concrete elements. Most importantly, the formwork and the associated works are eliminated and the material can be deposited in specific locations, enabling a significantly lower consumption of concrete. A further optimization of this technology, currently developed at Empa, becomes feasible with the process of prestressing of the embedded reinforcement. Prestressing, commonly used in precast concrete, improves the cracking resistance and strength-to-weight ratio of concrete elements. However, the practical aspects of the prestressing process are very challenging, if not impossible for 3D printed concrete.

Scientists from Empa's Structural Engineering and Concrete & Asphalt labs, in cooperation with colleagues at ETH Zurich, therefore work on possible solutions. Two strategies are developed in parallel. The first one consists of using ribbed bars made of shape memory alloys (SMAs), a material recently developed at Empa with support of Innosuisse and the Swiss National Science Foundation (SNSF). The embedded bars are activated and hence prestressed by means of heating with electrical current. The first pilot elements 3D printed at ETH Zurich and analyzed at Empa show very promising results – beams with embedded activated SMA bars have a higher cracking resistance compared to those with passive reinforcement. The second strategy under development consists of using expansive, self-prestressing concrete. Self-prestressing, a method recently patented at Empa, is based on using concrete that expands during hardening and prestresses itself, with no need of external actions.

1
3D printing of concrete in a layered extrusion process. The concrete elements are reinforced with embedded shape memory alloy (SMA) bars that, after thermal activation, will exert a prestress on the hardened concrete.

2
A robotic arm lays out a thread on a bed of aggregates. The entangled thread reinforces the aggregates and improves the stability of the layered structure under load, replacing bitumen traditionally used in asphalt pavements. In future, this technique could strongly reduce the environmental impact of road construction.

Potential applications are 3D printed filigree, hollow concrete structural elements with excellent strength-to-weight ratio to be used, for instance, as low-bearing girders for roofs or slabs.

AM to spare bitumen in roads

Asphalt pavements commonly used in road construction usually consist of bituminous agents that provide cohesion to the mineral aggregate filler. Both the bitumen obtained from petroleum and the scarce aggregates are responsible for the large environmental impact of asphalt. An Empa project funded by the Swiss Federal Roads Office (FEDRO) can offer a solution by reducing or even fully eliminating the need for bitumen or other binding agents in pavements. The novel concept is based on the use of soft reinforcement in a form of a thread laid down in a specific pattern by a robotic arm on a bed of aggregates, layer by layer. Thanks to the entanglement of the aggregate particles (stones) with the inlayed thread, tensile forces can be transferred into the depth of the pavement structure providing stability to the aggregates – a role thus far played by bitumen. In addition to reducing the use of bitumen, sustainability can be further increased because this novel method allows the use of recycled aggregates or aggregates of inferior quality compared to those currently used. The mechanical properties of the structures are investigated using discrete element methods (DEM) of computer modelling. The first experimental results prove the feasibility of this breakthrough concept. //

Reducing emissions for better health

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Environmental influences such as air pollutants and noise impair our well-being and performance and have a proven negative impact on the health of the Swiss population. An interdisciplinary team including Empa researchers demonstrated that chronic noise exposure is not the only detriment to health. Even short-term disturbances caused by aircraft noise at night can lead to cardiovascular death within hours. That is why Empa is focusing its research on models of sound generation and propagation and is developing solutions for noise reduction. Empa researchers are for example working on vibration-insulated railway sleepers, low-noise aircraft approach procedures and noise-reducing lightweight construction materials, contributing to noise reduction and thus to a higher quality of life.

Silent traffic

To date, Switzerland has invested around CHF 1.3 billion in railway noise remediation. Nevertheless, almost 100,000 people are still living at noise levels that exceed the permissible limits. In railway traffic, vibro-acoustic phenomena over a very wide frequency range (from a few hertz to the audible range) play a major role, as does the propagation of sound waves through various media. The structure and condition of rail embankments must meet a number of sometimes contradictory requirements: on the one hand, they should transmit as few mechanical and acoustic waves as possible to the environment, and on the other, they should be relatively rigid to make the rails in the embankment as stable as possible – and thus safe – and to reduce wear on rails, sleepers and ballast. Empa, together with EPFL and SBB, has developed new types of rail pads that efficiently damp rail vibrations and allow optimization of the dynamic stiffness of the entire track system depending on the frequency. The newly developed components consist of elastomers with customized viscoelastic properties.

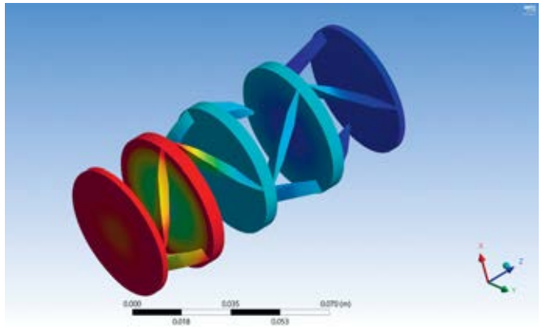
In order to avoid traffic-related transmission of vibrations into the subsoil that cause problems with tremors, Empa acoustics researchers are also developing innovative solutions based on phononic crystals. These are macroscopic crystal structures that use internal rotational movements to mitigate the propagation of sound waves and thus are able to specifically meet the contradictory requirements of high static stiffness on the one hand and low wave transmission on the other at low frequencies.

