Annual Report 2021

Empa
Materials Science and Technology

Our Vision.
Materials and Technologies for a Sustainable Future.

Cover Photo:
Data flow in glycerol: An Empa team has developed a fiber that is significantly more robust than glass fibers and can transmit data just as reliably. The core of the kilometer-long optical fiber consists of liquid glycerol. Such fibers are suitable, for example, for microhydraulic components and light sensors.

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Focus on people

After almost 13 years at the helm of Empa, this is my last editorial. I have had the privilege of serving as the CEO of a great institution with a unique culture, and of walking part of the way with it. I have always been impressed by the openness of our staff to tackle new challenges and to use their knowledge to break new ground. I have repeatedly been able to experience how new things have emerged through cooperation across different laboratories. After all, it is often at the interface between different disciplines that new things emerge. This agility is a hallmark of Empa's culture and allows us to initiate new innovations in materials science and technology development, based on fundamental research. The following pages will give you an insight into the broad spectrum of research and knowledge and technology transfer at Empa.

The last two years have been dominated by the pandemic, which has triggered major changes – and will continue to challenge us. Local solutions and production are once again in demand as global supply chains collapse. In addition, geopolitical challenges are now greater than ever. Switzerland's relationship with the EU has been severely tested, with a serious impact on science as well. Furthermore, the fault lines between Western democracies and autocratically dominated states like Russia and China, as well as in the Middle East, have increased dramatically. The attack on Ukraine has radically demonstrated that a new era has dawned, which Switzerland will also have to face and which will demand sacrifices from all of us.

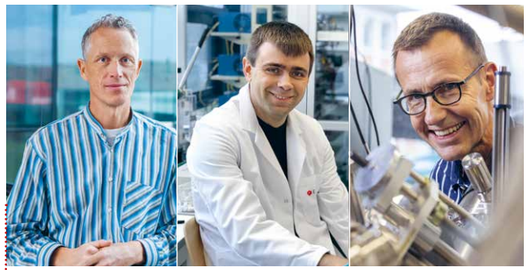
Independence from foreign fossil energy will cost Europe as a whole significantly and will thus also demand a great deal from Switzerland in its transition to a sustainable energy system. Changes in production technologies by additive manufacturing and digitalization will challenge us just as much. It is important to ensure that these developments are in line with our social priorities – for a Switzerland that is fit for the digital age and an economy, for which people are at the center. Data science allows intelligent control and secure monitoring of numerous production processes, for example via artificial intelligence and sensor networks. With 3D printing of new materials as well as machine learning in manufacturing processes and digital twins in system solutions, exciting new possibilities are opening up.

At first glance, this seems to make our world much more complex. But on closer inspection, this is a huge opportunity for all of us: for Empa as an interdisciplinary research institute, as well as for the highly diversified Swiss economy. Just as we are already conducting research across all our labs and disciplines and transferring the results to industry, concepts from one sector of industry will in future be quickly transferred to others. What is being developed today for solutions in the automotive industry may already inspire the medtech sector tomorrow.

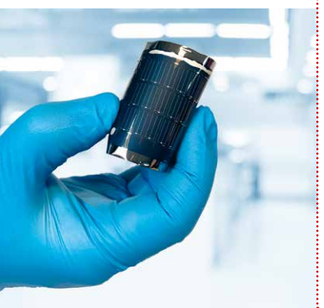
I am convinced that Empa, as a driver of innovation, will continue to be of utmost importance to Switzerland's ability to face the future in the years to come. The know-how and broad experience of our highly motivated staff will lead to new materials and technologies that will make a significant contribution to shaping our future in a livable and sustainable way.

Prof. Dr Gian-Luca Bona Director

Year at a Glance

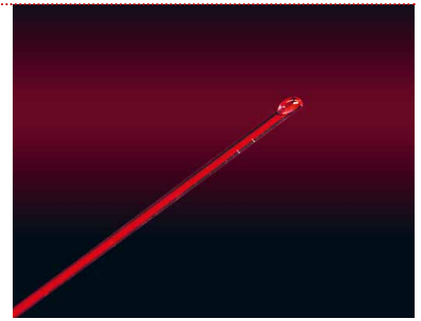


Three Empa researchers honored as influencers
Influencers exist not only in social media, but also in the scientific sphere. The influence of researchers is measured by how often their work is cited by other scientists. Every year, the analytics firm Clarivate announces highly cited researchers in various fields. In 2021, for the first time, three Empa scientists were featured in this scientific who's who: Bernd Nowack, Maksym Kovalenko and Roman Fasel.



Making flexible solar cells competitive
Scientists at Empa have achieved a new efficiency record of just under 21.4 percent for flexible CIGS solar cells. Solar cells of this type are especially suited for applications on roofs, transport vehicles or mobile devices. Flexible CIGS solar cells consist of very thin layers of a semiconductor compound composed of the elements copper, indium, gallium and selenium. By contrast, the top efficiency of a regular (non-flexible) solar cell made of crystalline silicon is 26.7 percent.

Data streams in glycerin
Data and signals can be transmitted quickly and reliably with glass fibers – as long as the fibers do not break. Tensile stress or bending them too far can quickly destroy them. An Empa team has developed a fiber that is much more robust and can transmit data just as reliably. The core of the optical fiber, which extends for miles, consists of liquid glycerin. These fibers can even be used to build microhydraulic components and light sensors.



Green fuels for aviation
Researchers at Empa and the Paul Scherrer Institute (PSI) have launched the joint initiative SynFuels. The goal is to develop a process for producing kerosene from renewable resources. This process aims to create liquid fuel using CO_2 and hydrogen, which would allow the most residue-free combustion possible and thus be suitable for aircraft propulsion. Photo: Pascal Meier / Unsplash

High-resolution models merge weather and climate
With torrential rain, hailstorms and floods, 2021 has highlighted just how severe thunderstorms can affect the environment. But how exactly are extreme weather events connected to global warming? In order to gain a better understanding of this phenomenon and forecast storms with greater accuracy, ETH Zurich, Empa and further partners are developing a new generation of high-resolution weather and climate models through the EXCLAIM research initiative. These models integrate regional weather models and simulate windstorms, thunderstorms or hurricanes. File photo: Wikipedia

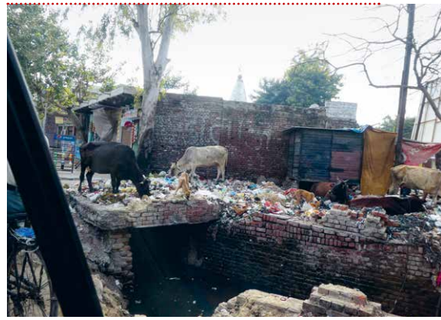
Innovation Park East becomes part of Switzerland Innovation
The national innovation platform Switzerland Innovation is expanding its network in Eastern Switzerland with its latest addition, the Innovation Park East. In April 2021, the Swiss Federal Council approved the project. The main location is in the immediate vicinity of Empa in St. Gallen.

NCCR Automation develops intelligent energy systems
The new National Center of Competence in Research (NCCR) Automation has been launched – with the goal of establishing Switzerland as one of the world's leading hubs for research, education and innovation in automation and control technology. As one of the four participating institutions, which also include ETH Zurich, EPFL and the University of Applied Sciences and Arts Northwestern Switzerland (FHNW), Empa is contributing its expertise in data and energy management. Photo: Claudio Schwarz / Unsplash

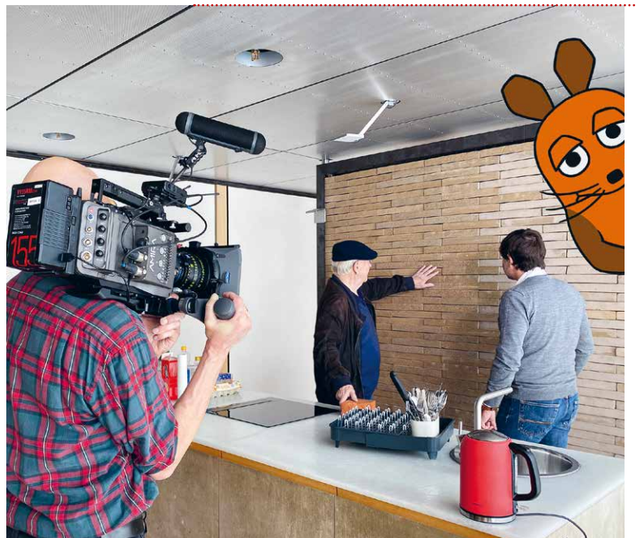
Storing solar energy underground
During the winter months, the renewable energy that accumulates in our region is not sufficient to get us through the cold (and dark) season. That is why research on seasonal storage and conversion technologies is currently in high gear. Empa is part of an international project that is considering an unconventional solution: pumping renewable hydrogen and CO_2 into the ground together, where naturally occurring microorganisms convert the two substances into methane, the main component of natural gas. Image: Karin Lohberger / RAG

Powerfuel exhibition at the Swiss Museum of Transport
Together with its partners Avenergy Suisse and Hyundai, Empa has displayed a permanent exhibition on sustainable fuels of the future at the Swiss Museum of Transport in Lucerne since March 2021. Among other things, the exhibition focuses on the questions of how to use green energy to fuel vehicles and how to find out which fuels are suitable for which purposes. In an interactive game, visitors can even virtually produce hydrogen themselves.

Detoxifiers from landfills
Valuable bacteria that can degrade environmental toxins and chemical contamination are buried in the midst of waste. The focus here is on combating pesticides such as lindane or brominated flame retardants, which accumulate in nature and in food chains. Researchers at Empa and Eawag used bacteria from a landfill in India to generate enzymes that can break down these and similar chemicals. Image: Avinash Kumar / Unsplash



In-flight diagnosis
Together with teams from England and Germany, Empa researchers have developed a monitoring system for aircraft components. In future, it may be possible to detect and monitor minor damage during flight without the aircraft having to go into the hangar for maintenance. This will reduce operating costs and increase safety at the same time. File photo: carlos photos



A mouse in the NEST
In March 2021, the German TV program "Sendung mit der Maus" (the show with the mouse) celebrated its 50th anniversary. For the anniversary edition of the most successful children's show on German TV, Armin Maiwald, the show's host since the very beginning, visited NEST. This show focused on the question: How can we ensure circular construction in the future? As a concrete example, the special features the unit Urban Mining & Recycling, where recycled materials such as bricks made from construction waste and a kitchen worktop made from recycled glass are used.

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.

Quantum materials made of carbon

Prof. Dr Roman Fasel, roman.fasel@empa.ch

As reported in the journal Nature in October, an international team of researchers led by scientists at Empa and the International Iberian Nanotechnology Laboratory has succeeded in building carbon-based quantum spin chains. Using scanning tunneling microscopy, the team provided experimental evidence of one of the cornerstone models of quantum magnetism: the Haldane phase, first proposed in 1983 by F. D M. Haldane, one of the three 2016 Physics Nobel laureates. The results could have widespread implications in the understanding of low-dimensional quantum magnetism and make a contribution to the emerging field of quantum computing.

Sawing quantum magnets in half

All elementary particles have a spin, a fundamental property that governs their interaction with magnetic fields. Spins are quantized, which means they can only assume discrete values. Electrons have the smallest possible spin that can take two discrete values, while the systems at the next higher level have a spin that can take three discrete values – these are dubbed spin 0, spin ½ and spin 1, respectively. Haldane predicted that a one-dimensional chain of interacting spin 1 units should be fractionalized in order for the two terminal units of the chain to behave like spin ½ objects. Therefore, much like a magician who seems to saw a person in two and pull the halves apart, quantum correlations in the chain divide one spin 1 into two spin ½ entities.

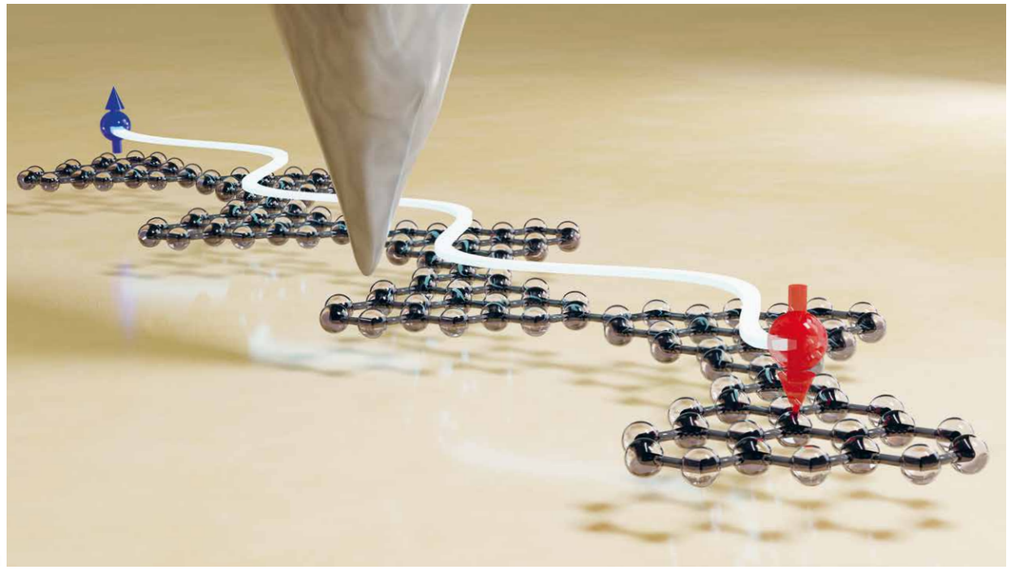
One-dimensional molecule chains are better than crystals

To date, testing this prediction in a laboratory has been challenging for various reasons, chief among them being that conventional materials are not one-dimensional. While researchers found indirect evidence of spin fractionalization in crystals of organometallic compounds containing such spin chains, it was not possible to directly observe the phenomenon.

Combining organic chemistry and ultrahigh vacuum surface science, the Empa team fabricated one-dimensional spin chains out of carbon together with colleagues from Spain, Portugal and Germany. Using a scanning tunneling microscope, the team probed magnetic excitations of these spin chains on a gold surface. They found that the terminal units of the chains exhibited Kondo resonances, which are a characteristic spectroscopic fingerprint of spin ½ quantum objects in contact with a metal surface.

From chains to networks – and to quantum computers?

