Empa Quarterly

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Urban Mining

Precious metals from e-waste

Fireproofing made of recycled paper

Optimizing energy flows

Empa
Materials Science and Technology

MICHAEL HAGMANN Head of Communications

Switzerland – a country of natural resources?

Dear readers

"Resource-poor" is generally one of the less gratifying attributes that Switzerland is associated with. If we compare ourselves with raw material heavyweights like China, which are simply teeming with classic mineral resources, it is not so far of the mark. And yet veritable gold mines are lurking here, just waiting to be extracted – for instance in the piles of domestic e-waste like our discarded smartphones and other gadgets.

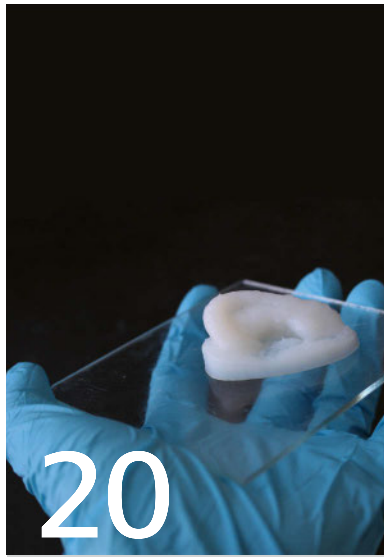
This, however, calls for bright minds and innovative technologies – one of the "raw materials" Switzerland thankfully has in abundance. The latest issue of EmpaQuarterly presents some of these resource-saving approaches and the resourceful researchers behind them. You will encounter a number of astonishing innovations, such as an insulating material for fireproofing made of recycled paper, or wood-decaying fungi that convert conventional beech wood – somewhat cheap and plain-looking – into valuable "marbled wood", beautifully grained and highly coveted by interior designers.

Irrespective of their specific use, the concepts showcased in this issue have one thing in common: They stand for a more responsible handling of our limited natural resources. This is something, though, we can only achieve if – besides relying on new technologies – we also adapt our daily behavior accordingly – maybe a good New Year's resolution for 2019 once the Christmas spending frenzy is over.

I hope the latest issue of EmpaQuarterly will inspire you and wish you a riveting read as well as a very happy new year. Until the next issue!

Focus

Natural resources from Switzerland



Cover
*St. Gallen's old town. Resources are lying dormant here: 80 percent of the energy required in winter is heat. Do we really need to generate it from fossil fuels? Thousands of LCD monitors, hard drives and cell phones are piling up in every Swiss city. How can the precious metals they contain be recovered? **Page 09–23**. Photo © St.Gallen-Bodensee Tourismus, Mattias Nutt*

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Empa Social Media

Virtual noise

Railway noise is annoying. Trains cause numerous sleepless nights, especially in the vicinity of residential areas. This makes it all the more important to optimize trains and tracks in such a way as to dampen sounds. Empa researchers have devised a computer simulation that demonstrates how railway noise is created in the first place and which technical measures are effective in preventing it.

Here you can see what you are about to hear: Empa's noise simulation also runs on virtual reality glasses. Wearable and in stereo.

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TEXT: Cornelia Zogg / PICTURES: Empa

The train whooshes closer, the noise level rises, there is an unpleasant booming in the ears as the coaches clatter past. A few seconds later, the ordeal is over; the noise subsides and the coaches vanish in the distance. What at first glance might seem like a normal recording of a passing train is actually much more. Neither the noises you hear through the speakers or headphones nor the images you see are real: It was all created in a computer simulation.

Noise: an ensemble of over one hundred sound sources

“Noise consists of various components,” explains Reto Pieren from Empa’s Acoustics/Noise Control lab, who is in charge of programming the simulation developed by a team of Empa researchers in an EU Horizon2020 project. “The wheels, the tracks, the ventilation, the engine – they all generate sounds and together cause the train’s noise emissions.” In other words: Pieren developed individual algorithms for the more than 100 sound sources of a moving train. This allows Pieren and his colleagues to render the entire train “audible” – or just individual components, say, the rolling wheels.

Besides the diverse sound sources of a moving train, Pieren also factors environmental influences into his calculations. These include noise barriers, the speed, at which the train is traveling, the state of the tracks, the ambient temperature and even ground conditions. The goal of the simulation is not only to reveal optimization potential for existing train compositions, but also to be able to predict how new wheels or new components (or any other measure, for that matter) might affect the perceived noise of a railway line.