Urban oasis of calm

Noise-associated health disorders are widespread today. With comprehensive noise analyses, Empa contributes significantly to noise-related health research programs. The aim is to prepare the foundations for preventive and regulatory measures based on a detailed understanding of the factors. New findings on road, rail and aircraft noise were provided, for example, by the SiRENE study ("Short- and Long-Term Effects of Transportation Noise Exposure"), a collaboration between Empa researchers and colleagues from the Swiss TPH ("Swiss Tropical and Public Health Institute"). Thanks to their sophisticated calculation models, Empa researchers succeeded in calculating the noise exposure of the Swiss population to an unprecedented level of detail and with unparalleled accuracy. In addition, a number of "green" metrics were added to the SiRENE study data. The study demonstrated that increased greening of residential areas is associated with reduced noise pollution from road traffic and railways, but with increased noise pollution from air traffic. The overall effect corresponded to an equivalent reduction of about 6 decibels (dB) for road traffic and 3 dB for railroad noise, but an increase of about 10 dB for aircraft noise once the vegetation index increased from "sparse vegetation" (fifth percentile of the sampling distribution) to "abundant vegetation" (ninety-fifth percentile). Especially in cities, visible vegetation and public green spaces with good accessibility can significantly reduce the disturbance caused by road traffic noise. The study concluded that green spaces and vegetation are crucial for the well-being of the urban population and should therefore be an essential element in urban planning. In the follow-up project RESTORE, which, like the SiRENE study, is funded by the Sinergia program of the Swiss National Science Foundation (SNSF), Empa researchers collaborating with the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) are investigating the influence of noise on stress build-up and how urban green spaces can contribute to stress reduction and recreation. //

1
Phononic crystals with multiple applications for vibration isolation.

2
Noise mapping for urban environment (SiRENE project).



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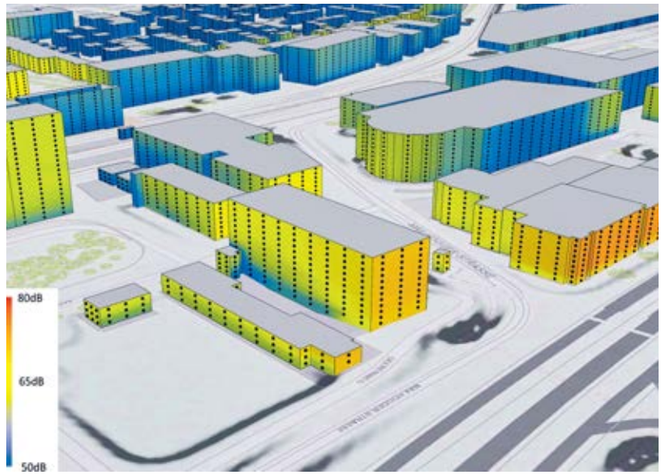

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Energy research – from nanostructured materials to the national energy system

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The plan is for Switzerland to become climate-neutral by 2050 and thus – excluding measures for CO_2 storage – to no longer produce any greenhouse gas emissions. With this long-term goal in mind, concrete steps must now be taken; restructuring the energy system is of key importance here. However, the path to a climate-neutral energy system is strongly influenced by the economic, legal and social framework conditions. In June 2020, Empa held a webinar in which it explored the following question with representatives of regulatory authorities, associations and companies in the energy sector: What framework conditions are inhibiting or accelerating the shift to renewable energy? The lively panel discussion led to the conclusion that this question will continue to be relevant in the future.

Sustainable on-site energy supply

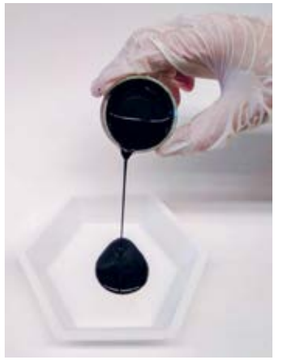
However, the path to a sustainable energy system also presents many communities and companies with very specific challenges, for example with regard to the right decisions when developing a site. Depending on the location and existing infrastructure, specific opportunities and challenges arise, such as in building heating, local electricity production and storage and electric car charging infrastructure. How can the greatest CO_2 reduction be achieved with a given budget? Are there any parameters that have a major effect on a particular area at comparatively low cost? To find quick and accurate answers to these questions, the "Urban Energy Systems" lab at Empa has been developing algorithms, models and methods for several years. After several field tests, these became market-ready in the past year. In April 2020, the Empa spin-off "Urban Sympheny" was founded, which is further developing this technology as a cloud application and has already been able to convince numerous customers.

Empa coordinates European battery research project

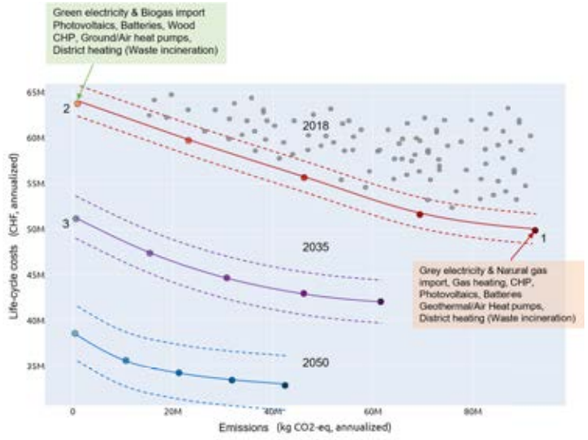
Batteries play a key role in achieving climate neutrality, for example in the field of electromobility and as stationary storage units for solar and wind power. Several Empa labs are conducting research in this area, including "Materials for Energy Conversion", which is coordinating the European "Horizon 2020" project SeNSE, which has been running since the beginning of 2020. In this project, research institutes and industrial companies from seven European countries are looking for solutions to further develop lithium-ion technology, which currently dominates the market. In addition to improvements in cell chemistry and battery management, which, among other things, are intended to increase the fast charging capability and service life of the battery cells, the project seeks to improve safety through the use of non-flammable electrolytes.

Novel materials for compact energy storage devices

Networked mobile devices and implants often require energy storage units. Here, extremely compact electricity storage units are particularly in demand for a reliable energy supply. Micro-supercapacitors are ideal in this context as they have a higher cycle stability than batteries and can be charged and discharged very quickly. Materials research is making significant contributions in this area to achieve higher performance and to enable simpler – and thus cheaper – production. Previously overshadowed by the much better-known graphene, another class of two-dimensional materials called MXenes has come to the fore for this application. They consist of a compound of a metal (M) from the group of transition elements, e.g. titanium, and either carbon or nitrogen (X). Individual 2D layers of these MXenes have different electrical, optical and mechanical properties, depending on the chemical composition and functionalization of their surfaces. Among other things, MXenes can be used to produce electrically conductive inks with adapted flow behavior that do not require any auxiliary materials. This significantly simplifies the production of printed electrodes for micro-supercapacitors. The "Functional Polymers" lab at Empa developed such an MXene-based ink in the past year. According to the motto "turning trash into treasure", MXene production also used the components of the starting material that are normally disposed of as waste. The great potential of this low-waste ink was demonstrated using high-performance micro-supercapacitors. //



1
High-viscosity water-based MXene ink for printed electronics applications.



2
Pareto fronts (set of optimal solutions) for the energy supply of the city of Chur for the years 2018, 2035 and 2050, determined by Sympheny's software. The grey dots show all non-optimal solutions for 2018.