The researchers are convinced that easily accessible molecular spin systems exhibiting strongly correlated behavior of electrons offer a fertile experimental environment for developing and testing new theoretical concepts. Such spin networks can in turn be a promising material platform for developing novel quantum computers. //



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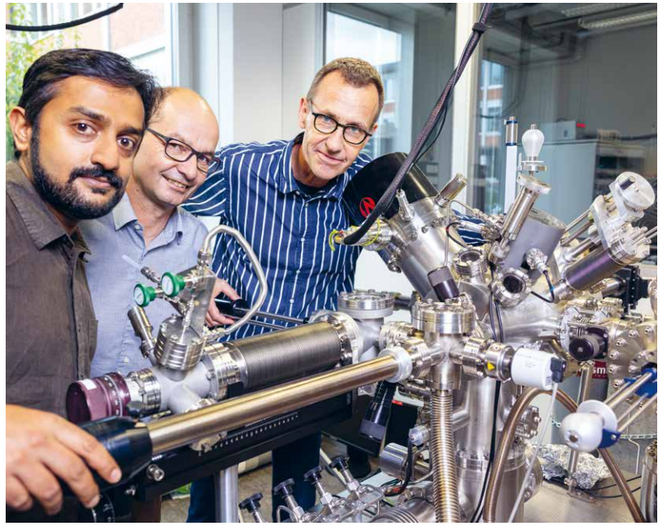

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Schematic representation of a molecular quantum spin chain on a gold surface being examined with the sharp tip of a scanning tunneling microscope. While each of the seven triangular individual segments has a total spin of 1, quantum correlations in the chain lead to spin fractionalization, such that the terminal triangles exhibit a spin of ½.

2
Empa researchers Shantanu Mishra, Pascal Ruffieux and Roman Fasel (from left to right) at an ultrahigh vacuum facility for the preparation of quantum spin chains.

Sort first, then retrofit

Dr Kristina Orehounig,kristina.orehounig@empa.ch

Switzerland's building stock is quite extensive. There are around 1.8 million residential buildings in the country, but only one percent of this building stock undergoes an energy retrofit each year. In other words, it will take 100 years for the entire building stock in the country to be retrofitted – which would be too slow to achieve the energy transition. But before politicians decide on stimulating development schemes, this daunting task must first be structured. Which measures make sense for which buildings? And where to start?

Kristina Orehounig, leading a team from her Urban Energy Systems lab, sorted buildings to simplify decision-making on suitable measures and their proper order. In this process, the Empa researchers resorted to data mining. They searched national databases and sorted both residential and commercial buildings according to archetypes, which were organized by year of construction, heating type, number of occupants or specific type of use.

City and country

Since solar energy is an essential foundation for the energy supply of the future, all the archetypes were assessed regarding their suitability for photovoltaics. This was done using climate data for the respective region in which a building was located, as well as roof geometry data which provided information about the size and slope of the roof surface.

The selection of the appropriate energy retrofitting method also depends on building density: houses in the city can be efficiently connected to a heating network, but for widely spaced buildings in the countryside, a heating network often does not make sense. Hence, the Swiss building stock must also be sorted by urban and rural areas. This sorting resulted in twelve Swiss neighborhood archetypes: four urban, four suburban and four rural archetypes that describe the distribution of all buildings in Switzerland.

How to retrofit effectively

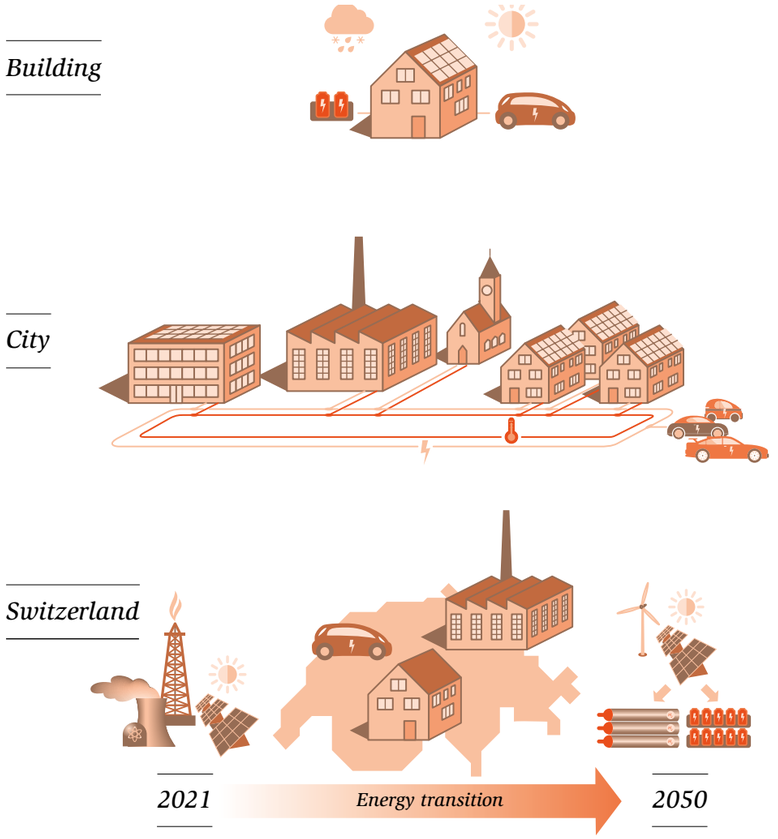
After all the sorting, retrofitting measures were calculated for the individual archetypes. The researchers concluded that it is worthwhile to tackle the retrofitting of roofs and the replacement of windows in older houses as quickly as possible. This alone can reduce heating and cooling energy requirements by 20 to 30 percent, regardless of where the building is located.

The next step should be to retrofit the heating systems in almost all types of houses, as apartment buildings, schools and office buildings can often be retrofitted more cost-effectively than detached single-family houses. This is because, in larger buildings, any retrofitting of the heating system will affect many square meters of occupied space at the same time, which is why any kind of technical intervention will be more effective and economical.

Cutting down on greenhouse gases

It is important to replace fossil fuels as fast as possible, for example with photovoltaics on roofs and façades. Heat can then be generated, for example, by air source heat pumps powered by the building's own solar electricity or other renewable energy sources. Biomass heating systems – biogas or wood pellets – also effectively reduce CO_2 emissions.

At the end of their analysis, the researchers concluded that, if all their proposed measures were taken, greenhouse gas emissions caused by Switzerland's building stock could be reduced by a whopping 60 to 80 percent. //



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Kristina Orehounig: "Greenhouse gas emissions caused by Switzerland's building stock could be reduced by 60 to 80 percent." Image: Daniel Kellenberger

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How we can convert our energy system: research on three scales. Illustration: Empa

Using nanomedicine to achieve gentler tumor treatment

Prof. Dr Inge Herrmann, inge.herrmann@empa.ch

Today, various cancer treatment methods are available that can be used in combination. Radiation therapy is frequently used, and can be combined with surgery and chemotherapy, for example. However, modern oncology is not satisfied with the effectiveness of radiation in some cases. The reason for this is that malignant tumors do not respond strongly enough to ionising radiation. If the sensitivity of the tumor cells were increased, radiotherapy could be carried out more effectively and more gently.

The team led by Lukas Gerken and Inge Herrmann from the Particles-Biology Interactions Laboratory at Empa in St. Gallen and the Nanoparticle Systems Engineering Laboratory at ETH Zurich is therefore working with oncologists at the Cantonal Hospital in St. Gallen to find ways to sensitize tumour cells to radiation.

Trial by fire

Nanomedical studies are currently underway in the field of cancer research that examine various classes of substances in order to make the irradiation of tumors more effective. Exactly how nanoparticles made of gold or more exotic metal oxides such as hafnium dioxide work in this context is not yet fully understood. What is known, though, is that a complex reaction cascade triggers oxidative stress in cancer cells. In this way, the repair mechanisms of the malignant cells may be shut down.

Empa researcher Lukas Gerken has now succeeded in producing just such radiosensitizers consisting of metal oxide using a method that is ideally suited to industrial applications: he used flame synthesis to obtain top-quality oxides of hafnium, zirconium and titanium. Thanks to this production method, it is even possible – depending on the production facility – to synthesize several kilograms per day. For the laboratory analyses at Empa, however, the scientist made do with just a few grams.

Better than gold

As experiments with cell cultures showed, this method produces sterile, high-quality metal oxide nanoparticles that are harmless to healthy cells. In the process, metal oxides accumulated in large quantities inside the cells. The front-runner was hafnium dioxide, where half a billion nanoparticles entered each individual cell without being toxic. Compared to the metal oxides, nanogold did significantly worse with the same particle size: about 10 to 30 times fewer gold particles made it into the cell.

Using cancer cell lines, the team demonstrated the powerful effects of metal oxides. If the cell cultures were treated with metal oxides and then bombarded with X-rays, the elimination effect increased significantly. Hafnium dioxide turned out to be the most potent tool. Tumor cells treated with hafnium particles were eliminated with less than half the radiation dose.

The team now wants to continue on this path to explore the nanoparticles' mechanism of action and further optimize their efficiency. The studies are intended to advance the clinical application of nanoparticles in radiation therapy. //

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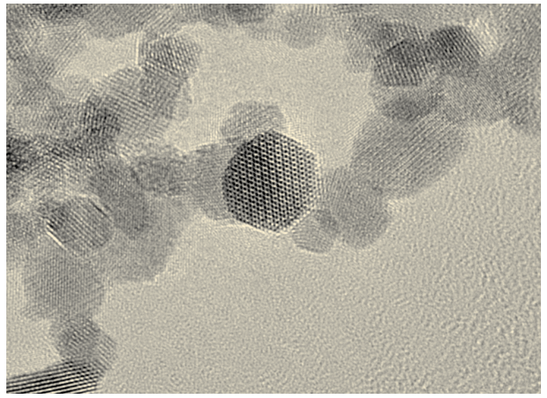

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Lukas Gerken produces nanoparticles for cancer therapy using flame synthesis. To make the tiny metal particles visible, the electron microscope is cooled to freezing temperatures with liquid nitrogen.

2
Tiny metallic particles: hafnium dioxide nanoparticles produced by flame synthesis are only about seven nanometers in size. Image: Empa / ACS Chemistry of Materials

Are nanoparticles in the environment harmless or dangerous?

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Wherever scientists look, they can spot them: whether on remote mountain peaks, in Arctic sea ice, on the deep-sea floor or in air samples, even in edible fish – thousands upon thousands of microscopic plastic particles. In April 2021, a team from Empa and ETH Zurich presented the state of current knowledge – or lack thereof – on these microscopic particles in the journal "Nature Nanotechnology", highlighting which areas were most in need of research.

There is a widely growing concern about the potential harmful effects nanoplastics could have on various ecosystems. Several media reports seem to confirm the importance of the problem, and some use quite emotional language to do so. However, very little has been scientifically proven to date. This is because the research on the material flows of synthetic microparticles and nanoparticles in the environment is still in its infancy.

Lack of a uniform definition

There is not even a globally uniform definition of size for nanoparticles yet. Various organizations are working on the standardization of these particles. This multiplicity is also reflected by the numerous different specialist fields that are examining nanoparticles and nanomaterials. For example, the US Food and Drug Administration (FDA) considers everything under one micrometer a nanoparticle. The European Commission's relevant size range is between one and 100 nanometers, but effectively, only an exactly defined threshold value of the particles must correspond to this size range.

However, there are already initial findings, including by Empa researchers, on how microscopic particles spread. As early as 2019, Bernd Nowack and his team modelled the release of microrubber due to car tyre abrasion. In Switzerland, tyre abrasion accounted for approximately 200,000 tons overall over the past 30 years. A study by Utrecht University, with the participation of Empa researcher Dominik Brunner, estimated the accumulation of nanoplastic particles in the snow on an Alpine mountain peak at 42 kilograms per square kilometer on annual average. However, this number is still very uncertain and requires further research.

The right measurement technology has to be developed first

This is also due to the fact that it is enormously difficult in terms of measurement technology to accurately record the number of artificial nanoparticles. The corresponding quantitative analysis methods are still in an early stage of development. On account of the enormous gaps in current knowledge, more research into microplastics and nanoplastics is required, and it should be as systematic and broad-based as possible. This is because polymers have become almost indispensable due to their positive properties. Many everyday objects cannot be produced with the desired material properties without using polymers.

Empa takes a closer look

So, there continues to be a need for research in this field. Currently, Bernd Nowack is examining how clothing releases nanoparticles during washing. Also, Christoph Hüglin is set to analyze the atmospheric distribution of microplastics in a study funded by the Federal Office for the Environment (FOEN). In this manner, Empa will also help to render the problem of nanoparticles tangible and assessable in future. //

Alpine research: the observatory of ZAMG, the Austrian Central Institute for Meteorology and Geodynamics, is located at an altitude of over 3,100 meters in the High Tauern mountains in Salzburg and has existed since 1886. Source: ZAMG / Christian Schober

Wood as the basis for materials scientists

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Prof. Dr Ingo Burgert, Ingo.Burgert@empa.ch

Wood is not only a building material, but also an interesting resource for materials scientists. Four spectacular research examples of Empa's Cellulose & Wood Materials laboratory illustrate the wide range of this renewable resource.

Wood that generates electric voltage

If you want to generate electric voltage with wood, the piezoelectric effect comes into play. In this process, the elastic deformation of certain solids creates a charge separation, which generates electric voltage. Researchers at Empa and ETH Zurich strengthened wood's natural piezoelectric effect by placing it into a mixture of hydrogen peroxide and acetic acid. The resulting elastic sponge consists of layers of cellulose that can easily be compressed and then expand back into its original form.

A cellulose test cube with a length of approximately 1.5 cm per side survived 600 load cycles and generated around 0.7 volt each time it was compressed – the amount of voltage required to run one operation in a sensor, for example.

Compostable power storage units

Micro-devices in the Internet of Things require new, sustainable materials approaches and additive manufacturing technologies. Empa researchers have developed a biodegradable mini-capacitor that consists only of carbon, cellulose, glycerine and table salt. These ingredients are combined to form gelatinous inks and sprayed on a surface by a 3D printer.

The mini-capacitor can withstand thousands of charge and discharge cycles and years of storage, even in freezing temperatures, and is resistant to pressure and shock. When it is no longer needed, it can be composted or simply left outside in nature; after two months, it decomposes into its individual components.