Created on the computer

Empa’s simulation is unique as previous programs use real audio recordings. Pieren, however, generated the individual sounds on the computer. The acoustic signal is calculated for every train component, taking into account the physical parameters – properties such as the surface condition and the materials the tracks and the individual wheels are made of. Pieren obtains these parameters from his own measurements, from measurements from vehicle manufacturers and from computer calculations, and then feeds them back into the simulation. The algorithm uses this data to calculate the emitted sound pressure level, which in turn is used to simulate the sound at any given listening point.

But it gets even more complicated: For the rolling sound, for instance, the brake system of the carriages is factored in. “Hidden behind it are datasets that describe the surface microstructure of the wheels. An individual surface structure is calculated for each wheel,” explains Pieren. This surface structure is instrumental in the friction between tracks and wheels and thus the development of sound and noise. The fewer irregularities on the surface of the wheels and the tracks, the quieter the traveling sound.

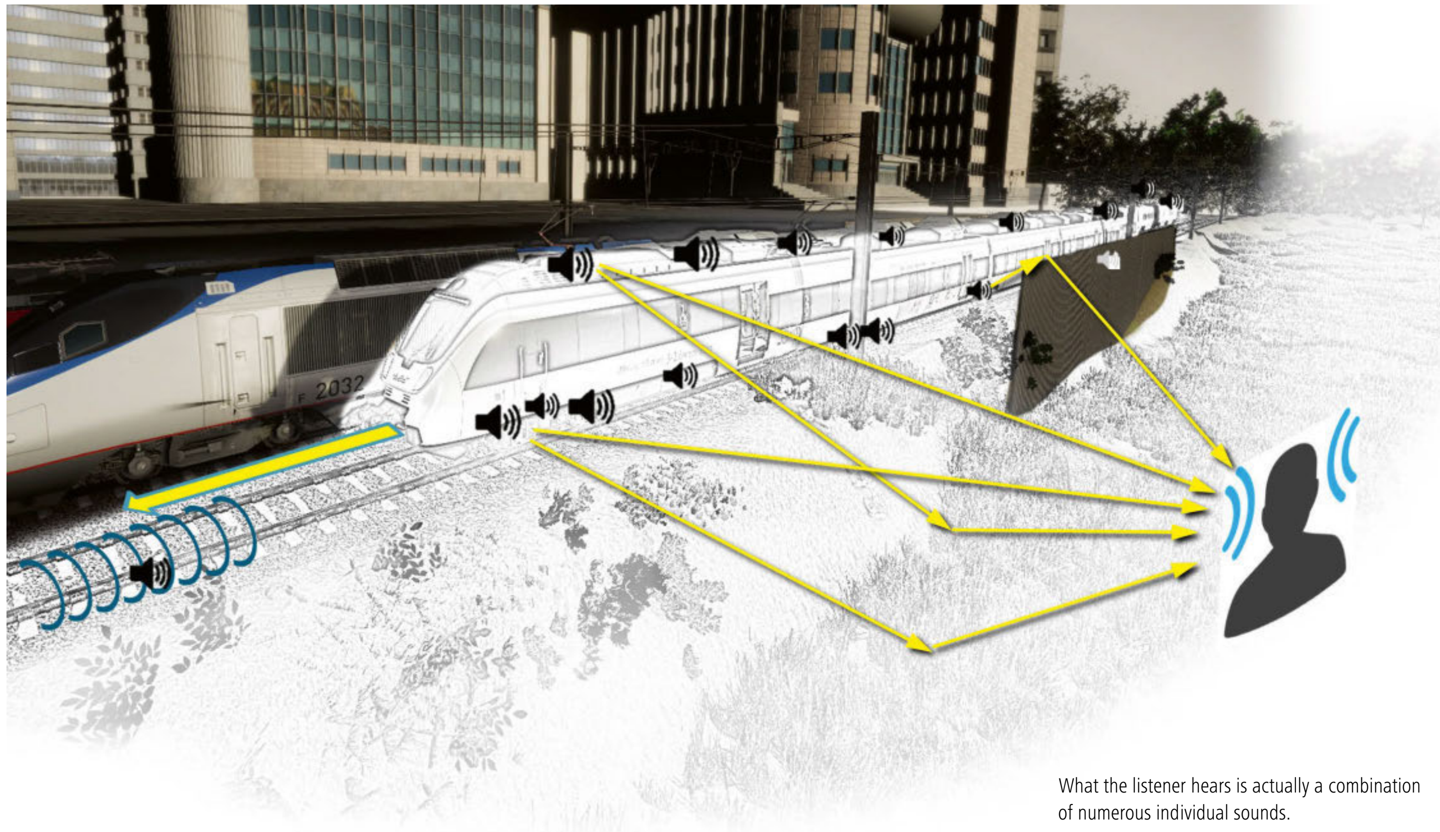
The sound makes the difference

A passing train creates noise; that much is obvious. How a resident perceives this noise, however, depends largely on the local environment and the propagation of the sound. Sound undergoes diverse changes during propagation. It is absorbed by air, which causes higher frequencies to be dampened more than low ones. It is a similar story with noise barriers: While high frequencies are actually not as loud behind the barrier, low sounds are bent over the wall. All these factors can be reconstructed in the simulation, along with the specific location of the listener.

Pieren verified the artificially generated noise using volunteers in an audio experiment. Fortunately, the volunteers rated the simulations and the artificial sounds as highly plausible. Therefore, the simulation can be used to “auralize”, i.e. render audible, the effects of various measures. For instance, Pieren runs the simulation, then places a noise barrier and makes another train pass. “If we say a specific measure reduces the noise level by three decibels, hardly anyone can imagine what that actually means. If I render these three decibels audible by direct comparison, however, the effect immediately becomes clear.”

The simulation does not just work in the lab or with a virtual reality set; Videos on YouTube also display the comparison and highlight what the simulation is capable of. In future, it should support the decision making process regarding the construction and expansion of railway lines and train compositions. In the long run, railway operators, planners and above all residents stand to benefit. //

The Empa railway noise experience
Is it annoying? You can compare Empa train noise simulations with different trains and noise abatement measures on YouTube.
https://youtu.be/rtEB_qsaiWw


What the listener hears is actually a combination of numerous individual sounds.


The simulation can be tested on volunteers in a sound-proof room in Empa’s “AuraLab”.

Resources made in Switzerland