Challenges to societal health solutions

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

The COVID-19 pandemic has highlighted the importance of cooperation between research, hospitals, industry, federal offices and policy makers. It is no coincidence that Empa, with its long-standing relationships, is well connected with all of these key partners as part of the Swiss federal COVID-19 Science Task Force. A pandemic always requires a holistic approach. Specialists from different research areas have to work together as a team so that developments, for example regarding textile face masks, can be achieved in the short time available. Understanding the material properties, the textile construction of the individual layers and industrial feasibility are important foundations for a high-quality product.

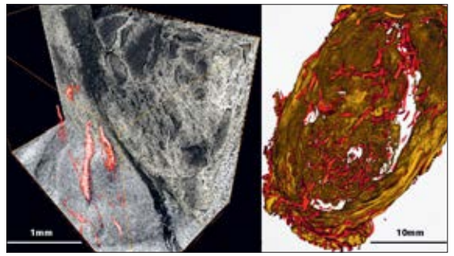
Notably, we have been able to apply our achievements in bioinformatics over the last few years to the pandemic, which proved very valuable for data processing. We established the bioinformatics unit for a quicker and more accurate analysis of health data, including genetic fingerprints, in order to be prepared for the challenges posed by precision medicine. At the same time, the simulation options were also expanded extensively. It is becoming increasingly clear that the synergy of experimental work and simulations is the key to rapid and effective solutions. Our shared viewpoints and expertise in the areas of material synthesis, material processing, bioanalytics, computational modelling and simulations, bioinformatics, imaging and life science are our biggest strength in these challenging times.

Simulation

Long-term medical monitoring is a promising approach for the early diagnosis of future health problems. Reliable and safe data collection as well as sensor technology without restrictions and side effects for the patient are of crucial importance for long-term monitoring that is accepted by the patient as well as the medical staff. Currently, electrically and optically conductive fibres and textiles are being developed that can measure various body signals such as the electrocardiogram, respiratory activity or blood oxygen saturation. These are being tested in clinical practice with partners such as the hospitals Kantonsspital St. Gallen, University Hospital Zurich and Inselspital. In addition, statistical prediction models can be developed by intelligently combining these body signals. These prediction models represent sub-aspects of a patient and, when combined with a multiphysical model of human tissue, act as digital twins. In addition to health monitoring, these twins allow for customized medical treatments such as non-invasive drug administration via the skin using transdermal bandages. The goal is for these virtual doppelgangers to demonstrate how pain patients or diabetics need to be treated individually. The digital avatar also allows for a personalized prognosis of the course of treatment and enables controlling of non-invasive drug administration, as the physiological data of the actual person is fed into the avatar in real time.

Nanomedical systems

In order to develop individual, patient-specific health solutions, Empa researchers anticipate pioneering material designs and concepts by combining their expertise in nanomaterial synthesis with preclinical examinations and customizing the solution to the needs of the clinic. Our multicellular tissue barrier models are capable of depicting human physiological processes so that complex interactions, signalling pathways and healing processes can be holistically mapped using multiscale imaging techniques and bioinformatics. Through the exchange with clinics, this knowledge again led to resounding success in 2020. We have succeeded in developing new nanomaterials which can be used as adhesives after surgical interventions, to positively influence wound healing or to stimulate tissue vascularization. In the year under review, this development was successfully launched as an Empa spin-off.



1
Vascular network (in red) in a partial (left) and in an entire human thyroid carcinoma (right), made visible by high-resolution phase contrast CT.

Systems biology activities were intensified and, as of this year, the team is a member of the Swiss Institute of Bioinformatics. Only an excellent network of experts can keep up with the rapid developments in this field. For example, a new approach was launched in collaboration with Kantonspital St. Gallen to better understand the role of immune cells in cancer tissue, with the aim of developing new nanoparticle-based solutions for cancer treatment.

Implants and prevention of bacterial infections

Materials that steer the response of tissues and cells for regeneration or the replacement of tissue function or which can prevent the infection of tissue implants (e.g. in wounds) or devices are another focus of Empa's research activities. There is a dire need for instructive material concepts for medical therapies, 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 and materials for soft tissue integration or regeneration all the way to materials that optimize and accelerate wound healing. Such concepts are often inspired by principles found in nature. One example is a hybrid cellulose-polymer-based wound material that can be given various functions adapted to clinical needs via cellulose-specific binding peptides.

Biomedical imaging technologies

The development of precision medicine depends heavily on the availability of high-resolution, distorted 3D data of structures in tumor tissue. This will deepen our understanding of the relationship between individual disease symptoms (phenotype) and equally individual genetic traits (genotype). This is the reason why we are pioneering the development of three-dimensional analytical imaging methods for the non-invasive, digital pathology of tumor tissue. This significant amount of data is processed using machine learning and made available for personalized and targeted diagnostics for precision medicine in oncology. The example shows the vascular network in a human thyroid carcinoma. //

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.

Out of Empa and into the market

Marlen Müller, marlen.mueller@empa.ch

In a constantly changing economic and social environment, agility and adaptability are crucial. In other words, new findings and laboratory results should have a positive effect on the real economy as quickly as possible – in the form of marketable innovations. To accelerate this process, Empa relies on rapid technology transfer to the industry and close cooperation with its numerous industrial partners.

In 2020, Empa launched 208 new research projects with industrial partners. It also filed patent applications for 15 inventions and concluded 14 new licensing and technology transfer agreements with business partners.