Mass-produced melanin

The pigment melanin, which, for instance, protects human skin from UV light, is a veritable treasure trove for materials and technologies. Empa researchers discovered a fungus that is actually a common saprophytic fungus that grows in the forest: Armillaria cepistipes. Its amazing metabolism enables the fungus to bind heavy metals, make wood glow in the dark – and produce melanin. In fact, it produces a thousand times more melanin than the other microorganisms that have already been used in attempts to manufacture the pigment on an industrial scale. The cost-effective and sustainable production now makes new projects possible. As melanin binds heavy metals, it can be used in water filters, for example. The researchers mixed melanin with the plastic polyurethane to fabricate extremely thin textile membranes that were able to filter up to 94 percent of lead from contaminated water.

Teaching fungi how to write

Each decaying piece of wood is uniquely patterned with colors and lines. However, naturally obtained spalted wood from the forest floor may take several years to grow fungal-induced patterns. Often, this spalted wood is no longer solid enough for furniture making. Empa researchers specifically treated native hardwoods such as ash, beech and maple with fungal cultures to ensure that particular patterns developed. The wood's stability and shape is maintained in this process. Finally, the researchers were able to use the fungi to write letters on (and in) the wood – a world first! //

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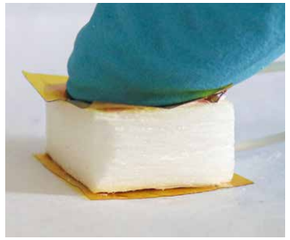
Xavier Aeby and Gustav Nyström invented a fully printed biodegradable battery made from cellulose and other eco-friendly components.

2
Just a little pressure can generate electrical voltage in the cellulose sponge. Image: ACS Nano / Empa

3
Empa researchers can control the spalting process for various types of wood and thus use fungi to engrave letters into the wood's structure. Image: Empa



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From basic research to ear implants

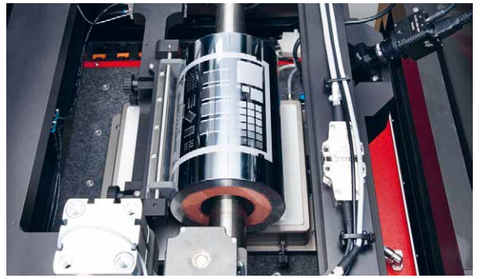
Dr Lars Sommerhäuser, lars.sommerhaeuser@empa.ch

At the Coating Competence Center, Empa's basic research meets industrial applications. An understanding of physical or chemical phenomena is often the starting point for innovations. Let's take high-resolution gravure printing for printed electronics as an example: first, we have to understand the ink's flow behavior, i.e. we must examine how the engraved structures of a gravure cylinder can be filled to the brim with ink without creating air pockets and how the droplets can be transferred to the object to be printed on. How strongly do the droplets adhere to the surface and how do they spread to create the structures to be printed? Only once we understand all these phenomena in detail can we identify what parameters to change to make innovations and technological breakthroughs possible. The SCALAR research project, supported by the ETH Domain's Advanced Manufacturing strategic focus area, uses the Coating Competence Center's high-precision printer to print delicate structures in the micrometer range at printing speeds of 1 m/s. If this succeeds, it would allow for high-resolution touch sensors to be printed on films: a low-cost way to turn the surfaces of devices or cars into control elements.

Additive manufacturing and 3D printing of metals

However, findings from Empa's basic research are also being used in completely different areas of application, for example for implants. Using additive manufacturing, and in particular 3D printing of metals, implants for hip joints and knees are printed from titanium. This requires an exact understanding of additive manufacturing processes, where both the material characteristics and the product geometry are created in one step. The research findings are not only used in the Coating Competence Center, but also in Empa's close collaboration with the Swiss m4m Center in Bettlach, a technology transfer center that also makes the 3D printing technology accessible for smaller companies in the Swiss medtech industry.

Often, medical implants cannot be too hard, as they are intended to replace soft tissue or cartilage. In these cases, other materials or material combinations such as hydrogels reinforced with lattices are used. Working together with the team headed by Marcy Zenobi-Wong at ETH Zurich, 3D printed semi-flexible lattices made of titanium were developed and printed in the Coating Competence Center. The lattices are designed in such a way that the surrounding hydrogels do not warp too much and "flow out" under pressure. This concept allows for the manufacture of intervertebral disc and ear implants that have the elasticity and stability required for each application. //



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Gravure unit of the high-precision printer NSM Challenger 600. Photo: Nsm Norbert Schläfli AG

2
Titanium lattices for ear implants 3D printed at Empa's Coating Competence Center. Photo: ETH Zurich

New normal for the construction industry

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Early last year, the world finally realized that the COVID-19 pandemic would not be over and done with as quickly as hoped. What this means for the construction industry is that it must become more flexible and think outside the box due to the ongoing material shortages and new requirements for buildings. NEST, the modular research and innovation building jointly created by Empa and Eawag, continued to provide answers to current challenges in the construction industry during these unprecedented times. As a result, the past year saw the opening of two new NEST units, Sprint in August and HiLo in October.

Two new resource-efficient units

The two new NEST units Sprint and HiLo demonstrate in different ways how buildings can be constructed and operated in the most sustainable manner possible. Sprint focuses on closing cycles in circular construction. The unit was designed by baubüro in situ and largely consists of reused materials and components. It offers flexible office space that complies with COVID-19 regulations. The fact that the unit was built in only ten months highlights the large reuse potential of the industry that can simply be tapped into. Sprint also shows that quick and high-quality construction is possible with reused materials. From dismantling to reuse, the various different challenges were examined step by step and possible solutions were developed at NEST.

By contrast, HiLo's approach is to reduce materials and efficiently operate buildings. The unit brings together innovative planning and design methods for effective, resource-efficient concret structures with self-learning and adaptive building technologies. The unit on the top platform of the NEST building was implemented by ETH Zurich's Block Research Group and Architecture and Building Systems Group in cooperation with numerous industrial partners and boasts an intricate, doubly curved concrete roof and an intelligent and adaptive solar façade.

Focus on bringing innovations to market

In the past year, a great deal also happened behind the scenes at NEST. Planning for the next NEST unit STEP2 is already at an advanced stage. The preliminary project was completed in the past year and construction is to begin at the end of 2022 beginning of 2023. The unit combines innovations in the areas of circular economy, industrial and digital fabrication as well as building envelope and energy systems, and focuses on bringing to market new solutions and processes.

Virtual NEST

In order to ensure that everyone could continue to experience the innovations at NEST despite the current difficult circumstances, Empa and Eawag's research and innovation building opened its doors virtually in the past spring. The launch of the virtual NEST tour is a further step towards closing the gap between laboratory research and market entry. By making numerous innovations, developed and demonstrated at NEST, accessible to a much broader and more international audience, the virtual NEST is making a significant contribution to ensuring that sustainable innovations in the building and energy sector can spread faster and thus gain a foothold in the construction industry. //

1
The Sprint unit uses various types of partitions that can all be dismantled if need be. For example, used books and carpet tiles were used as materials. Photo: Martin Zeller

2
HiLo combines medieval building principles with futuristic construction methods: the two-story building module with its striking, doubly curved concrete roof was planned and built using state-of-the-art design and fabrication techniques. Photo: Roman Keller

1

2

Approaches to solutions for the energy transition

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At the move mobility demonstrator, 2021 was dedicated to preparations for the installation of the Climeworks direct air capturing system. It forms part of the methanation system currently being in the engineering phase and supplies the process with CO_2. Coupling methanation and CO_2 generation from the atmosphere is not only sensible for technical and heat engineering reasons: in addition to carbon dioxide, the Climeworks system also generates water from the ambient air, which can in turn be used to generate hydrogen. This creates a system that operates independently of a water supply and could therefore also be very important for desert regions.

Since last year, the important question of calibrating hydrogen dispensers is being addressed in collaboration with the Swiss Federal Institute of Metrology METAS, and other partners as part of an EU project, and the heat generated in pressurized gas cylinders during hydrogen refuelling is being investigated in a dissertation co-financed by the Swiss Federal Office of Energy (SFOE).

Cooperation with Migros and its collaboration with the geodata service HERE also resulted in a software co-developed by Empa to calculate the real consumption and real CO_2 emissions of heavy-duty trucks, which will soon be available worldwide.

Partner demonstrator for industrial decarbonization in Zug

At move, the main focus is on technical systems that enable a transition from fossil to renewable energy in the mobility sector. However, these systems can also be used for industrial processes. Together with the Tech Cluster Zug, the canton of Zug and the energy provider WWZ, a demonstrator for decarbonizing industrial processes was therefore initiated in Zug.

There is still a lack of realistic approaches to decarbonize industrial process heat, the third-largest energy consumer in Switzerland. Switching to hydrogen could be an option. But generating hydrogen through electrolysis is currently significantly more expensive in Switzerland than the previous energy prices. Also, the significant electricity requirements for electrolytic hydrogen production would put additional strain on the power supply in winter.

Therefore, a novel approach is to be tested in Zug: the splitting of methane (CH_4) into energetically usable hydrogen (H_2) and non-energetically useable solid carbon (C). If renewable methane is used in this process, it might even be possible to reach negative levels of CO_2 emissions. That's because only the hydrogen is used as an energy carrier. The carbon is not returned to the atmosphere, as it can be captured as a solid and used in construction or agriculture.

Synthetic methane from desert regions

The energy potential for producing methane in desert regions is enormous. If it were possible to transport synthetic methane to Switzerland via the existing trading mechanisms and transport infrastructures and to separate it into hydrogen and solid carbon here in Switzerland, several problems could be solved at once: renewable hydrogen would be available to supply industrial processes and to bridge the winter electricity gap. At the same time, negative CO_2 emissions could be generated in the country through this process. This concept will keep researchers busy in the coming years. //

Special delivery for move: at the end of November 2021, a Climeworks direct air capturing system was delivered to the Empa mobility demonstrator. This system collects CO_2 from the atmosphere that is used for the production of synthetic methane in a further step.

Making the energy system more sustainable

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To effectively reduce CO_2 emissions of buildings, it is necessary to optimize energy flows at the individual building, building complex and city levels. Empa's Energy Hub (ehub) demonstrator is a platform where new approaches and technologies in the field of energy can be validated and further developed.

Using clean energy

How clean the electricity is that is used to power any given building varies widely nowadays. The ehub team is involved in various projects that touch upon this issue. The project Sustainable Demand Side Management (S-DSM) supported by the Swiss Federal Office of Energy (SFOE) is developing and testing a building automation system that takes the carbon footprint of the Swiss power grid into account. This allows building automation to be operated in an optimized manner, using clean energy from the grid whenever possible. Initial estimates show that, with this system, a poorly insulated single-family house could reduce its CO_2 emissions by over 20 percent. The approach is now being tested for practicability at NEST and the office and commercial building complex K3 in Wallisellen.

As part of SFOE's project PATHFNDR, Empa researchers are investigating how to further improve the integration of renewable energy sources in the energy system. This project observes the interplay of various different technologies at the individual building, building complex, municipal and national levels. The approaches developed in this process are implemented and validated using the demonstrators NEST and move, as well as in participating districts and cities.

Using waste heat as a heat source

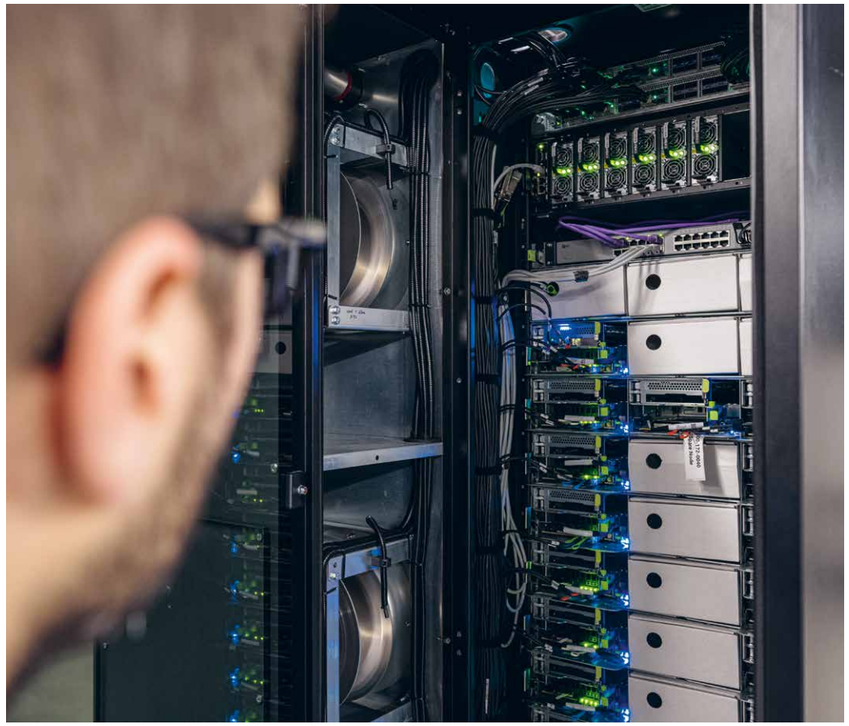
As part of the ECO-Qube project supported by the EU funding program Horizon 2020, the ehub team is researching the integration of data centers into building systems together with international partners. A data center was installed at NEST for this purpose. The team's focus is on integrating the computer into the thermal network so that the waste heat generated during operation can be used as a heat source, as well as on the efficient and sustainable operation of the data center.

Looking ahead to save energy

Over the past few years, two ehub team researchers developed an algorithm that predictively controls the room temperature in buildings. It uses building data such as valve positions and room temperature to learn a model of the building. In combination with forecasts on the local outside temperature and global isolation, the algorithm then independently calculates the ideal energy input for heating or cooling the building to the desired temperature, up to twelve hours in advance. Initial field tests at NEST showed that this saves between 25 and just under 50 percent of energy. In 2021, the two researchers decided to launch their algorithm on the market and created the Empa spin-off viboo for this purpose. The first pilot projects with industry partners began at the end of 2021.