For some time now, extremely precious raw materials have been lying dormant in our cities rather than underground. How can we mine them successfully? We could recover indium, neodymium and gold from e-waste. We could toughen up old buildings with memory steel for new uses. We could produce cartilage implants made of cellulose and insulating materials made of recycled paper for timber houses. We could store summer heat and use it on cold winter's days. Find out how in this issue.

Precious metals from e-waste

Indium, neodymium and gold are natural resources that can be found in many electronic devices. At the same time, the three substances are elements that rarely occur in nature. What happens to the valuable materials when they are no longer needed? And how much of these elements can be found in mobile phones, computers and monitors that are currently in use? Empa researchers have investigated these questions.

Gold from electronic devices is largely recovered today – indium and neodymium, on the other hand, are lost.

TEXT: Karin Weinmann / PICTURES: Empa, iStockphoto

The three natural resources gold, neodymium and indium are among the rarest elements on earth: each of the three metals accounts for less than 0.00001 % of the earth's crust. They can be found in a large number of electronic devices, in small quantities, but in key functions: Indium as indium tin oxide is electrically conductive and transparent at the same time. Because of these properties, the material is used in LCD screens, for example. Neodymium is used in combination with iron and boron to produce strong magnets. These are found in hard disks, loudspeakers, headphones and mobile phones. Gold finally is a very good conductor that cannot corrode. The metal is therefore used in electronic components such as switching contacts or printed circuit boards.

The problem is that neodymium and indium in particular are considered critical metals. This means that on the one hand there is a risk of supply interruptions, as the two rare elements are almost exclusively mined in China. On the other hand, their importance for key technologies is regarded as high and, accord-ingly, the effects of possible interruptions as particularly serious.

However, in fact Switzerland also has mines for these three resources. Among other things, they are found in electronic devices that are in use or are already obsolete. Empa doctoral student Esther Thiébaud from the Department of Technology and Society has now for the first time investigated where the three rare metals can be found in Switzerland – and how much of them has already been lost for further use.

Her analysis revealed that the largest proportion of all three substances is found in devices that are currently in use. Then the paths of the elements diverge: The second largest share of indium is found in slag from waste incineration plants – and is therefore lost for possible recovery. The same applies to the second largest share of neodymium; it is found in slag from metal smelters, which is used in the construction sector. Gold, on the other hand, is already recovered at 70 % for economic reasons when equipment has reached the end of its life cycle. While the recycling rate for gold is already very good, neodymium and indium are not yet recovered at all in Switzerland.