Successful cooperation on polymer actuators

The Empa spin-off CTsystems AG has been working together with the Swiss industrial company Dätwyler AG in the field of polymer actuators since 2018. Polymer actuators are electroactive polymers (EAP) that change their shape when exposed to electrical voltage and become longer or thicker, for example. Because they function similarly to natural muscles, they are often referred to as "artificial muscles". To date, the spin-off has produced initial prototypes for an electromechanical polymer converter in stack construction. This consists of a large number of thin, stacked elastomer layers, which are coated with special electrodes and are elastic and malleable. In this way, they enable the conversion of electrical energy into mechanical force. Possible applications include the automotive industry, with valves, pumps, closing systems, seat adjusters, haptic feedback systems and switches. The advantages of the new technology, in addition to its robust design, are low energy consumption, a lack of complicated mechanical parts and silent operation with simultaneous sensor function.

CTsystems focuses on the development of product technologies and their production processes as well as on advanced research activities. To introduce the technology to the market, the start-up licences the production of the actuators to various industrial companies. The first production partner is Sateco XT AG, which is currently constructing a pilot plant. Dätwyler AG also intends to produce very large quantities of the actuators.

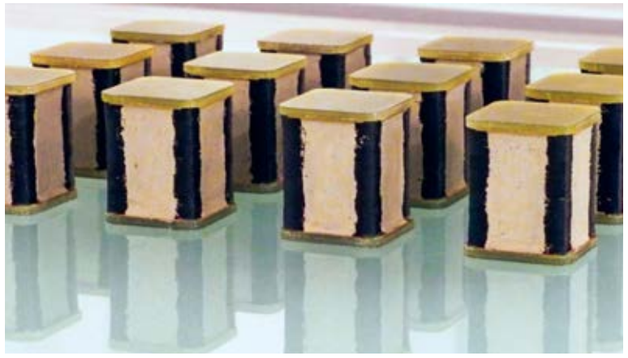
Empa Innovation Award 2020

If innovative projects and achievements in technology transfer stand out, they should also be honored accordingly. Empa has been honoring outstanding innovation and technology transfer projects with the Innovation Award every two years since 2006. In 2020, the award went to three successful technology transfer projects.

The first prize went to a health technology that makes surgical sutures obsolete. Nanoglue is a novel tissue adhesive that promises faster and safer wound healing. It was developed by researchers at Empa and the Nanoparticle Systems Engineering Lab at ETH Zurich. The technology is now being developed for the market by the spin-off anavo AG.

The "HelloMask" project, in which researchers from Empa and EPFL developed a transparent face mask that is marketed by the newly founded start-up HMCare AG, was awarded with a recognition prize. Another recognition prize was awarded to "Sympheny", a software platform for planning sustainable energy systems, which is being commercialized by the Empa spin-off Urban Sympheny AG. //

1
Prototype polymer actuators made from stacked, wafer-thin elastomer layers.
Image: CTsystems



2
Gian-Luca Bona, director at Empa, far left, with the prize winners: Joshua Avossa (HelloMask), Andrew Bollinger (Urban Sympheny AG) and Empa researcher Tino Matter (anavo AG).

Innovative bridges between science and business

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Peter Frischknecht, peter.frischknecht@empa.ch

In the past year, Empa's business incubators have supported 48 start-ups with a total of 474 employees from the initial business idea up to market launch.

Twelve of these start-ups were tenants of the glatec business incubator in Dübendorf; the teams of a further 10 fledgling companies – some of which have yet to be founded – received consulting or coaching. Kilian Schillai, with his company eptra Engineering, is one of the highly motivated young entrepreneurs of the future. After many years of research at Empa and ETH Zurich, his objective is to put his knowledge and experience with ageing energy infrastructures into practice. Key parts of the energy grid are over 50 years old. The materials, construction designs and processes used in the past differ significantly from the current state of the art, so that the use of design procedures and fittings common today can cause damage. He plans to focus on condition and damage analyses as well as simulations and measurements.

However, the established Empa spin-offs at glatec also continued to develop successfully in a difficult year. Urban Sympheny, for example, received a recognition prize as part of the Empa Innovation Award 2020 for its software platform for planning sustainable energy systems. With this award, Empa honors the efforts of its researchers to build further bridges between the worlds of science and business with applied, market-oriented research (see page 46).

"Swiss Wood Solutions" developed wooden bank cards with the name "Wooden Smart Cards". These cards are made from native woods such as maple, curly maple, cherry, oak or spruce. They offer first-class aesthetics, are pleasant to the touch and fully functional. They are intended to replace conventional plastic cards, at least in part. Manufacturing petroleum-based plastic products not only produces large quantities of greenhouse gases, their use also creates an enormous waste problem due to the lack of sufficient recycling concepts and infrastructure.

The Innovation Park East is coming!

Startfeld in St. Gallen celebrated its 10th anniversary in 2020. The joint incubator of Empa, the University of St. Gallen and the Eastern Switzerland University of Applied Sciences OST provided 2020 more than 150 initial consultations, supported twelve projects with funding packages of up to 10,500 Swiss francs and provided three financings totalling 900,000 Swiss francs.

The Empa project "anavo" received the title of spin-off from Empa and the University of St. Gallen. Its nanoparticle paste is based on a unique formulation that uses state-of-the-art nanotechnology. It increases the body's ability to heal itself and keeps bacterial infections at bay. The paste helps surgeons to ensure patient safety and survival by reducing surgical complications and enabling rapid healing. This technology was developed at Empa in St. Gallen and at ETH Zurich. anavo was the winner of the Empa Innovation Award 2020.

matriq AG, a spin-off of the OST Campus Buchs, won the Startfeld Diamant 2020 award, won phases I and II of the Venture Kick program "at venture" and was a finalist matriq offers innovative solutions for the individual marking of plastic parts of all kinds. With its DynamicMold technology, the marking takes place directly in the production machine, whether during injection moulding, blow moulding or thermoforming. In addition to the track & trace application, DynamicMold technology also offers the possibility of integrating product protection.
Startfeld's activities were also included in Eastern Switzerland's application for the Innovation Park East as part of the "Switzerland Innovation" network. This application was positively assessed by the Foundation Board of "Switzerland Innovation" for the attention of the Federal Council. Therefore, nothing stands in the way of the implementation of the Innovation Park East with the main location in the immediate vicinity of Empa in St. Gallen and another location in Buchs. //

1

2

1
The main location of the planned Innovation Park East is in the immediate vicinity of Empa.

2
"Swiss Wood Solutions" developed bank cards made from local wood with the name "Wooden Smart Cards". Image: Swiss Wood Solutions

Empa Zukunftsfonds – Research for tomorrow

Gabriele Dobenecker, gabriele.dobenecker@empa.ch

Limitless mobility, increasing demand for energy, good health and performance into old age, comfortable living space – how can these needs be met if we want to treat the earth with care at the same time in order to pass it on to our children in such a way that they will still be comfortable on it? The answer lies in developing innovative technologies and novel materials that will enable us to shape a sustainable, liveable, resilient and economically successful future.