New employees, partners and ideas

In 2021, ehub took a further important step in inter-institutional cooperation by participating in the newly founded National Centre of Competence in Research (NCCR) Automation. In the new NCCR, more than 40 scientists from Empa, ETH Zurich, EPFL and the University of Applied Sciences Northwestern Switzerland investigate new approaches to reliably control complex automation systems and develop applications in the fields of energy, mobility and industrial manufacturing. //



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1
A data center was installed in the NET Energy Hub as part of the ECO-Qube project. By connecting to the building's thermal networks, its waste heat can be used for heating. At the same time, researchers are investigating how such a data center can be operated in the most efficient and sustainable way possible.

2
Empa researchers have calculated that the solar potential on roofs, façades, parking lots and other infrastructure, in other words on already sealed surfaces, is sufficient for the energy transition. This solar façade on the K3 Handwerkcity building in Wallisellen has been in operation since 2020. Image: die werke versorgung wallisellen ag

co-operate – Campus Expansion Dübendorf

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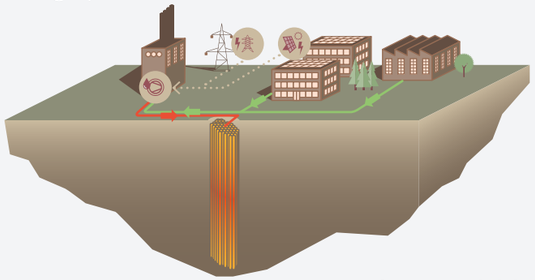


co- operate

A modern research campus is taking shape

On 5 May 2021, the expansion of the Empa and Eawag research campus in Dübendorf began with a groundbreaking ceremony. As of 2024, the new buildings will provide significantly more space for research and innovation and will make the campus more comfortable, attractive and safe for both staff and guests. Until then, a new cutting-edge laboratory and a multifunctional building with a multi-story car park will be constructed. The project has an evocative name: co-operate – because that's what Empa is all about.

Innovations from Empa's labs for practical applications

Developments and innovations from the Empa labs will also be utilized on the new campus, especially in the areas of energy and buildings. In future, research will therefore not only be carried out in, but also on and with the new buildings. For example, an experimental, seasonal energy storage facility is being built under the campus, which will supply energy not only to the new buildings but also to the entire Empa campus. A field of 144 geothermal probes reaching a depth of 100 meters will store the buildings' waste heat. In wintertime, this heat will be extracted from the ground by a heat pump to be used for heating. In the center of the geothermal probe field, the maximum temperatures can reach 50 °C. Via the installed pipe system, each individual pipe or defined areas can be controlled to achieve the optimum mix between temperature, efficiency and energy storage. Although such an underground storage system is very effective, it is also sluggish due to its huge mass. Empa researchers assume that the final operating temperature will only be reached after three to four years.

co-operate and its digital twin

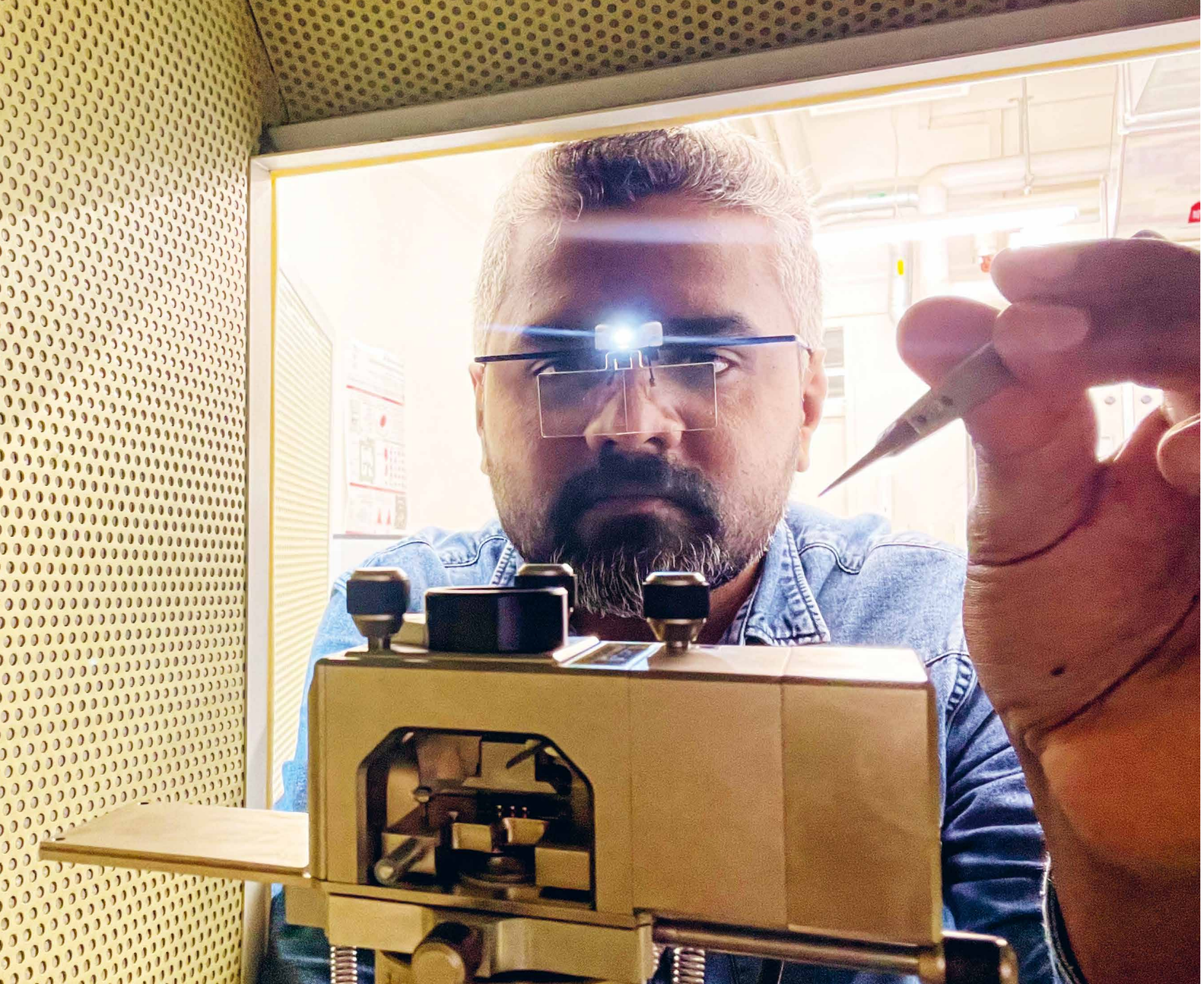
Digital construction using building information modelling – BIM for short – is a future trend: more efficient, lower cost and more transparent, from design to building operation. The new research campus is also being designed with the help of a digital twin, which will also simplify the buildings' facility management. Around 3,800 cubic meters of concrete for foundations and ground slabs under the building, more than 2,450 square meters of windows and almost 13,000 meters of electric cabling: with the help of the digital model, information on the planning status of the future Empa research campus can be accessed with only a few mouse clicks.

Massive resistance to vibration

Whether researchers are using electron microscopes, with which they examine atoms under the magnifying glass, or devices for thermogravimetry, with which they weigh masses of far less than a microgram, such devices must be protected even from tiny vibrations. Heavy footsteps from a nearby hallway or the rumbling of a tram several streets away are enough to falsify measurement results. Empa makes extensive allowances for this risk in the plans for its future laboratory building, covering the entire process from the preliminary planning to the completed building. The result is an extremely rigid concrete construction that is almost impossible to vibrate, an extremely heavy building. 48 piles of a combined pile and slab foundation transfer the loads into a more load-bearing soil layer via friction, at a depth of up to 18 meters. The area intended for highly sensitive measurement devices has a ground slab that is 80 centimeters thick. Under the foundation, this zone rests on harder sheets of foam glass instead of pliable polystyrene insulation boards – this detail is intended to ensure even more rigid deflection behavior.

Greening the campus

To make the research campus car-free, parking areas will be transferred into the new multi-story car park. The entire campus will be revegetated to an increasing degree, for example through a green belt connecting the two research institutes Empa and Eawag. This will make the research campus more welcoming and safe. A campus square will be created around NEST, offering employees and guests an attractive place to spend some time outdoors. Today, co-operate can already be experienced on smartphones and tablets. This is made possible by the augmented reality app co-operate AR. It is an impressive experience, and we expect that several visitors will continue to enjoy it during the course of construction.



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.

30 years of nanotechnology

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There is plenty of room at the bottom." Under this heading, US physicist Richard Feynman presented his ideas to design and build materials, structures and machines on the molecular and atomic levels for the first time in 1959. However, he conceded that the required analysis methods and synthesis methods did not yet exist. Thanks to the spectacular progress in this field in the past decades, Feynman's vision is now in reach for certain areas.

Heinrich Rohrer and Gerd Binnig took the first big step in this direction when they developed the scanning tunnelling microscope around 40 years ago at the IBM research lab in Rüschlikon, thus opening the door to the nanocosmos. In 1991, Sumio Iijima's discovery of carbon nanotubes, the first nanomaterial that is stable under normal conditions, gave the still young nanoscience another important boost – for all intents and purposes, this was the birth of nanotechnology. Nanotechnology was quickly hailed as the key technology of the twenty-first century, alongside biotechnology. Did and does it live up to this claim? The answer to this is: absolutely!

In the materials and computer sciences, as well as in the life sciences, there is hardly a field in which nanotechnological approaches are not already part of everyday life. Economically, nanotechnology is also gaining momentum. Analysts currently estimate the global market – without the chip industry – at 40 to 75 billion dollars. This large variation is due to the fact that the categorization as a nanoproduct is often not clear-cut. However, the analysts agree on the forecast of more than 30 percent of annual growth in the next years. This makes nanotechnology one of the fastest-growing markets.

Architecture at the nanometer scale

In line with Feynman's vision, Empa researchers develop nanomaterials with physical properties that are largely determined by their perfect structure, right down to precision at the atomic level, i.e. each atom is right where it should be. A group of Empa researchers led by Jakob Heier, collaborating with their colleagues at ETH Zurich, EPFL, the Paul Scherrer Institute (PSI) and the IBM research lab in Rüschlikon, thus succeeded in increasing the quantum yield of fluorescent dye molecules from the typical five to a whopping 60 percent. This is achieved by the perfect arrangement of the dye molecules in the form of J-aggregates at the phase boundaries of bicontinuous emulsions. The molecules in these J-aggregates are stacked on top of each other, similarly to the bricks in a brick wall. In this arrangement, the molecules are closely coupled so that they can excite each other without much loss of energy, which explains the drastic increase in quantum yield. The next step is to convert the emulsion into a solid state to enable applications in sensor technology, optical data transmission or solar cells, for example.

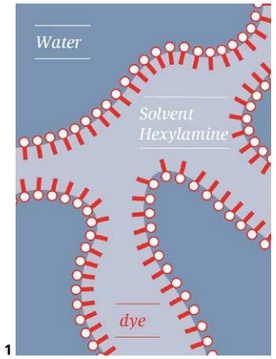
For several years, a team of researchers at Empa and ETH Zurich led by Maksym Kovalenko has followed a "Lego approach" in order to produce perfectly structured nanomaterials with unique optical and optoelectronic properties. They synthesize nanocrystals with various compositions and nearly monodisperse particle size distribution to act as "Lego bricks". Their physical properties are not only determined by their chemical composition, but also, significantly, by their size. If they are in a solution and charge-neutral, these nanocrystals organize into colloidal supercrystals, driven only by entropy. The building blocks of supercrystals are not atoms as in an inorganic solid, but individual nanocrystals with independent physical properties. What physical effects and properties caused by the collective behavior of the individual nanocrystals can form in such supercrystals is not yet known. However, a first unique effect has already been demonstrated, namely superfluorescence in lead halide perovskite supercrystals. Due to the almost identical size and composition of the nanocrystals, they form coherent couples, which means that the photon emission of the individual nanocrystals occurs coherently, i.e. simultaneously. This behavior is called superfluorescence, which was demonstrated for the first time in a solid in these supercrystals. Potential applications are, for example, the areas of LED lighting, quantum sensing and quantum communication.

Empa researchers like Roman Fasel and Oliver Gröning come closest to Feynman's vision with their development of graphene nanostructures with adjustable quantum properties. Just over ten years ago, their team developed a method to synthesize graphene nanostructures with atomic precision. They use specially designed precursor molecules that, when vapor-deposited on a gold surface, lead to the desired graphene nanostructure via a two-step catalytic process. In this process, the carbon nanostructure's geometric structure is clearly determined by the shape of the precursor molecules. In turn, the geometry or atomic topography of the edges defines the electronic, magnetic and quantum states of the graphene nanostructure. Recently, the researchers were able to demonstrate the spin fractionalization in triangulene chains (see page 12) predicted in 1983 by F. Duncan M. Haldane, who later won a Nobel Prize. This now opens up promising prospects for creating spin networks from graphene nanostructures, which could serve as a platform for the next generation of quantum computers. The CarboQuant project, funded by the Werner Siemens Foundation with CHF 15 million, aims to work towards this goal over the next ten years. //

1
Schematic diagram of the agglomeration of dye molecules at the phase boundaries of a bicontinuous emulsion.

2
AFM image of a graphene nanostructure with atomic resolution.

3
Colloidal supercrystals under the white-light microscope.



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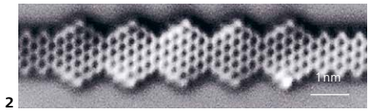

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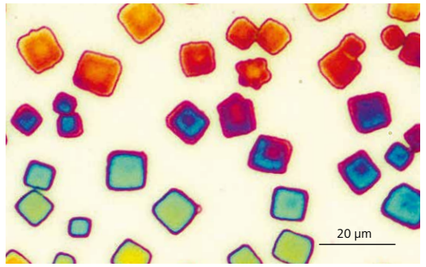

3

Sustainable solutions for thermal insulation of buildings

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Dr Tanja Zimmermann, tanja.zimmermann@empa.ch

A sustainable built environment requires minimizing the consumption of energy necessary for heating or cooling. In this respect, one of the crucial aspects of saving the energy is a proper thermal insulation. Different teams at Empa have recently delivered novel solutions in this field.