Recycling would be feasible

As early as 2015, an Empa team led by Heinz Böni was commissioned by the Federal Office for the Environment (FOEN) and the Swiss Association of Information and Communication Technology Providers (Swico) to investigate whether the recovery of indium and neodymium makes ecological sense and is economically viable. Technically, indium can already be recovered today, albeit at relatively high effort. And from an economic point of view, only moderate additional costs are incurred for the recovery of indium from screens. These could be covered by increasing the early recycling fee by 50 centimes per screen. Ecologically, however, the matter is clear: a mountain of disused screens has a higher indium content than a mine with the same volume from which indium is extracted as the primary resource. According to the study, the environmental impacts of recycling are also as high, if not better, than those of primary production from minerals. However, this only applies if the discarded equipment is manually dismantled in the first processing step and not mechanically crushed.

In the case of neodymium, the ecological balance is even clearer: if the material originates from the recycling process, then the burden on the environment is one third less than if it were extracted from a mine.

The quantity makes the difference

Similar to gold, indium and neodymium can be clearly located in separable components of an electronic device. It would also be technically feasible to recover the raw materials, albeit at considerable cost. So why have these metals not been recovered so far?

To answer this question, it is important to consider the quantities involved. Indium has only been used in significant quantities since the turn of the millennium. In 2014, the year for which the latest figures are available, around 1.7 tonnes of the metal were present in devices in Switzerland that were still in use. However, the devices that were disposed of in the same year contained only about 135 kg of indium. Around a third of these did not reach the recycling process at all – for example, because the devices were thrown into normal rubbish or exported abroad. Of the approximately 90 kg of

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indium that went through the recycling process, 90% ended up in incinerators, 5% was lost in the melting process – and only 5% was stored for possible future reprocessing, according to the study.

Neodymium has been present in large quantities in sold electronic equipment since the early 1980s. In 2014, around 39 tonnes of neodymium were still present in equipment still in use, while the equipment disposed of in the same year contained 3.9 tonnes. Of these, 2.8 tonnes reached the recycling process, where the element ended up in the slag of the smelting process.

The figures for gold lie between these two: 4.8 tonnes were in equipment, 440 kilos were separated into gold-containing components and 330 kilos of these reached the recycling process. From then on, the losses are low: 95% of the gold that reaches the manual dismantling phase can be recovered.

So it cannot be purely due to the quantities that the additional effort for recovery is only required for gold. Looking at the value of the metals reveals an interesting fact: The 90 kg indium that ends up in the disposal process is currently worth around US$ 36,000; 2,800 kg neodymium US$ 200,000 – and the 330 kg gold US$ 13,600,000. So from an economic point of view, the effort for gold is worthwhile despite the small quantities – for neodymium and indium, on the other hand, the financial motivation for the recycling companies is currently (still) low.

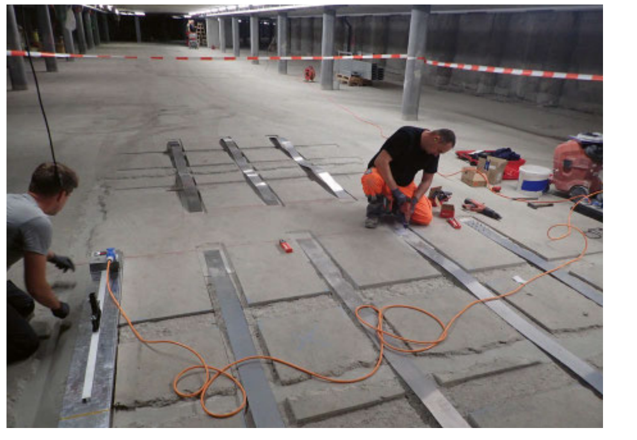
"By far the largest proportion of neodymium and indium is still in the equipment currently in use," explains Esther Thiébaud. "A slight increase in the prepaid recycling fee would already be enough to turn recycling into an economically attractive option". Until then, it would at least make sense to temporarily store components with a relatively high proportion of indium and neodymium – so that the resources are not lost forever. //

above
LCD screens contain small amounts of indium. From an ecological point of view, it is worth extracting the material – at least if the devices are disassembled manually.

below
Indium and neodymium are considered critical metals: there is a risk of supply disruptions as the two rare elements are almost exclusively mined in China. At the same time, their importance for key technologies is considered high and the impact of possible interruptions particularly severe.

New lease of life for old buildings

A new building material developed at Empa has been launched on the market: "memory-steel" can be used to reinforce not only new, but also existing concrete structures – an effective means of preparing old buildings for new uses.



left
Reinforcement rods made of memory steel have been on the market since late 2018.

right
Reinforcing an intermediate slab in an old building with strips made of memory steel.