What we envision is an economic system that ultimately thinks and acts in cycles and abandons the previous throw-away society as much as possible. That is why closing materials cycles wherever possible is one of our central tenets. Our reserves of raw materials are finite and far too valuable to not recycle.

The Empa Zukunftsfonds supports research projects and promising research talents at Empa that have not yet received any other funding: forward-looking ideas that can make an important contribution to a more sustainable world. The Zukunftsfonds grants funding committed to it as non-profit donations by companies, foundations and private citizens.

Towards a sustainable circular economy

An ecologically and economically functioning circular economy needs new types of recyclable materials, processes and systems. With its "Research Call 2020" with the strategic topic "circular economy", Empa called for novel and potentially groundbreaking ideas for solving these challenges and initiated forward-looking research projects for recyclable materials, processes and systems. A total of almost 40 projects were received, 15 of which received funding; two of these 15 projects also received funding from the Ernst Göhner Foundation.

Fluorine recycling for lithium-ion batteries

One of these is the "Fluoribat" research project. Due to the enormous number of batteries that have to be manufactured and recycled, a chemical element that has rarely been discussed comes into focus: fluorine. It is found – in small quantities – in all lithium-ion batteries. The electrolyte fluid of these batteries contains fluorine-rich salts which decompose in moist air, releasing toxic, highly corrosive hydrogen fluoride. So, while the battery is in use, it must be in a completely sealed, airtight casing, or it will emit toxic fluorine compounds. However, this airtight casing is slit open at the very latest during the recycling process. The release of hydrogen fluoride makes recycling complicated and expensive. "Fluoribat" aims to solve this problem. This could make the life cycle of a rechargeable battery much more sustainable and simultaneously safer.

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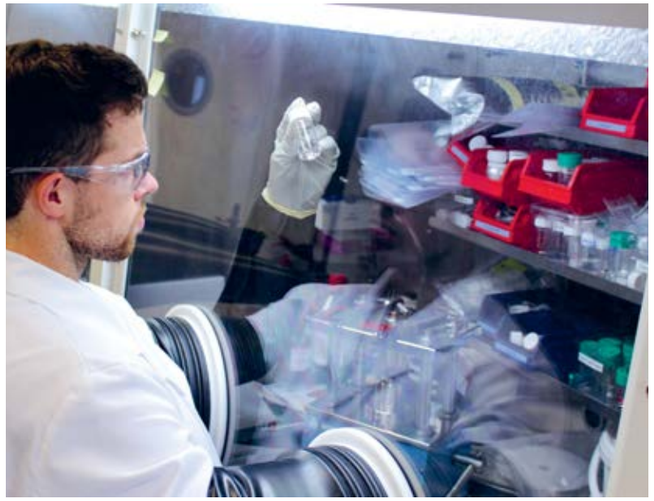


2

1
Maximilian Becker researches water-stable lithium salts for use in novel lithium-ion batteries at Empa.

2
Sparking flame during the explosion of a lithium-ion battery (type 18650). Water-based lithium-ion batteries would be safer to handle and easier to recycle.

Development of environmentally friendly ultra-high-performance concrete

Another project aims to make a significant contribution to sustainable development in the construction industry by developing an environmentally friendly ultra-high-performance concrete that is volumetrically prestressed with shape memory alloy (SMA). The aim of the project is to reduce CO_2 emissions by using concrete with significantly less ordinary Portland cement – which is mainly responsible for the poor carbon footprint of concrete – and to improve the durability of structural concrete in order to produce thinner concrete elements and extend the life of structures.

Entirely online

Since in-person events were hardly possible in 2020 due to the pandemic, the Empa Zukunftsfonds' donor event in December was held as a completely virtual affair for the first time. An entertaining presentation gave donors an overview of the most exciting projects of the year. //

Maintaining global networks in a pandemic world

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

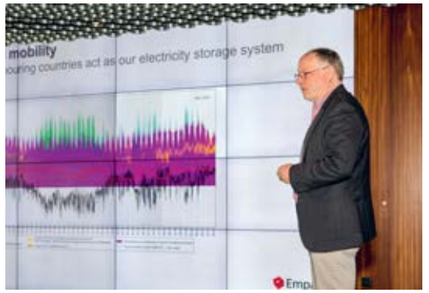
Direct exchange with our international partners – Empa's network is more or less global and includes cooperation projects with researchers from almost 100 countries – has probably suffered the most as a result of the pandemic. Numerous meetings were cancelled or moved to virtual space thanks to Zoom and the like.

At the beginning of the year, networking was nearly "normal". Thus, in the first two months of 2020, Empa was able to welcome various international delegations to its campuses and exchange ideas with them on future challenges and innovative approaches to solutions. In February, for instance, a delegation from the British Embassy in Switzerland was given a guided tour of the NEST innovation building by Empa CEO Gian-Luca Bona. Shortly before that, the energy delegation of the German Federal Institute for Materials Research and Testing (BAM) had already visited NEST and discussed further possibilities for future cooperation in the energy sector with Empa Deputy CEO Peter Richner.