Silica aerogels for applications in thin insulation layers

Silica aerogels are nanostructured materials with a thermal conductivity of only about half of that of conventional insulation materials, e.g. expanded polystyrene (EPS) or mineral wool. First commercial aerogel products entered the Swiss market about 13 years ago, and today there are different product types available such as blankets, boards, renders and loose fillings. Compared to conventional materials, silica aerogel insulation is significantly more expensive, which is currently the main barrier to a broader use. The application of aerogels is indicated in situations where conventional materials cannot achieve a satisfying insulation performance due to space constraints and hence too thin insulation layer. For historic buildings, it is often not possible to retrofit the façade without changing their appearance. Aerogel boards or renders provide a significant reduction of thermal transmission losses through the façade with just a few centimeters of insulation. Similarly, there are certain smaller areas in the building envelope, in both new building projects and retrofits, where space for insulation is limited and aerogel materials can eliminate thermal bridges, for example as roller shutter housings.

Wim Malfait and his team from the laboratory for Building Energy Materials and Components are working on streamlining the aerogel production process to make aerogel cheaper and more sustainable by e.g. combining with biopolymers, and on developing new application solutions with improved properties such as the integration into bricks or wooden, prefabricated façades.

Cellulose-based insulation material from recycled paper

Cellulose-based systems made from recycled paper waste were the subject of a project carried out by Thomas Geiger and his colleagues from the laboratory for Cellulose and Wood Materials in collaboration with industrial partner isofloc AG and with the support of Innosuisse. Recycled paper fibers can be blown into cavities of wooden structures to form a uniform insulating layer. A major challenge the researchers faced (and successfully mastered) was to develop a stabilizer that prevents the blown-in flakes from settling after the filling process, transport and installation of prefabricated wooden structures. Cavities in constructions lead to poor insulation performance and can cause a chimney effect and thus fire propagation in the event of a fire. Empa researchers developed an additive that preserves the integrity of the compacted layer even in the event of a fire. This solution not only improves thermal insulation and fire resistance, but also provides a sustainable way to recycle the large quantities of waste paper.

Thermal insulation webs from recycled PET bottles in high-end aluminum windows

While improving the insulation of walls, decks, etc., one must not forget oto reduce the heat losses through thermal bridges in window frames. Empa researchers and their partners have been recently working on a novel product for insulation webs in window profiles and façade glazing with an environmentally friendly filling: recycled material from PET bottles.

An Empa team led by Michel Barbezat and Giovanni Terrasi from the Mechanical Systems Engineering lab together with experts from the metal construction company Hochuli developed a new type of product. The project was supported by Innosuisse and the new solution is being commercialized by the spin-off named “Hochuli Advanced”.

1

The highlight of the “Alpet” insulation web: inside the glass-fiber-reinforced plastic is a finely porous foam made of polyethylene terephthalate – PET obtained from recycled bottles. The thermal conductivity of the prototypes averages around 0.1 W/mK – far less than a standard insulation web made of another polymer, polyamide (around 0.25 W/mK), and also significantly lower than high-end products available today. The use of recycled plastic is another step towards sustainability and circular economy. In parallel to the commercialization efforts of the industrial partner, detailed tests are also carried out by the manufacturers of window profiles. Empa’s experts will continue to support the future developments of the insulation webs to deliver even more sustainable and eco-friendly solutions. //

2

3

1
The Alpet insulating web: the greenish color of the filling material comes from the use of PET from recycled bottles. Image: Hochuli advanced

2
Old mill in Oberhallau near Schaffhausen, during and after retrofit with silica aerogel blankets (2007 – 2008). Images: Max Schweizer AG

3
Empa expertise for industry: Franziska Grüneberger and Willi Senn developed a new binding technique that renders the isofloc insulating material more fireproof than before

Developing the urban environment in a sustainable way

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Cities and urban agglomerations will be home to an ever increasing proportion of the world's population – and thus be the central human "habitat" of the future. These highly complex and dynamic systems, if developed in a targeted manner, can make important contributions to solving global challenges. However, developing these urban environments in a sustainable way requires an intricate interplay of various parameters. In addition to closed material cycles in the building sector and a sustainable energy supply with a corresponding reduction in CO_2 emissions, health aspects and the social acceptance of upcoming changes play an important role.

Gamification: a new way of experiencing urban development

Any successful implementation of the Paris Climate Agreement will require a massive conversion of infrastructure in urban spaces. As part of the national research program Sustainable Economy (NFP 73), Empa researchers teamed up with colleagues at the University of Zurich, the Norwegian University of Science and Technology (NTNU), the Eastern Switzerland University of Applied Sciences (OST) and the company Ulrich Creative Simulations GmbH to make these changes and their underlying processes tangible in a computer-based simulation game. In "postfossilCities", participants can influence possible climate scenarios themselves and assess the effects of the envisioned development on the quality of life in urban environments. The game, which helps to identify and evaluate possible pathways to post-fossil cities, was developed on the basis of a fictitious Swiss City in the year 2050 in the Swiss Plateau, which gets by without fossil energy sources. As time moves on, the players – adopting the roles of various actors (in politics, society, economy, etc.) – explore numerous challenges on the way to a post-fossil future. Each actor makes their own decisions on which measures are a top priority that have to be tackled immediately, and which ones can wait. They must also decide whether these measures should be implemented as a solo effort or as part of (yet to be forged) alliances. Eventually, the game is about learning to assess the effectiveness of climate protection measures and putting the experiences gathered in the game in specific terms with regard to practical applications in one's own field of action. As it turns out, achieving the goals of the Paris Climate Agreement is possible, but requires drastic and rapidly implemented measures.

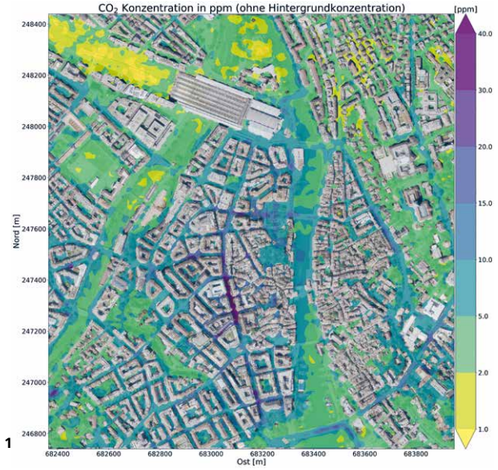
Targeting CO_2 emissions in cities

Urban spaces generate more than 70 percent of direct and indirect CO_2 emissions worldwide. In order to be able to limit the global temperature increase to between 1.5 and 2 °C, as agreed internationally in the Paris Climate Agreement, significant efforts are therefore required to reduce emissions, especially in cities. However, this is a huge challenge due to the extremely heterogeneous structures of different cities and the large number of different emission sources such as traffic, buildings, etc.

The EU project Pilot Application in Urban Landscapes – Towards integrated city observatories for greenhouse gases (ICOS Cities) is a key contribution to the European Green Deal, the European Commission's roadmap for a climate-neutral, sustainable EU economy. Due to their many years of experience in combining modelling and measurement of greenhouse gas emissions, Empa researchers are heading the activities in the Zurich pilot region, which forms the core of the ICOS Cities project together with Paris and Munich.

Zurich, which is a rather small metropolitan region in international comparison and which poses significant topographical and meteorological challenges, can serve to build on the experience of Empa researchers in this context through various groundbreaking projects. Some examples are Carbosense, in which Empa, together with the Swiss Data Science Centre (SDSC) and industrial partners Swisscom and Decenlab, has set up a Switzerland-wide network of over 300 low-cost CO_2 sensors to obtain information on man-made CO_2 emissions and CO_2 fluxes in the biosphere with a high spatial and temporal resolution, and EXCLAIM, a collaboration with ETH Zurich and the Centro Svizzero di Calcolo Scientifico (CSCS) in Lugano to develop regional and global weather and climate models with unprecedented spatial resolution.

A particularly innovative approach of the ICOS Cities project is the joint development of services, models and observations by municipalities and scientists from different disciplines, including social and administrative sciences. In this process, the research projects are intended to take into account the needs of the various stakeholders right from the start, supporting politics, administration and industry through facts-based decisions in climate protection measures and strategic investments to achieve the net zero target. //



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1
Distribution of the CO_2 concentration in the city of Zurich above the regional background. The simulation for a typical westerly wind situation includes thousands of emission sources, classified into nine categories, and an atmospheric dispersion with a resolution of 10 meters overlaid in a detailed building model of the city.

2
Participants of postfossilCities, a simulation game for developing and assessing future climate scenarios: Which measures can be implemented alone, which ones need teaming up? Caps in different colors symbolize the various societal actors.

Switzerland is (not) an island

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Swiss energy policy has been through a turbulent year: the revised CO_2 Act was rejected by Swiss citizens, and the planned electricity agreement has been significantly postponed due to the temporary failure of its framework agreement with the EU. This challenging environment is currently exacerbated by the steep rise in gas and electricity prices and the unexpected outages of several French nuclear power plants. Accordingly, a report by the Federal Electricity Commission published last autumn which pointed out the risks of power shortages in the coming winters caused quite a stir. In this situation, it is particularly important for Empa, as an independent research institute, to discuss today's possibilities and scenarios with society representatives as well as business and political decision-makers, and to continue researching promising technologies and processes to make an affordable, renewable and reliable energy supply possible.

Further reducing energy requirements in the building sector

Better building insulation is a decisive measure to prevent the threat of energy shortages in winter. This sometimes poses considerable challenges in existing buildings, especially when historic buildings are involved. For years, Empa has been developing highly efficient insulation materials based on aerogels, which have an excellent insulating effect thanks to their countless pores at the nanometer scale. In this manner, historic buildings can be retrofitted using a thin layer of insulation that does not impair their appearance. In order to publicize the possibilities offered by aerogel applications, Empa introduced the Aerogel Architecture Award last year, which was granted to several listed buildings.

In tandem with the development of these high-tech materials, the Building Energy Materials and Components lab at Empa is also working on a completely different approach: sustainable insulating materials made from plant waste, such as washed-up algae. Here, a somewhat lower insulation performance is acceptable, but in return, these materials require much less energy to produce compared to conventional insulation materials based on polystyrene or mineral wool; in the best-case scenario, they can even remove CO_2 from the atmosphere and store it in the building for decades.

Expanding renewable energies

As another essential pillar of the Energy Strategy 2050, the rapid expansion of renewable electricity generation is of central importance. Due to the sometimes great resistance to and long delays in the construction of wind power plants and the expansion of large-scale hydropower plants, Switzerland's hopes in this area rest primarily on photovoltaics. Lightweight, high-efficiency modules suitable for applications on rooftops and façades as well as for vehicles and mobile devices have a great deal of potential in this context. The Thin Films and Photovoltaics lab took another step in this direction in 2021, setting an efficiency record of almost 21.4 percent for copper indium gallium diselenide solar cells on flexible polymer film.

However, the production of photovoltaic modules also requires energy which, when beginning to expand renewable electricity generation, must come predominantly from fossil sources. So how do we transition the global energy system to a post-fossil future with minimal cumulative CO_2 emissions? Empa's Technology and Society lab has developed a model to investigate which transition strategy is best for the climate. Quite counterintuitively, the researchers came to the conclusion that during the transition, fossil power plants should be utilized at maximum capacity in order to invest the generated energy in the fastest possible expansion of photovoltaics. The transition would thus result in minimal cumulative emissions and have the greatest possible probability of limiting global warming to 1.5 °C.

1
Insulation panel based on fibers from algae washed up on Mediterranean beaches and typically disposed of as waste.

2
Aerogel Architecture Award ceremony on 15 July 2021 at NEST: jury member Volker Herzog honors the submitted projects.

Conversion of the Empa campus energy system

According to the adage "put your own house in order" – or roof, in this case – Empa plans to partner with Eawag in order to lead by example and increase the photovoltaic electricity output on their joint campus in Dübendorf, currently around 460 kWp, to over 1000 kWp in the coming years. This is planned as part of a comprehensive conversion of the campus energy system, which also includes the use of heat pumps, a combined heat and power plant and a high-temperature geothermal probe field for seasonal heat storage. The goal is to reduce the energy requirements on the premises by around 25 percent by 2024 and to reduce CO_2 emissions by over 60 percent, for which additional hydroelectric power and biogas will be procured. Empa's Urban Energy Systems lab provides scientific support for the conversion of the campus energy system to optimize operations and test new approaches in practice, such as bidirectional charging of battery electric vehicles to increase own photovoltaic electricity consumption. //

New approaches in medical materials science

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

In order to meet the needs of an ageing society, Empa is concentrating on material-based innovations. Novel materials can benefit a wide range of developments for maintaining human health and performance levels.

Wearables: accessories for personalized medicine

Thanks to wearable sensors and digital twins, tools for the early diagnosis of life-threatening or chronic illnesses can now be developed, for example by integrating active and responsive components into sensory devices such as fibers, membranes and textiles. The system is then used both for body monitoring by means of physical, chemical and biological sensors and for the transdermal, controlled delivery of medication. In closed-loop systems for automated therapy, a sensor element measures a certain value and the system reacts by releasing the corresponding substance for treatment. The reactions of patients to the therapeutic agents administered can be estimated with the help of digital twins, for example of certain organs, but also of a whole person. Support from various foundations as well as partnerships with hospitals such as the Cantonal Hospital St. Gallen (KSSG) and the University Hospital Zurich (USZ) enable joint research projects on individually customized pain therapy, the prevention of pressure sores or the detection of bacteria in skin wounds.

Implants and bio interfaces

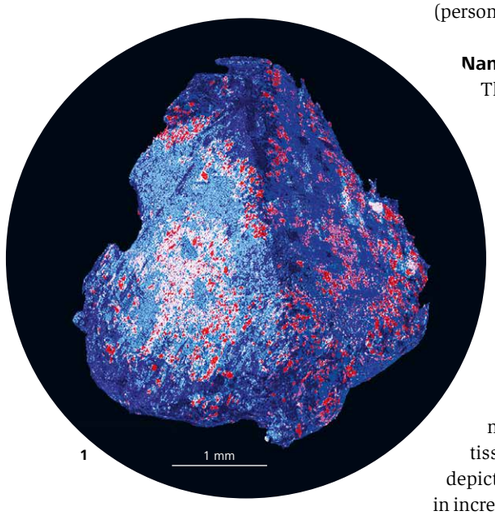
Medicine is facing a growing need for materials and implants that are applicable in biomedicine for an increasingly ageing society. These are intended to support the repair, regeneration and function of impaired tissue and organs. The increasing demand requires advanced materials research in a wide range of areas such as coatings, tribology, corrosion, biomechanics and additive manufacturing. The goal of Empa's research is to investigate the reactions of different cell and tissue types, i.e. their specific adaptations and changes at the interface to material surfaces. To this end, extremely interdisciplinary approaches and close connections with industry and clinical partners have been developed. Empa utilizes its interdisciplinary strength in materials research and applies important findings to clinical practice.