TEXT: Rainer Klose / PICTURES: Empa

So far, the steel reinforcements in concrete structures are mostly prestressed hydraulically. This requires ducts for guiding the tension cables, anchors for force transfer and oil-filled hydraulic jacks. The space requirements of all these apparatuses created the geometric framework conditions for every prestressed concrete structure; the strengthening of older structures therefore sometimes fails due to the high space requirements of this proven method.

In around 15 years of research work, experts from Empa and refer AG have now brought an alternative method to series production readiness: shape memory alloys based on iron, which contract during heating and thus permanently prestress the concrete structure. Hydraulic prestressing can thus be avoided – it is sufficient to heat the steel shortly, for example by means of electric current or infrared radiators. The new building material is named "memory-steel". Several pilot projects, such as the reinforcement of various reinforced concrete slabs, have already been successful.

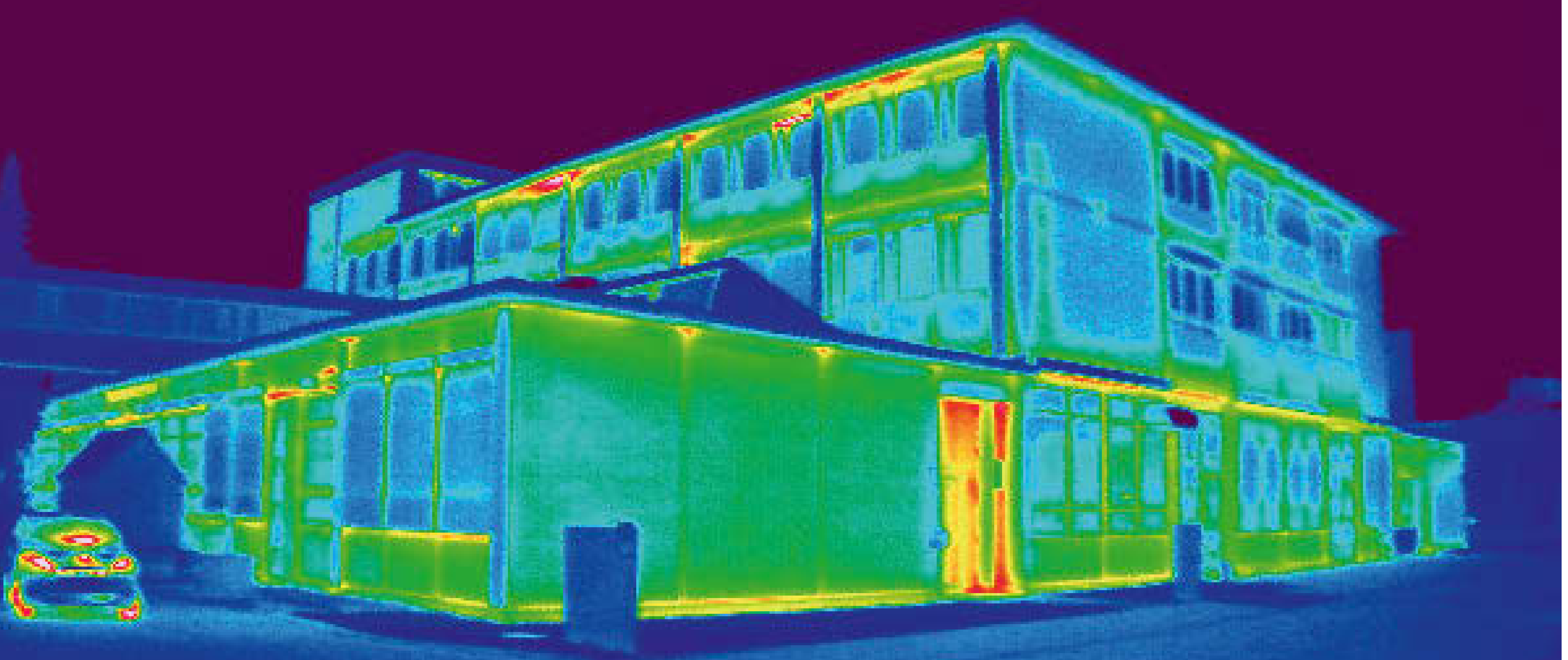
New opportunities for old buildings

"memory-steel" should first of all be used for the strengthening of existing buildings. As soon as, for example, new windows, doors or lift shafts are installed in the concrete structure of an old building, a new reinforcement of the load-bearing structure is often unavoidable. In industrial buildings, the load-bearing capacity of an old suspended slab sometimes has to be increased. Thanks to memory-steel, such tasks can now also be easily solved in confined spaces: Either a strip of special steel is fastened under the ceiling using dowels and then heated with electricity or an infrared radiator. Alternatively, the reinforcement can also be set in concrete.