From March and April onwards, only a few meetings took place live; apart from these, Empa's Board of Directors (almost) only saw its peers on screen, for example in the context of various board of trustees and advisory board meetings of foreign universities and research institutions, as well as for meetings as part of large-scale international research projects, in which Empa is involved, such as the ICON project for the development of novel battery technologies with the Fraunhofer-Gesellschaft. Pierangelo Gröning represented Switzerland, together with representatives of the State Secretariat for Education, Research and Innovation (SERI), at an expert meeting for the field of nanotechnologies, advanced materials, biotechnology and advanced manufacturing and processing (NMBP) of the new EU research funding framework program "Horizon 2020". And in June, Brigitte Buchmann and Empa researcher and head of the ehub demonstration platform (see page 28) Philipp Heer, as a speaker, participated at the "Swiss-US Energy Innovation Day 2020" (SUEID).

What has this new experience taught us for the future, the "new normal" of tomorrow? Many things work quite well, some even better. It is faster and easier to meet in virtual space than to travel across the (real) globe in any case. Another positive side effect is that Empa's carbon footprint could also be reduced by the decrease in business travels in 2020. Nevertheless, Empa will continue to seek and maintain direct personal exchange with its central stakeholders in future, as soon as this is possible again. Some things are simply easier to discuss face to face, especially when meeting a potential partner for the first time – the pandemic has taught us this, too. //

1
Empa CEO Gian-Luca Bona with the British ambassador Jane Owen (second from the right) and further members of the delegation at the Urban Mining NEST unit.



2
Empa lab head Christian Bach presents move, Empa's Future Mobility Demonstrator, and options for post-fossil mobility to a group of visitors at the NEST multimedia wall in February 2020 – shortly thereafter, such meetings could only be held virtually.

Dialog and exchange go virtual

Dr Michael Hagmann, michael.hagmann@empa.ch

Normally, this section would include how important a direct exchange and the dialog with all its stakeholders is to Empa and how it cultivates this. Nothing has changed in terms of importance, but manners and methods have had to be modified because of COVID-19.

The figures are clear – or rather, sobering. While we were able to welcome more than 15,000 visitors in 2019, 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, this number fell by a staggering 80 percent to less than 3,000 last year. Countless visits and events that had already been planned had to be cancelled – including, unfortunately, our Open Lab Days in June to mark Empa's 140th anniversary.

Empa goes virtual

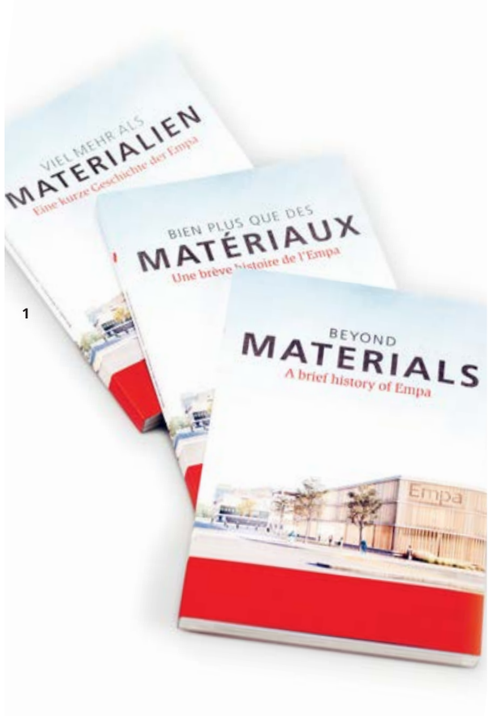
In response to this, Empa has become increasingly "virtualized", significantly faster than originally anticipated: to a large degree, the Empa Academy held hybrid and purely digital events, which were at least able to draw 850 online participants, and it will continue to expand its offerings in this area in the future. At NEST, visitors will soon have the opportunity to take a virtual walk through the various units of the research building and experience their numerous innovations interactively – via podcasts, videos, chatbots and the like. In this way, we want to try to offer a digital substitute that is as adequate as possible for live events and visits in the digital world, while knowing perfectly well that the lively exchange and networking – central elements of our communication activities – cannot be cultivated to the same extent.

As soon as circumstances allowed, various delegations, mainly made up of C-level representatives, nevertheless visited Empa in the past year and exchanged information with Empa's Board of Directors and researchers on upcoming challenges and projects. These included institutions such as the Swiss National Science Foundation (SNSF), the industry associations Scienceindustries and Swissmem as well as the Federal Office for the Environment (FOEN). On the occasion of its visit in July, FOEN's senior management, together with the Empa project managers, was also able to officially open the brand-new measuring station of the Swiss National Air Pollution Monitoring Network (NABEL) in Dübendorf, albeit on a modest scale.

Unprecedented media response "thanks to" COVID-19

Digital communication is less affected by (biological) viruses. Accordingly, it was extremely successful in 2020, despite or maybe even because of COVID-19. Empa researchers, also in their capacity as members of the Science Task Force, contributed various projects towards getting the situation under control (see page 30). Thus, media interest in Empa research was also enormously high in the pandemic year: almost 7,700 media articles in 38 languages reported on Empa's research activities – more (and more internationally) than ever before and a further increase on the already record-breaking prior year.

A very special communication product was published in 2020: the book "Beyond Materials – A brief history of Empa" describes Empa's 140-year history over nearly 220 pages with many images and illustrations, from its beginnings as a modest basement laboratory at ETH Zurich as a testing facility for building materials to the modern research institute it is today. Throughout its history, Empa has repeatedly played a decisive role in shaping Swiss industrial history. //



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1
Empa's book "Beyond Materials – A brief history of Empa" gives an insight into the institute's history, as well as an outlook on the future. The book describes how innovations from Empa's labs can help to meet the challenges of the future and keep Switzerland's economy internationally competitive.

2
A Swiss TV crew in an Empa lab: media interest in Empa's research – especially in connection with the coronavirus – was very high in the pandemic year.

3
The Empa PhD Symposium 2020 was held as hybrid conference, as were many other events in the past year. Only a few lecturers and participants were on site, most of them tuned in from home.

2

3

Women scientists extremely productive despite COVID-19

Dr Marianne Senn, marianne.senn@empa.ch

Since April 2020, there have been surveys of women's scientific publication activity worldwide that suggest women are publishing less due to COVID-19. This is because they are more involved in care work than men and spend more hours on housework and childcare. This particularly affects single parents. For this reason, Empa also conducted a survey on first authors of peer-reviewed publications. The results showed that no such adverse effect could be observed at Empa.