Biomedical imaging technologies

Empa has established a comprehensive concept for tissue analysis that is said to have a strong impact on the future development of precision medicine. This concept is based on multilevel and multimodal data integration through machine learning methods. It combines imaging data from high-resolution 3D X-ray tomography and spectral microscopy with genetic and molecular analyses, called omics data. This procedure deepens our understanding of the relationship between individual disease symptoms (phenotype) and equally individual genetic traits (genotype) of patients. With its concept, Empa is pioneering the construction of an imaging hub for precision medicine in Switzerland. Its three-dimensional analytical imaging methods provide new opportunities for non-invasive, digital precision pathology, for example of tumor tissue. These facilitate personalized and targeted diagnostics, not only in precision medicine and oncology, but also in the personalized treatment of stroke patients, for example.

Nanostructured materials for sanitary engineering and medical technology

In addition, Empa researchers are designing and examining nanoscale materials in order to utilize quantum effects resulting from reduced dimensions and heterogenous interfaces for applications in healthcare and medical technology.



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This requires mastery of the entire chain of competencies from material and system design to their implementation in a device architecture with customized manufacturing and analysis techniques. Typical applications for nanostructured materials are in biochemical sensing (biomarkers, proteins), imaging and spectroscopy, diagnostics (e.g. for monitoring protein aggregation) and theranostics (personalized medicine).

Nanomedical systems

The now established concept of treating each patient in an individually customized manner also opens up new approaches for materials research. Empa researchers anticipate forward-looking material designs by combining their expert knowledge in synthesizing nanomaterials with preclinical studies and then tailoring the results to meet practical requirements. The interaction of new materials and multicellular tissue models makes it possible to depict human physiological processes in increasing detail, using multimodal imaging techniques and bioinformatics in order to improve the understanding of the totality of complex interactions, signalling pathways and healing processes. Additionally, exchanging knowledge with clinics as well as pharmaceutical companies and authorities yielded impressive results. Empa succeeded in improving its verification of cell-based data as well as of new nanomaterial-based platform systems, and found new ways to reliably utilize in vitro data analogously to in vivo data for the risk assessment of nanomaterials. //

1
A stroke made visible: three-dimensional, non-invasive histopathology of a blood clot with proportions of red blood cells (red), calcifications (magenta), fibrin (light blue) and platelets (dark blue).

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.

Putting innovative ideas to the test

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Together with its industry partners, Empa develops exciting and innovative ideas for new materials and systems, often directly performing field tests on them, too. The ideas are examined in joint projects in order to develop new products, improve existing technologies and make them more sustainable or develop innovative solutions for concrete problems. In this manner, Empa aims to strengthen its partners' competitiveness and to support the technological shift.

In 2021, over 200 new research projects were launched, the majority of which are joint projects with industry partners. Empa filed patent applications for 13 inventions and concluded 14 new licensing and technology transfer agreements with business partners.

Fungi that upgrade wood

Spalted wood is a highly sought-after material for high-end furniture. In a newly developed process, Empa scientists around Francis Schwarze in the lab for Cellulose & Wood Materials succeeded at controlling the spread of fungi in native wood types such as ash, beech and maple to create elaborate patterns, pictures and even words, while retaining the stability and shape of the wood. Schwarze's team analyzed in the lab several fungi growing in nature to select those with the best properties as wood finishers. Depending on the combination of fungal species, dark lines appeared in the wood caused by the pigment melanin. Melanin is water-repellent, antimicrobial and protects the fungus from natural competitors such as bacteria. The researchers could even control the patterns in the wood depending on the type of fungi used, which resulted in stark differences: some lines were scrambled, others almost geometrically perfect. Together with its industry partner Koster Holzwelten AG, Empa developed this new process which is now being used to create one-of-a-kind pieces, within a project sponsored by Innosuisse

2

Insulation webs with a powerful core

Hidden inside metal profiles, insulation webs safeguard the mechanical connection between the inner and outer casings of windows and façade glazing and must hence be compact and robust. However, their purpose also is thermal separation, which typically requires porous and rather soft or brittle materials. Due to this conflict of objectives, current insulation webs offer significant room for improvement.

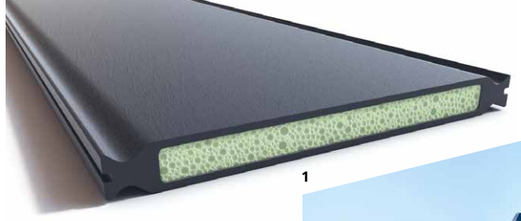
Researchers from Empa's Mechanical Systems Engineering lab developed a novel sandwich construction made of glass fiber-reinforced plastic and a core of PET foam, together with experts from the metal construction company Hochuli in Wigoltingen. The foam core obtained from recycled PET bottles ensures efficient thermal insulation.

Extensive series of tests at the ift, institute for testing and certification of building products in Rosenheim (Germany), and the corresponding certificates have proven that the Alpet insulating web has excellent product characteristics. A new company, Hochuli Advanced AG, was founded specifically to market the innovation.

Two in one: combined coating system for two methods

An innovative coating system named SC-1 is the core product of Empa spin-off Swiss Cluster AG. It combines two coating methods in one device: atomic layer deposition (ALD) and physical vapor deposition (PVD). The product to be coated does not have to be moved back and forth between different chambers, and the integrity of the vacuum atmosphere does not have to be broken. This allows multilayers consisting of alternating thin layers to be produced quickly and cost-effectively. Such multilayers can combine the properties of different materials in a complementary way; they are currently a research area of great interest.

The system was developed in Empa's Mechanics of Materials and Nanostructures lab, and Empa filed a patent application for it and licensed the technology exclusively to Swiss Cluster AG in 2020. Currently, a team of six is designing and constructing adjusted systems for large corporate customers based on ALD and PVD technologies. Selling individual components, providing technical support and research support services round out the young company's portfolio. //



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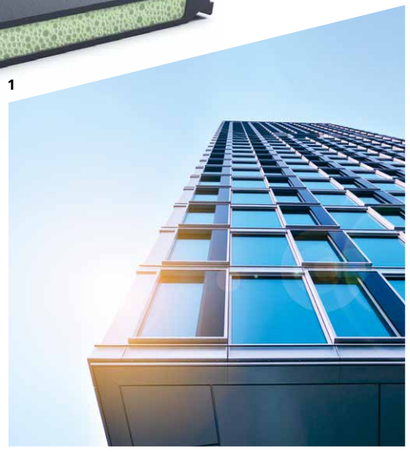

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Above: Alpet insulating web made of plastic: The greenish color of the filling material is due to the use of PET from recycled bottles. Image: Hochuli advanced
Bottom: insulating webs inside metal profiles on façades must be load-bearing on the one hand, and serve as thermal insulation on the other. Pictures: Hochuli Advanced AG

2
A clock one meter in diameter made of spalted ash, beech and maple wood using the soft rot fungus Kretzschmaria deusta. The wood was processed under controlled conditions and is streaked with dark lines – a unique specimen created together with Empa's industrial partner Koster Holzwelten AG.

3
The innovative coating system SC-1 is the core product of Empa spin-off Swiss Cluster AG.

From the prototype to founding and sales

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Peter Frischknecht, peter.frischknecht@empa.ch

In the past year, Empa researchers with new business ideas were again coached at the glatec business incubator in Dübendorf and Startfeld in St. Gallen.

Empa's Urban Energy Systems lab, for example, developed technology for the efficient operation of buildings based on machine learning with physical frameworks and mathematical optimization. With only minimum effort needed to put building systems into service, the energy requirements for heating or cooling can be reduced by between 25 and 50 percent while increasing thermal comfort. In future, the spin-off viboo aims to market this technology in an affordable, scalable range via a cloud service. Future customers, for example building automation companies, can easily integrate the software in their digital products using an interface in order to provide their customers with innovative building automation. viboo's technology was validated at NEST, Empa's demonstrator for innovative building technology. The future spin-off has already passed two of three rounds at the start-up support program Venture Kick, started a pilot project with the heating and cooling technology company Danfoss and is being sponsored by Innosuisse as part of the BRIDGE Proof-of-Concept program.

Perovskia Solar AG, founded in 2021 by a former Empa staff member, digitally prints customer-specific solar cells. The start-up, which is being supported by glatec, is situated at the intersection of printed electronics, photovoltaics and materials science.

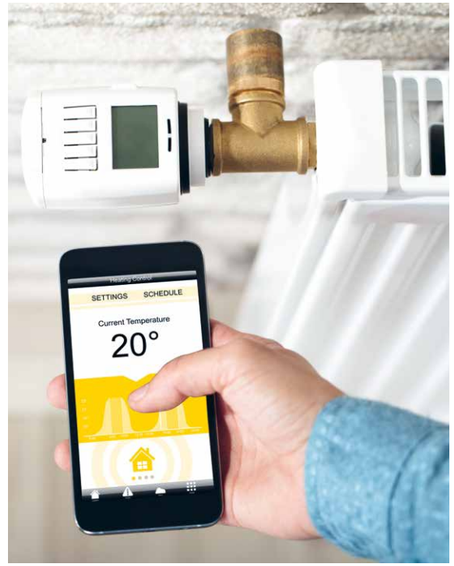
2021 also saw a positive takeover. Sensirion Holding AG, a leading provider of environmental and flow sensor technology solutions, acquired the former glatec start-up IRsweep AG, a provider of optical sensors. The ETH and Empa spin-off develops, produces and markets optical spectroscopy solutions based on semiconductor quantum cascade laser (QCL) frequency comb technology in the mid-infrared range.

Adhesive electrodes for medical application

The Empa spin-off Nahtlos AG, founded in 2017 and headquartered in Startfeld, initially wanted to put Empa's laser welding technology on the market. Since 2019, the start-up has instead focused on textile electrodes, which were also developed at Empa. While further developing this technology, Nahtlos made sure to find a solution fulfilling all the requirements (effectiveness, practicality and profitability) for cost reimbursement on the medical market.

The development trajectory of the past two years started with an electrocardiogram (ECG) strap with stitched-in electrodes, which later became an ECG strap with clip-in electrodes and finally turned into adhesive electrodes. Nahtlos' adhesive electrodes are the first valid alternative to the 60+ year old gel electrodes for medical long-term application. Compared to gel electrodes, Nahtlos electrodes offer better signal quality (effectiveness), higher patient comfort (practicality) and increased profitability in medical long-term application for medical service providers. The signal quality of Nahtlos adhesive electrodes was jointly validated by Empa and Schiller AG, one of the world's leading manufacturers of ECG devices. In the next phase, Empa and the Cantonal Hospital of St. Gallen will conduct a study with arrhythmia patients.

In addition to the electrocardiogram application of Nahtlos long-term electrodes, they will also be used in a clinical study of patients with the pulmonary disease COPD to record their heart rate variability over a period of several weeks, with the objective of identifying any exacerbation (lung deterioration). Nahtlos AG is also developing underwear with functional electrical stimulation based on Empa electrode technology for the Swiss Paraplegic Foundation. This provides long-term electrical stimulation (several times throughout the day) in order to strengthen or improve circulation in the gluteus maximus and thus comfortably prevent decubitus for wheelchair users. Nahtlos aims to obtain a round of financing and industrialize the adhesive electrode in 2022. //



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Thermostat manufacturers can integrate the viboo algorithm into their smart thermostats using a cloud-based solution. File photo: iStock/Andrey Popov

2
Seamless chest strap for long-term medical monitoring of the heart rate and its variability.

Cooperating for the future

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Dr Martin Gubser, martin.gubser@empa.ch

As a research institute in the ETH Domain, Empa receives about 60 percent of its basic funding from the Swiss government. The remaining 40 percent comes from third-party funding in Switzerland and the EU as well as from research projects with Swiss industry players. However, private foundation donations and contributions represent a growing share of this third-party funding and make it possible for Empa to sponsor innovative research projects and promising talents in the field that have not yet received funding elsewhere.

Full speed ahead

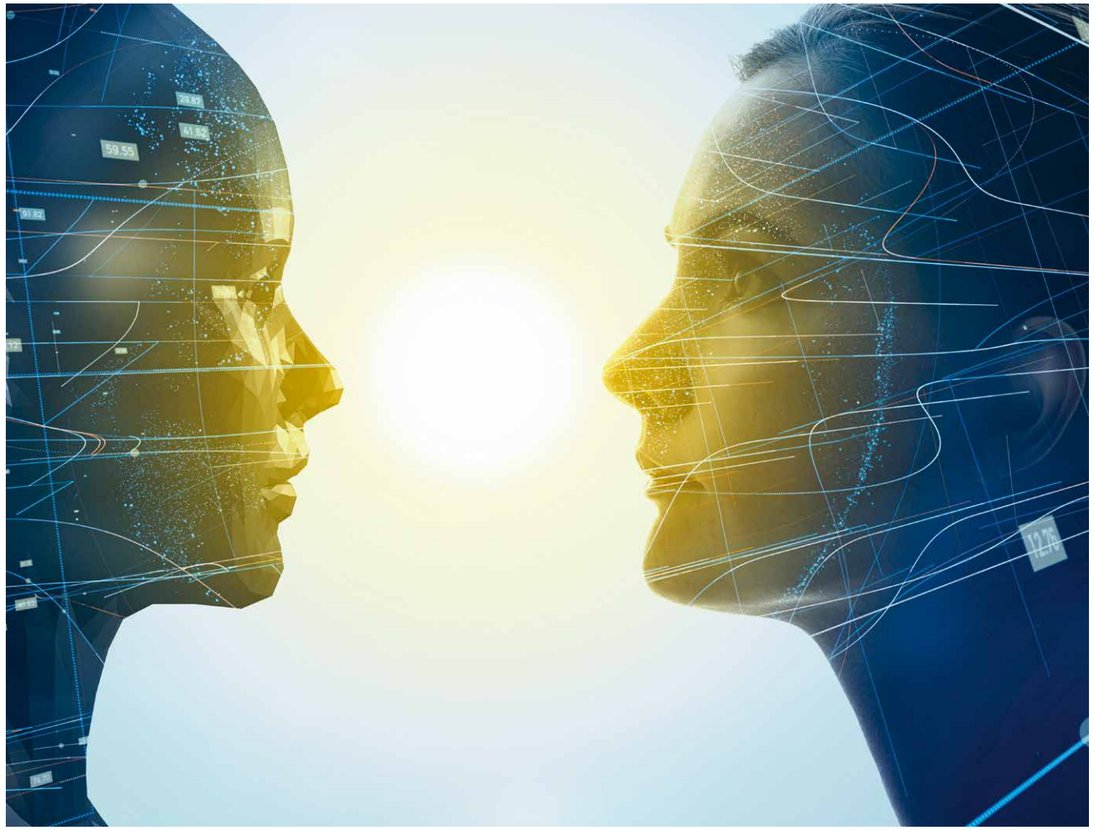
In February 2021, Martin Gubser joined the Empa Zukunftsfonds. In this new role, he brings to bear his years of experience in strategic fundraising – for example, in the last few years before joining Empa, he managed fundraising for the Swiss Paraplegic Foundation and subsequently for the UZH Foundation, the donation foundation of the University of Zurich.