The ready-to-install memory-steel profiles are manufactured by Voestalpine Böhler Edelstahl GmbH & Co KG in Austria. The company is also working with refer and Empa to further develop the composition of the alloy. //

Canned heat

The development of solar energy and the phaseout of nuclear power plants will drastically change our energy supply: surplus electricity and heat are produced in the summer, but both are lacking in winter months. Heat storage technologies that are capable of storing summer heat for the wintertime could come to the rescue. Empa researchers are trying to figure out how.



TEXT: Rainer Klose / PICTURES: QC-Expert AG, Empa

"Although our research area is nothing new, we are currently experiencing a renaissance," says Luca Baldini. He is a member of Empa's Urban Energy Systems lab, where he heads the BEST research group (Building Energy Systems and Technologies). Baldini and his colleagues are specialists when it comes to saving energy that accumulated during the summer for the winter months. "When we talk about storage technology, most people immediately think of electricity and batteries," says the researcher. "But if you just consider private households, more than 90 percent of their energy consumption in winter is heat. Thus, we also need to think about how we can store heat – not just electricity." Sure enough, research has been ongoing on this literally hot topic since the mid-1980s. There were pioneering plants to store heat, such as at the University of Stuttgart. Over the years these rather simple heat storage basins filled with water or a mixture of water and gravel had been refined, especially in Germany and Scandinavia.

Networks instead of self-sufficiency

Now a paradigm shift is on the cards, which Baldini describes as follows: "In the past, seasonal heat storage systems were something for eco-freaks who wanted to get their little houses through the winter in a self-sufficient manner, everybody on their own. Nowadays, heat storage systems need to be used all over the country and coupled with other energy flows, such as electricity. Using stored heat, we can cut down on CO_2 emissions and reduce the growing peak load on the electrical networks." But how can large quantities of heat be transferred from the summer to the winter? Current technologies can be divided into four categories (see graph on the following centerfold). Empa is actively engaged in all areas.

Pit and earth probe storage systems

Pit storage systems are vast covered storage basins, which – as mentioned earlier – are filled with water or a mixture of water and gravel. The water in what are known as storage systems for sensible heat is heated to up to 90 degrees Celsius using waste heat from industry. In this way, heat can be used directly. Low-temperature storage systems, on the other hand, are operated at 5 to 25 degrees. Heat pumps are used to withdraw heat from them. This kind of storage system includes earth probes.

Baldini's group uses a computer simulation to investigate the maximum amount of heat an earth probe field can store and how its operation can be optimized to emit as little CO_2 as possible. The soil at the edge of these fields heats up less compared to the soil in the center of the field. The researchers believe, based on their simulations, that such an earth probe field can suffer lower heat losses than individual earth probes and reduce the peak load on the electrical grid significantly.

Phase change storage systems

In this case, the storage medium cools down as heat is withdrawn until its aggregate state changes, say, from liquid to solid. In addition to the heat withdrawn from the liquid, the crystallization energy released during the solidification process can also be extracted. An ice storage system, for instance, gives off a mere third of the stored energy through the cooling down of the water from 30 to 0 degrees Celsius; two thirds of the energy is released when the water subsequently freezes. Another advantage: Depending on the melting temperature, heat losses are quite low – occasionally, even ambient heat can be extracted if the storage system is buried in the ground. Empa operates a roughly 70 cubic-meter ice storage system, which is used for the combined heat and refrigeration supply for the research building NEST and at the same time is available for research purposes. Besides water, phase change storage systems can also be run on paraffin or special salts.

Thermochemical storage systems

Here, a "dry" substance is moistened with water, for example. The absorption of water generates heat. Once the substance is soaked completely, the storage system has given off its entire thermal energy. To charge up again, it needs heat, which evaporates the water and "dries" the substance again. Some of these storage systems run on zeolite, a porous, synthetic silicate mineral. Microporous, metal-organic materials (known as MOFs) are also being studied.

Empa researchers are carrying out numerous projects in this field: In the NRP 70 (National Research Program) project THRIVE conducted in collaboration with IBM Research in Rüschlikon, Matthias Koebel is studying adsorption heat storage systems, which could become components in future AC units. Luca Baldini and the BEST research group are investigating liquid storage systems made of a concentrated sodium hydroxide solution. The alkali releases heat when diluted with water; to charge the storage system back up, the alkali needs to be heated and thus dehydrated. Thermochemical storage systems are more efficient than pit and phase change storage systems. This makes them ideal for compact seasonal heat storage systems in individual buildings.