The percentage of female authors rose in comparison with the last two years from 26.2 to 28.9 percent; although the proportion of women among the academic staff decreased slightly – from 26 to 25.5 percent. Surveys of female authors in the coming years will show whether the effects of COVID-19 may be delayed in this area. In this difficult environment, the researcher Dorina Opris almost bucks the trend since she succeeded in winning one of the prestigious Consolidator Grants of the European Research Council (ERC) in 2020, which is endowed with two million euros. With the help of the grant, the researcher will be able to further expand her research group in the field of novel polymers for energy conversion over the next five years.

Equal opportunity action plan for the next four years

Committed staff members have developed Empa's new equal opportunity action plan. Five key areas form the framework for the plan: permanently establishing equal opportunities at Empa; respectful behavior at Empa; equal opportunities for all, especially regarding women in leadership positions; life-domain balance between work and private life; diversity and inclusion.

The action plan includes various measures such as:

- annual awareness-raising for all Empa staff regarding the problem of unconscious bias
- the promotion of women's careers in science and industry through various programs ("Fix the leaky pipeline", CONNECT and the new "We advance")
- stimulating the exchange of knowledge regarding support programs and flexible working arrangements for young parents
- getting to know the cultures of foreign employees better

For additional information on the action plan, see the "Equal Opportunities" section on the Empa website.

Youth research

This summer, despite difficult circumstances, a one-week camp was again held for the children of staff members, where they got to know their parents' workplace in a playful way. The extremely popular Future Day for girls and boys with insights into the technical and scientific careers at Empa in November unfortunately had to be cancelled – like so many other events – due to COVID-19. //

1
Empa researcher Dorina Opris studies novel polymers. In 2020, she was one of almost 330 researchers from all over Europe to receive one of the coveted Consolidator Grants from the European Research Council (ERC). Image above: BM PHOTOS on behalf of SNSF

2
Stay cool at summer camp: when casting tin, you have to be patient, stay calm and always keep an eye on the flame.

Environment and energy in the year of COVID-19

Marcel Gauch, marcel.gauch@empa.ch

2020 was a very interesting year, as circumstances related to the pandemic also served as a basis for investigating real-world environmental impacts. Radical measures had to be taken, for example a decrease in business flights and reduced work on site in offices and laboratories in favor of working from home. Did these drastic measures also bring about a corresponding reduction in environmental impacts? In the area of business travel, the expected results were confirmed: flights and business trips by train and by car decreased significantly (flights by almost 80 percent). There was also a significant decrease in water and paper consumption. Surprisingly, however, the demand for electricity and heat hardly declined at all. Our infrastructure thus required the same amount of energy regardless of personnel use, which means that we must consider more flexible methods of adapting to requirements in future. From an environmental point of view, the effects of more work from home are difficult to assess. How much of an impact did the reduction in commuting have, and what are the effects of the significant increase in the use of virtual communications?

Compensating for CO_2 emissions from business travel

Environmental taxes to third parties are – often with good reason – viewed critically or even considered equal to selling indulgences as they do not involve taking personal responsibility. In 2020, Empa introduced an interesting compensation system for CO_2 that applies to the entire field of business travel by plane and car. The tax per tonne of emitted CO_2 is higher than for commercial providers with compensation projects that mainly take place abroad. At Empa, the proceeds from the CO_2 tax are now being used for the in-house switch from fossil fuels to biogas, resulting in a direct advantage in achieving our climate goals. According to the requirements of the "Climate package of the Federal Administration", the Swiss Confederation, including the ETH Domain, must achieve "net zero" CO_2 emissions by 2030.

Employee engagement in environmental issues

Environmentally friendly behavior is important to many employees in their private lives. At the workplace, by contrast, employees are at the mercy of the employer's decisions and accept the workplace conditions as given. Fortunately, this situation has been changing progressively; for example, a grassroots group for sustainability issues was established in 2020 which supports Empa's official efforts toward sustainability with small contributions. One example is the national Clean-Up Day, which was organized jointly with Eawag. //

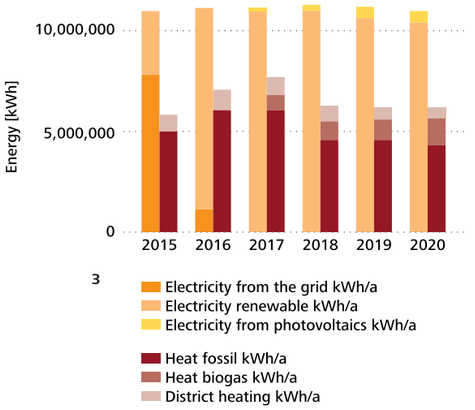
1
Joint effort of the grassroots group and Eawag, supported by Empa's Facility Management on Clean-Up Day in September 2020.

2
Massive restrictions of air traffic: empty check-in counters at Zurich Airport.

3
Development of Empa's energy consumption. The demand for thermal energy (building infrastructure) did not decrease despite lower numbers of staff on site, while the proportion of biogas/renewable energy was increased thanks to income from the internal CO_2 tax. The demand for electricity decreased slightly.

1

2



3

Facts and Figures

Researchers like measuring, including their own performance: in 2020, Empa researchers and engineers published 852 academic papers and filed patent applications for 15 developments. At the end of the year, 104 projects funded by the Swiss National Science Foundation (SNSF), 81 projects backed by Innosuisse and 72 EU projects were underway at Empa. Together with other start-ups in Empa's two business incubators, the 29 spin-offs employed a total of 1,147 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 at Empa is to identify potential risks for the company 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 culture of health and safety and thus constantly improves the 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 federal government. 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 health and 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 categories 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.

The challenge of COVID-19

As in all other walks of life, COVID-19 has dominated the work of risk management in 2020. The general lockdown also affected Empa. The Board of Directors decided to maintain minimum operations. A large proportion of the staff worked from home – with the exception of a greatly reduced minimum research and support staff necessary for critical research projects such as the development of masks and ensuring their safety.