Thematic funds for new ideas

New roads towards a climate-neutral and efficient energy future, innovative solutions for sustainable construction, increased recycling of materials in a circular economy, technologies to improve air quality or materials and systems for novel diagnostic procedures and therapies in medicine – at Empa, there are numerous opportunities to promote research and infrastructure projects or to specifically support the training of young, outstanding talent. In addition to the Zukunftsfonds as a central vehicle for donations, Empa set up five new subject-based funds in 2021: one fund each for research in the fields of sustainability, health, energy and nanotechnology, and one talent sponsorship fund.

Promoting the best

Promoting young talent is a key priority at Empa. With approximately 400 young researchers working on their theses or advancing their postdoctoral careers, Empa can access a huge talent pool. Supporting young researchers is a direct investment in the future of our country. In 2021, Empa awarded the Empa Young Scientist Fellowship for the first time. Over a period of two years, the fellowship offers outstanding young scientists the opportunity to work independently early on, address relevant research topics and thus kick-start their academic careers. The Ria und Arthur Dietschweiler-Stiftung pledged a further Empa Young Scientist Fellowship for researchers at the St. Gallen site in the amount of CHF 270,000, and the talent sponsorship fund received further donations not bound by a specific intended purpose.



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Digital twins are intended to facilitate the development of customized therapies, for example in pain treatment. File photo: Shutterstock

Digital avatars for pain therapy

Fentanyl patches are an effective alternative to the delayed release of morphine in chronic pain treatment. However, for effective pain relief without undesirable side effects, the concentration of fentanyl in the blood must be carefully controlled. In addition, the patients' physiological characteristics such as age, sex, weight, liver enzyme activity, etc. can influence the course of treatment. In a new project, Empa researchers are developing customized digital twins based on the physiological characteristics of each patient that can make an important contribution to pain management. This project was made possible by a donation of CHF 140,000 by the Margrit Weisheit Stiftung. //

Virtual networking, the new normal

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

The direct exchange of information and networking with Empa's national and international partners continued to be significantly impaired in the second year of the pandemic. Most of the physical meetings took place in summer and autumn, when the infection rate was relatively low.

In this vein, the Austrian Federal Ministry for Digital and Economic Affairs organized not one but two visits to Empa, where representatives of industry, research and administration exchanged views on energy and sustainability, for example novel battery concepts from Empa's Energy Hub (ehub) and sustainable concrete and asphalt technologies. In July, a delegation from Thailand headed by ambassador Chakri Srichawana visited Empa to learn about its newest developments and sound out opportunities for cooperation.

Meetings in the digital sphere

If meetings could not be held face-to-face in the real world, they were unceremoniously moved to the digital sphere. For example, a virtual voyage to the future took place in March where Empa experts discussed the future of materials and fabrication processes with (again) Austrian economy and industry delegates and introduced them to the Swiss m4m Centre – 3D printing of medical implants – and further Swiss initiatives in the field of advanced manufacturing (AM), among other things.

Also in March (and again with partners from Austria), Empa Deputy CEO Peter Richner virtually attended a conference of the international research platform ReConstruct where he also participated in a panel discussion on the topic of climate-neutral construction with Austria's Minister for Climate Action, Leonore Gewessler.

The renowned three-day NanoMed Europe conference, which was organized by Empa researcher Peter Wick as the conference chair together with the University of St. Gallen and the Cantonal Hospital of St. Gallen, was also held as a purely virtual event. It focused on medical applications of nanotechnological techniques and novel medtech applications, in particular regarding their implementation in medical practice.

Working together to ensure a sustainable use of resource

The World Resources Forum 2021 was held in a hybrid format in October, which is to say that it mainly took place online with additional smaller live events at the Empa Academy in Dübendorf and in Accra (Ghana). As part of the three-day event, a total of nearly 1,000 participants from the fields of politics, science, industry and society discussed the sustainable use of our natural resources.

In the area of international research cooperation, Empa and BASE (Basel Agency for Sustainable Energy) were among the eight winners of the prestigious global Inclusive Growth and Recovery Challenge in early January, which is endowed with a total of USD 10 million and sponsored by the Rockefeller Foundation, the Mastercard Center for Inclusive Growth and data.org in order to tackle the biggest societal challenges with computer and data science. For the project Your Virtual Cold-Chain Assistant, Empa researchers are developing a mobile app for smallholder farmers in India to protect food against decay and thus prevent food waste. In October, the project was also launched in Nigeria together with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) on the occasion of the West Africa Cold Chain Summit in Lagos.

Empa's new research cooperation with the University of British Columbia, arranged in October, also deals with the subject of sustainability: sustainable wood- and cellulose-based biomaterials, to be precise. In the course of this cooperation, Empa also joined the Boreal Alliance, an international initiative to coordinate research from nations along the Boreal belt and optimally utilize forest resources in keeping with sustainable development. //

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In 2021, not one but two Austrian delegations from the fields of industry, research and administration visited Empa to learn about energy and sustainability as well as sustainable concrete and asphalt technologies.

2
Empa Deputy CEO Peter Richner virtually attended a conference of the international research platform ReConstruct where he also participated in a panel discussion on climate-neutral construction with Austrian Minister for Climate Action, Leonore Gewessler (second from left).

Dialog on all channels

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After visitors attending tours and events at Empa dropped by 80 percent in 2020 due to COVID-19, the figures for events clearly improved again in the past year, even reaching the level before the pandemic. However, just under 70 percent of attendees took part virtually, for example for the virtual openings of the two new NEST units Sprint and HiLo (see page 24). Thanks to digitalization …

Speaking of NEST and digitalization, the research building opened its virtual doors last summer and has attracted more than 5,000 guests since then, about 40 percent of which were international. The two new units are currently being digitalized, after which they also will be integrated in the virtual NEST.

NEST definitely welcomed a very special (real? digital?) visitor last year: in March, the beloved German children's TV character Maus (mouse) from "Sendung mit der Maus" (the show with the mouse) visited Dübendorf. The team of Armin Maiwald, host of the program since the very beginning, produced an episode for the 50th anniversary of the children's show at NEST with the following topic: How can we ensure circular construction in the future?

Active dialog with politicians

Empa CEO Gian-Luca Bona also welcomed Federal Councilor Ueli Maurer, Director Pierre Broye and Vice-Director Herbert Tichy of the Federal Office of Construction and Logistics (BBL) to NEST in June. They toured various research projects and demonstrators and exchanged ideas with Empa's Directorate on innovative net zero concepts, for example in circular construction, mobility and energy research. The goal is to incorporate these approaches into the many federal buildings and scale them up.

In addition, various parliamentary commissions visited the Empa-Eawag campus in Dübendorf, for example the Swiss National Council Committee for the Environment, Spatial Planning and Energy (ESPEC) and members of the Finance Committee of the National Council.

The Switzerland Innovation Park Zurich, which is to be built not far from Empa at the Dübendorf airfield, was the topic of discussions with the special commission for area development of the Cantonal Council of Zurich. Empa CEO Gian-Luca Bona summed up what is required from a research point of view to successfully develop the Switzerland Innovation Park Zurich. According to Bona, the Innovation Park closes a gap in the innovation ecosystem for the greater Zurich area, offering much needed space for partnerships with industry, which is very limited in university settings, in particular for space consuming research with pilot installations and test infrastructures.

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The virtual tour gives the general public the opportunity to discover new technologies, materials and processes of the construction and energy sector in the NEST research and innovation building by themselves – on the road or from home.

2
Roland Bilang, Managing Director of Avenergy Suisse, and Brigitte Buchmann, member of Empa's Directorate, open the Powerfuel exhibition at the Swiss Museum of Transport in Lucerne in March 2021.

3
Empa CEO Gian-Luca Bona (right) in June 2021 with Federal Councilor Ueli Maurer at NEST.

4
At Salon Public, Switzerland's largest science festival, Empa Deputy CEO Peter Richner showed how broadly the interpretation of an intelligent building can be applied at the Kursaal in Bern in October.

COVID-19 remains a hot (research) topic

The virus continued to keep Empa researchers on their toes in the past year. In addition to Empa's participation in the Federal COVID Task Force, the institute also carried out several studies in close cooperation and coordination with the authorities of the canton of Graubünden. At the beginning of 2020, for example, Empa researchers analyzed (and modelled) the infection risk in cable cars and cabins and examined the effectiveness of regular mass testings to curb the pandemic as well as the effect of indoor air quality on the course of infection.

On the road – at the science festival, the Swiss Museum of Transport and at Olma

Empa also did not neglect to maintain its dialog with the public. At Salon Public, Switzerland's largest science festival, Empa Deputy CEO Peter Richner showed how broadly the interpretation of an intelligent building can be applied at the Kursaal in Bern in October and attempted to show a perspective that goes far beyond current standards in construction. In addition to Richner, other speakers such as former German Foreign Minister Joschka Fischer, solar visionary Bertrand Piccard and philosopher Richard David Precht held talks at Salon Public.

Sustainable mobility is also the focus of the current Powerfuel exhibition at the Swiss Museum of Transport, Lucerne, and of Empa's booth at the Olma trade fair in St. Gallen in October. Here, visitors were offered the opportunity to use a simulator to practice refueling a fuel cell car with hydrogen and learn how mobility in Switzerland can become climate-neutral.

And finally, Empa presented various livestreams on topics such as drones and artificial intelligence (AI), autonomous driving and digital twins to avoid food waste as part of the Digital Day 2021. //

Implementing the action plan together

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Melina Spycher, melina.spycher@empa.ch

We owe our strength in no small part to our diversity: at Empa, people from a wide variety of backgrounds, cultures and fields of activity research and work together. "Outstanding results can only be achieved on the basis of respectful interactions with each other", Empa CEO Gian-Luca Bona voices his conviction.

New Center of Competences for D&I established

On 1 September 2021, the new joint Competence Centre for Diversity & Inclusion (D&I) PSI – Empa – Eawag was formed, and Marianne Senn ceded her role as Equal Opportunity Officer to Melina Spycher. Over the past six years, Marianne Senn worked as Equal Opportunity Officer in an extremely competent manner, staying abreast of new trends and significantly shaping several action plans. In doing so, she made an important contribution to maintaining Empa's excellent reputation as an employer.

The new Competence Centre D&I PSI – Empa – Eawag consists of Natalie Lerch-Pieper (Head of the Competence Centre and responsible officer for PSI), Johanna Alves (intern for D&I at PSI) and Melina Spycher. As the Expert for Diversity & Inclusion, Melina Spycher is primarily responsible for Empa, although she also works for Eawag and PSI. Synergies between the three research institutes can be optimally exploited and a regular exchange of information can be facilitated thanks to the Competence Centre. For example, the Competence Centre D&I and the D&I Coordinator at WSL, Urte Reckowsky, institutionalized a frequent dialog in this manner.

Equal opportunities and diversity action plan 2021–2024

In 2021, the Centre's main focus was on implementing Empa's new equal opportunities and diversity action plan 2021 – 2024 (*www.empa.ch/web/equal-opportunities)*. The action plan concentrates on the following points:

- 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

Under the banner of equal opportunities, Empa became a member of Advance, the leading business association for gender equality in Switzerland, in April 2021. This network is comprised of over 120 Swiss companies committed to increasing the proportion of women in management positions. The association offers exciting skill-building and best practice workshops as well as networking events. To see the newest events, visit the equal opportunities intranet page or *www.weadvance.ch.*

"We are still CONNECTing"

In October 2021, the CONNECT (connecting women's careers in academia and industry) program started its third round. Two women at Empa are also part of the program and have the opportunity to meet exceptional women and learn about their careers from academia to industry during company visits to Medtronic, UVEK, Hitachi and GE.

Children learn to research through play

Despite the difficult circumstances posed by the pandemic, 24 children of staff were able to participate in the summer camp last year. Workshops like "buzz wire", "rocket car", "myBoomBox", "hot & cold" and "liquid nitrogen" introduced them to the world of engineers and materials researchers at Empa in a playful manner. //

1
Marianne Senn (right) symbolically hands over the role to Melina Spycher.

2
Two young scientists at the summer camp.

From gravelled area to ecological oasis

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The Natur&Wirtschaft foundation distinguishes building complexes and neighborhood concepts that are exemplary in terms of nature-orientated design and promotion of biodiversity in settled areas. Currently, over 500 institutions have been certified with the foundation's label, including Empa's two campuses in St. Gallen and Dübendorf. For a further ecological upgrade, the foundation's experts proposed remodelling the area covered in basalt gravel next to the laboratory building at the St. Gallen location. The plan is to return this barren gravelled area to nature in future in order to provide a habitat for small animals and plants. Due to the COVID-19 pandemic, this project could not be continued in 2020, but in 2021, a team of employees began the remodelling work.

Sprint – a new NEST unit in operation

While the pandemic curbed many projects or even made them impossible, it accelerated one in particular: the construction of the new Sprint NEST unit. In just ten months, flexible, COVID-19-compliant office spaces were built using mostly reused materials and components. This provides Empa staff with more individual offices (see page 24). The new unit demonstrates that the stock of reusable materials and the reuse potential in the construction industry are huge. This shows that building with reused materials and components is a quick and valid alternative to building with virgin materials. The unit follows the "design for disassembly" approach, so that when needed, the flexible partitions, among other things, can be dismantled, allowing individual offices to be used as open-plan offices.