Power-to-gas plants

In the case of power-to-gas technology, electricity is used to charge the storage system. Surplus electricity from solar and wind energy that cannot be used immediately in the summertime is converted via water electrolysis into hydrogen and can be stored in gas bottles. In another step, it is possible to generate methane (CH_4) from hydrogen and CO_2 – synthetic natural or biogas. The methane can be stored in and distributed via the existing natural gas grid. The advantage of this technology: The seasonally stored energy can be used in two ways – to generate either heat or electricity. Empa is studying power-to-gas technology at its mobility demonstrator move in Dübendorf. Just how much of the surplus electrical energy should be stored in heat storage systems or be converted into chemical energy sources such as hydrogen or methane Is a crucial question for our future energy system.

Storing heat and earning money

While the first generation of heat storage systems directly used solar heat from solar collectors, nowadays it seems more reasonable to charge heat storage systems using solar power and electric heat pumps. This creates a direct link to the power grid and enables it to be stabilized: If solar and wind power plants yield too much electricity and threaten to overload the grid, the storage system›s electric heat pumps could use the surplus electricity and charge the heat storage systems. The consumption of surplus electricity is already a profitable business. The demand for this "operating reserve" will only grow in the future. Thus, money can also be earned by storing heat.

Obtaining (waste) heat from AC systems in buildings and storing it for the winter is yet another opportunity. So far, most AC units give off their heat into the surroundings, additionally warming up urban areas – which are already heat islands compared to their surroundings.

Luca Baldini heads the BEST – «Building Energy Systems and Technologies» – research group at Empa.

Involvement in political committees

In order for the energy transition to become a reality, research on heat storage systems should not take place behind closed doors. As a result, Luca Baldini is an active member in the Forum Energiespeicher of AEE Suisse, the umbrella organization of the renewable energy and energy efficiency industry, where Baldini is also a member of the Scientific Advisory Committee. //

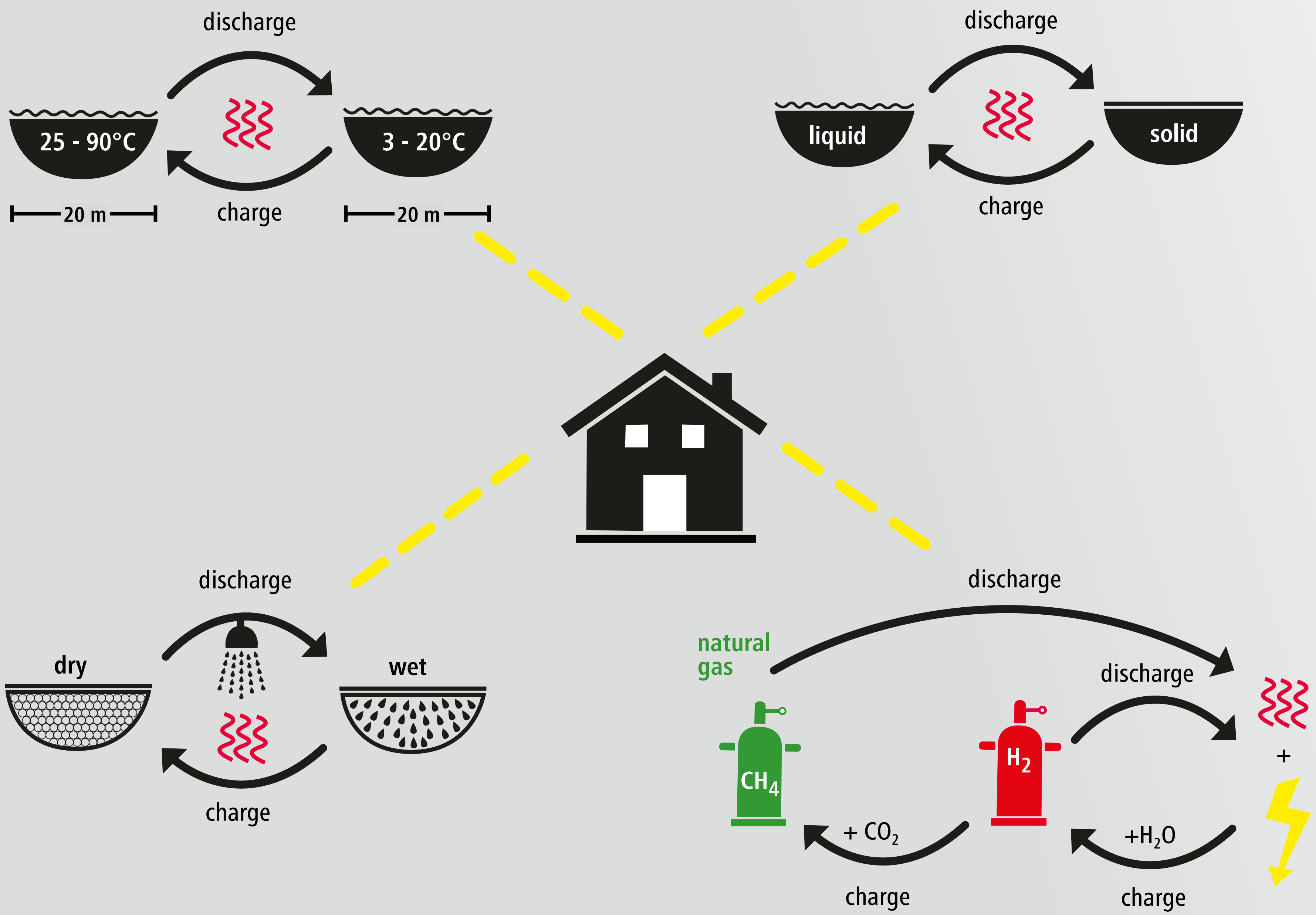
Seasonal energy storage: Which technology for which purpose?