Organizing and implementing minimum operations while maintaining the greatest possible safety for employees was a challenge for the risk management organization and tied up a large part of its resources. An existing pandemic concept facilitated a structured approach to a previously largely unknown situation. Empa's in-house rescue service played a special role in overcoming the crisis. It served as Empa's link to the national and cantonal authorities, incorporating all epidemiological findings into internal processes and measures and helping to shape the concepts. The in-house rescue service, in addition to providing normal medical care at Empa and Eawag, took over internal contact tracing and employee counselling regarding all issues specific to COVID-19. It also conducted over 100 training sessions on hygiene measures and the use of masks for all employees of Empa and Eawag at all three locations. Hundreds of conversations, e-mails and telephone calls, as well as a multitude of expedient measures, raised awareness among and reassured employees. Direct contagion between employees at the institutes was successfully prevented.

Developing security issues

A central aspect of prevention at Empa is the training of staff. The risk management division offers a wide range of training courses in the fields of chemical, nanotechnology and laser safety, etc. for different user levels. With 450 to 500 new employees and academic guests arriving at Empa each year, this is a mammoth task, which has not been made any easier by the COVID-19 situation.

The in-house rescue service, as well as the fire and chemical response team, have maintained their drill regime throughout 2020. The level of training was raised even further through selective advanced training. Cross-thematic drills were cancelled due to COVID-19 and rescheduled for a later date.

As a result of the increasing amount of drone air activity on the campus, a regulation for compliance with minimum security requirements was prepared and legal issues were clarified. It was also necessary to procure specific equipment such as various barrier and information materials and suitable fire extinguishers. The corresponding directive came into force on 1 October 2020.

The topic of information security has gained further relevance for our institution in the past year. A directive for dealing with the complex cloud issue has been drawn up and will be introduced shortly. A core team was formed with the aim of systematically addressing the issue of information security, analyzing the situation and defining and implementing a framework tailored to Empa's needs. //

Human resources development

(previous year's figures in brackets)

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At the end of 2020, 1022 (1033) people, including trainees, were working at Empa. This corresponds to a full-time equivalent (FTE) of 958.2 (967.5) positions, due to numerous part-time employments.

Scientific staff, including PhD and postdoctoral students, comprises 588 (593) individuals. Of these, 104 (103) are Senior Scientists. Technical and administrative staff comprised 393 (398) persons in the year under review. The proportion of women, at 29.7 (30.4) percent, reflects the gender distribution among graduates from Swiss universities and ETH in the scientific disciplines represented at Empa.

The proportion of foreign citizens was 470 (468), or 46.0 (45.3) percent of the total staff. The EU accounts for 285 (287) persons, or 60.6 (61.3) percent of all foreign employees. Empa offers vocational training for a number of professions and currently employs 41 (42) apprentices. As in previous years, all Empa apprentices successfully passed their final exams in 2020. //

STAFF END OF 2020

	2019	2020
Scientific staff	593	588
Technical and administrative staff	398	393
Apprentices	42	41
Total	1033	1022

Key Figures

SCIENTIFIC OUTPUT

	2019	2020
ISI publications	718	852
Conference contributions	1250	494
Doctoral studies completed	37	28
Doctoral studies in progress	208	199
Teaching activities (in hours)	4406	4942
Prizes and awards	81	46

MEDIA EXPOSURE

	2019	2020
Radio	169	118
TV	63	55
Print	1730	1405
Online	5500	6090
Total	7460	7665
Languages	34	38

EMPA ACADEMY

	2019	2020
Empa events	48	24
Participants	2280	1300
On-site visits / online		450 / 850
Scientific conferences	12	6
Events for industry	21	13

KNOWLEDGE DISSEMINATION & TECHNOLOGY TRANSFER

	2019	2020
New R&D Agreements	193	208
Active exploitation contracts	66	66
New exploitation contracts	12	14
New patent applications	12	15

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

	2019	2020
Companies total	104	119
thereof spin-offs	27	29
Employees total	956	1147
thereof employees of spin-offs	136	155

CURRENT PROJECTS

	2019	2020
Swiss National Science Foundation (SNSF)	105	104
Innosuisse	89	81
EU projects	72	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).

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Urs Mäder Dr, SATW, Zürich
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 Dürig Dr, IBM, Rüschlikon
Thomas Egli Prof. em. Dr, Feldmeilen
Marcus Textor Prof. Dr, ETH Zürich
Alexander Wokaun Prof. Dr, Endingen

Organizational chart

as of May 2021

RESEARCH FOCUS AREAS
(Research priorities)

Nanoscale Materials and Technologies
Dr Pierangelo Gröning

Sustainable Built Environment
Dr Tanja Zimmermann
Dr Mateusz Wyrzykowski

Health and Performance
Prof. Dr Alex Dommann

Resources and Pollutants
Dr Brigitte Buchmann

Energy
Dr Peter Richner
Dr Björn Niesen

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

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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

Mobility, Energy and Environment
Dr Brigitte Buchmann

Functional Materials
Dr Tanja Zimmermann

Scientific IT
Dr Tanja Zimmermann

Materials and Technology Center of Robotics
Prof. Dr Mirko Kovac

Corporate Services
Dr Urs Leemann

Library (Lib4RI)
Dr Lothar Nunnenmacher

Fundraising / Entrepreneurship / Industry Relations
Gabriele Dobenecker

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

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Prof. Dr Edoardo Mazza

Urban Energy Systems
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Prof. Dr René Rossi

Particles-Biology Interactions
Dr Peter Wick

Biointerfaces
Prof. Dr Katharina Maniura

Transport at Nanoscale Interfaces
Prof. Dr Michel Calame

Materials for Energy Conversion
Dr Corsin Battaglia

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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

High Performance Ceramics
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Concrete and Asphalt
Prof. Dr Pietro Lura

Cellulose & Wood Materials
Dr Gustav Nyström

Building Energy Materials and Components
Dr Wim Malfait a.i.

Advanced Fibers
Prof. Dr Manfred Heuberger

ICT-Services
Stephan Koch

Mechanical Engineering / Workshop
Stefan Hösli

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Heidi Leutwyler

Communication
Dr Michael Hagmann

Human Resources
André Schmid

Knowledge and Technology Transfer / Legal
Marlen Müller

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Empa – The Place where Innovation Starts

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