Net Zero Day for research institutions

In order to develop solutions for transforming our society in line with net zero CO_2 emissions, the four ETH Domain research institutes Empa, PSI, Eawag and WSL organized the Net Zero Day in October 2021. The objective was to exchange knowledge on current research in this field, initiate and strengthen networks between researchers at all the institutes and identify possibilities for new cooperation ventures. Some of the initial joint topics that emerged from this exchange were life cycle analyses, batteries, synthetic fuels, data and multiscale simulations. These topics are now being further defined in working groups.

Publications on 100 percent recycled paper

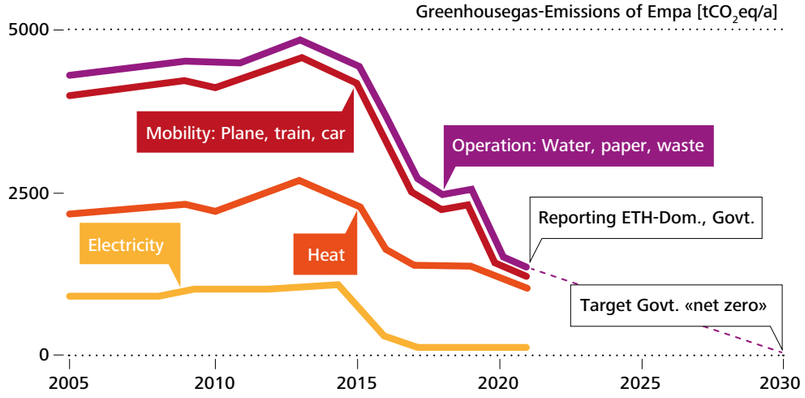
While Empa has been using recycled paper exclusively in its photocopiers for some time, its periodic publications, such as the annual report, the research magazine Empa Quarterly and the staff magazine EmpaIntern, are now also being printed on paper made from 100 percent recycled paper. In addition, most of the magazines are shipped without plastic film packaging. This saves around 80 kilograms of plastic per year.

Impressive reduction in greenhouse gas emissions

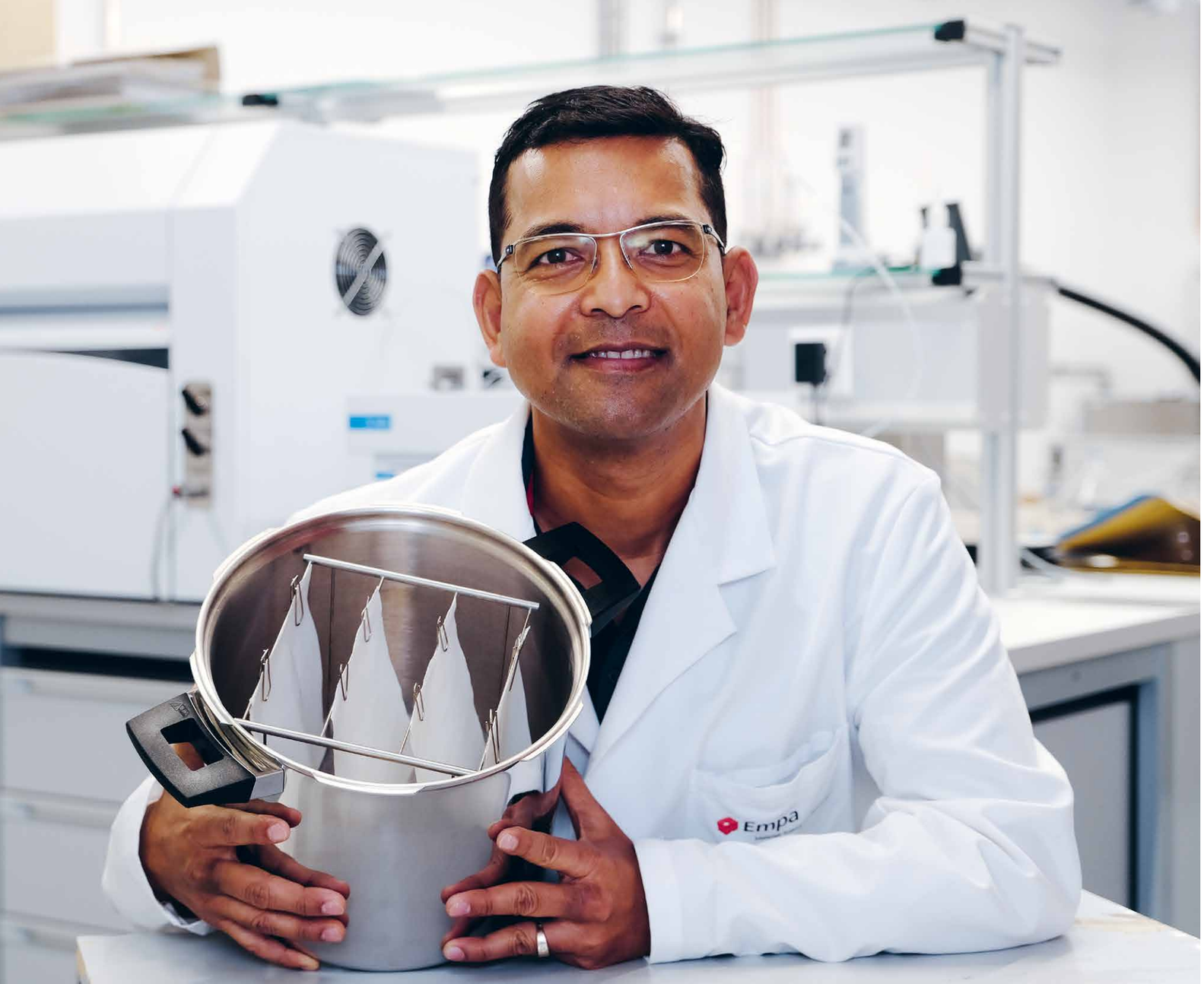
After the significant COVID-related reductions in greenhouse gas emissions through restrictions on air traffic, a declining trend in the mobility sector continued to emerge. It seems that employees are now increasingly using modern means of communication. However, air travel is generally expected to catch up in future.

A lasting trend towards decreasing greenhouse gas emissions is emerging in the heating sector. Thanks to comprehensive conversion measures in Dübendorf, energy efficiency has been increased and dependence on fossil fuels reduced, and the first positive effects are becoming visible. //

1
What happens when nature is given free rein? In a barren gravel area at the St. Gallen site, "wild" growing plants are not burned down. This allows a habitat for small animals and plants to emerge.



2
Development of Empa's greenhouse gas emissions: compared to the reference year 2006, significant reductions were achieved in electricity and mobility. It remains to be seen whether the COVID-related slump in mobility will remain permanent. Thanks to technology changeovers, interesting reduction potentials are expected to be exploited in the heating sector. According to federal requirements, Empa aims to achieve the net zero goal by 2030.



Facts and Figures

Researchers like measuring, including their own performance: in 2021, Empa researchers and engineers published 850 academic papers and filed patent applications for 13 developments. At the end of the year, 112 projects funded by the Swiss National Science Foundation (SNSF), 98 projects backed by Innosuisse and 71 EU projects were underway at Empa. Together with other start-ups in Empa's two business incubators, the 28 spin-offs employed a total of 1,097 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 and to take appropriate measures to mitigate them. 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 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 material assets and 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 necessary – adjusted.

The challenge of COVID-19

As in all other walks of life, COVID-19 continued to dictate the work of risk management in 2021. Empa's Board of Directors decided to maintain operations in a manner adapted to the situation. This required a high degree of flexibility and pragmatism from the members of the COVID-19 Task Force, Risk Management staff and all other Empa employees. The Task Force and the Risk Management staff monitored the situation, maintained contact with the authorities and, respectively, submitted adequate recommendations for safe working to the Board of Directors for a decision and subsequently implemented them. For this reason, the number of employees working from home fluctuated widely. So did the number of events that Empa was able to host, as well as their turnout. The only exceptions were events in connection with basic vocational training. As it is very important for Switzerland as a business location to train junior staff for industry, Empa decided to maintain this type of event almost entirely, with added protection concepts.

This year, Empa's in-house rescue service again 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. Furthermore, high priority was given to supporting staff regarding all issues specific to COVID-19. Hundreds of conversations, emails and phone calls have helped to keep the atmosphere relaxed at all locations and, in combination with the tailor-made measures, to keep direct contagion between employees low.

Developing security issues

A central aspect of prevention at Empa is the training of staff. With around 500 employees and academic guests arriving at or leaving Empa each year, this is quite a challenge, which has not been made any easier by the COVID-19 situation. 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.

The in-house rescue service, as well as the fire and chemical response team, have maintained their drill regime throughout 2021. The level of training was raised even further through selective advanced training. Interdisciplinary exercises were conducted despite COVID-19 and provided important input for further process improvements. The technically demanding replacement of the alarm server was also used as an opportunity to optimize and expand the alerting processes based on new technical possibilities.

The topic of information security gained even more relevance in view of the general threat level which resulted from the increased number of cyberattacks in 2021. An information security team was established that developed an instruction on information security and started gathering information assets as a basis for defining the rules for handling specific information. Its aim is to protect the information based on a business risk analysis regarding confidentiality, integrity and availability. Systematic development of this issue will continue in future in line with the standard and optimized for the institution. //

Human resources development

(previous year's figures in brackets)

André Schmid, andre.schmid@empa.ch

At the end of 2021, 1012 (1022) people, including trainees, were working at Empa. This corresponds to a full-time equivalent (FTE) of 948.2 (958.8) positions, due to numerous part-time employments. Scientific staff, including PhD and postdoctoral students, comprises 574 (588) individuals. Of these, 101 (104) are Senior Scientists. Technical and administrative staff comprised 395 (393) persons in the year under review. The proportion of women, at 28.2 (29.7) 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 457 (470), or 45.2 (46.0) percent of the total staff. The EU accounts for 268 (285) persons, or 58.6 (60.6) percent of all foreign employees. Empa offers vocational training for a number of professions and currently employs 43 (41) apprentices. As in previous years, all Empa apprentices successfully passed their final exams in 2021. //

STAFF END OF 2021

	2020	2021
Scientific staff	**588**	**574**
Technical and administrative staff	**393**	**395**
Apprentices	41	43
Total	**1022**	**1012**

Key Figures

SCIENTIFIC OUTPUT

	2020	2021
ISI publications	852	850
Conference contributions	494	942
Doctoral studies completed	28	34
Doctoral studies in progress	199	226
Teaching activities (in hours)	4942	4529
Prizes and awards	46	50

MEDIA EXPOSURE

	2020	2021
Radio	118	143
TV	55	57
Print	1405	1370
Online	6090	6880
Total	7665	8450
Languages	38	39

EMPA ACADEMY

	2020	2021
Empa events	24	70
Participants	1300	4490
On-site visits / online	450 / 850	1266 / 3224
Scientific conferences	6	18
Events for industry	13	14

KNOWLEDGE DISSEMINATION & TECHNOLOGY TRANSFER

	2020	2021
New R&D Agreements	208	232
Active exploitation contracts	66	54
New exploitation contracts	14	14
New patent applications	15	13

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

	2020	2021
Companies total	119	107
thereof spin-offs	29	28
Employees total	1147	1097
thereof employees of spin-offs	155	173

CURRENT PROJECTS

	2020	2021
Swiss National Science Foundation (SNSF)	104	112
Innosuisse	81	98
EU projects	72	71

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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Barbara Haering Dr, Dr h. c., Econcept AG

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Christiane Leister Leister AG
Joël Mesot Prof. Dr, ETH Zürich
Cornelia Ritz Bossicard 2bridge AG
Martin Vetterli Prof. Dr, EPF Lausanne

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

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Christian Koitzsch Dr, Robert Bosch GmbH
Katharina Lehmann Blumer-Lehmann AG
Chris Luebkeman Dr, ETH Zürich
Céline Mahieux Shell (Switzerland) AG

Research Commission

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

MEMBERS
Urs T. Dürig Dr, SwissLitho AG
Thomas Egli Prof. em. Dr
Marcus Textor Prof. Dr, ETH Zürich
Alexander Wokaun Prof. em. Dr

Organizational chart

as of May 2022

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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Director
Prof. Dr Gian-Luca Bona

Deputy
Dr Peter Richner

Dr Brigitte Buchmann, Prof. Dr Alex Dommann, Dr Pierangelo Gröning, Dr Urs Leemann, Dr Tanja Zimmermann

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Electron Microscopy Center
Dr Rolf Erni

Engineering Sciences
Dr Peter Richner

Center for Synergetic Structures
Dr Cédric Galliot

Materials Meet Life
Prof. Dr Alex Dommann

Center for X-ray Analytics
Prof. Dr Antonia Neels

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

Experimental Continuum Mechanics
Prof. Dr Edoardo Mazza

Urban Energy Systems
Dr Kristina Orehounig

Magnetic and Functional Thin Films
Prof. Dr Hans Josef Hug

Biomimetic Membranes and Textiles
Prof. Dr René Rossi

Particles-Biology Interactions
Dr Peter Wick

Biointerfaces
Prof. Dr Katharina Maniura

Transport at Nanoscale Interfaces
Prof. Dr Michel Calame

Materials for Energy Conversion
Dr Corsin Battaglia

Advanced Analytical Technologies
PD Dr Davide Bleiner

Air Pollution / Environmental Technology
Dr Lukas Emmenegger

Automotive Powertrain Technologies
Christian Bach

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

Technology and Society
Dr Patrick Wäger

Acoustics / Noise Control
Dr Jean Marc Wunderli

High Performance Ceramics
Prof. Dr Thomas Graule

Concrete and Asphalt
Prof. Dr Pietro Lura

Cellulose & Wood Materials
Dr Gustav Nyström

Building Energy Materials and Components
Dr Wim Malfait

Advanced Fibers
Prof. Dr Manfred Heuberger

ICT-Services
Stephan Koch

Mechanical Engineering / Workshop
Stefan Hösli

Finances / Controlling / Purchasing
Heidi Leutwyler

Communication
Dr Michael Hagmann

Human Resources
André Schmid

Knowledge and Technology Transfer / Legal
Marlen Müller

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Empa – The Place where Innovation Starts

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