Underground thermal storage = storage for sensible heat

Storage material: Water or a mixture of water and gravel
Advantage: Simple, robust technology
Disadvantage: Only worth it for large-scale storage systems from 100 cubic meters
Function: Storage system is heated up with surplus heat, heat is used directly or via a heat pump

Phase change storage systems = storage for latent heat

Storage material: Water, aqueous salt solution or paraffin
Advantage: More storage capacity per volume than in pit storage systems
Disadvantage: More expensive storage medium (paraffin).
Function: Storage in the form of crystallization energy: water turns to ice, paraffin solidifies. Heat is released during solidification. Energy is stored during liquefying process.



Sorption heat stores = thermochemical storage systems

Storage material: Sodium hydroxide solution, zeolite or MOF («metal-organic frameworks»)
Advantage: Higher energy density, loss-free storage, even small-scale stores possible
Disadvantage: Expensive storage medium, more complex technology
Function: Heat is stored in the dry medium. Energy is released during the wetting process. Energy is stored during the drying-out process.

Power-to-gas plants = electrolysis by surplus electricity

Storage material: Hydrogen, natural gas
Advantage: Uses electricity, generates heat and electricity. Loss-free storage
Disadvantage: High losses during the conversion of electricity into hydrogen or natural gas
Function: Surplus solar and wind power is converted into hydrogen via electrolysis. Natural gas can be generated from hydrogen. Use of energy with fuel cells or gas turbines.

Rotten to the core

Fungi that decompose tree trunks can conjure up real works of art in wood. In nature, however, the decay-causing fungi not only decorate the tree, but also destroy it. Empa researchers are now teaching the fungi how to draw. The result: upscale marbled wood that can be processed into design furniture or musical instruments.

TEXT: Andrea Six / PICTURES: Jan Thornhill, Empa

Sometimes there is true beauty to be discovered in very unusual places. Like Phoenix from the ashes, the coveted truffle beech is made from rotting wood on the forest floor. Uniquely patterned, it has been a sought-after as a raw material for furniture production since antiquity. However, the search for natural truffle beeches is tricky. Even those who deliberately leave tree trunks to rot in the forest have to wait years before they can hope to obtain wood that is decorated with fungal-induced patterns and, furthermore, still usable. Empa researchers have now developed a technology, with which hardwoods such as beech, ash and maple can be specifically treated with fungal cultures so that the patterns in the wood can be controlled.

The fine black lines running through the wood are the traces of a battle. Sometimes they meander turbulently towards each other and separate small plots with lightened background. In other places, the dark drawings flow calmly as if they wanted to remind us of a boundary that none of the participants likes to cross: Fungi that have fought in a battle for territory and resources in the wood clearly separate themselves from each other with pigmented lines. With these demarcation lines, the fine threads of the fungal community not only protect their colony from other fungi – the black boundary also ensures that bacteria and insects stay away and the habitat retains an ideal amount of moisture.

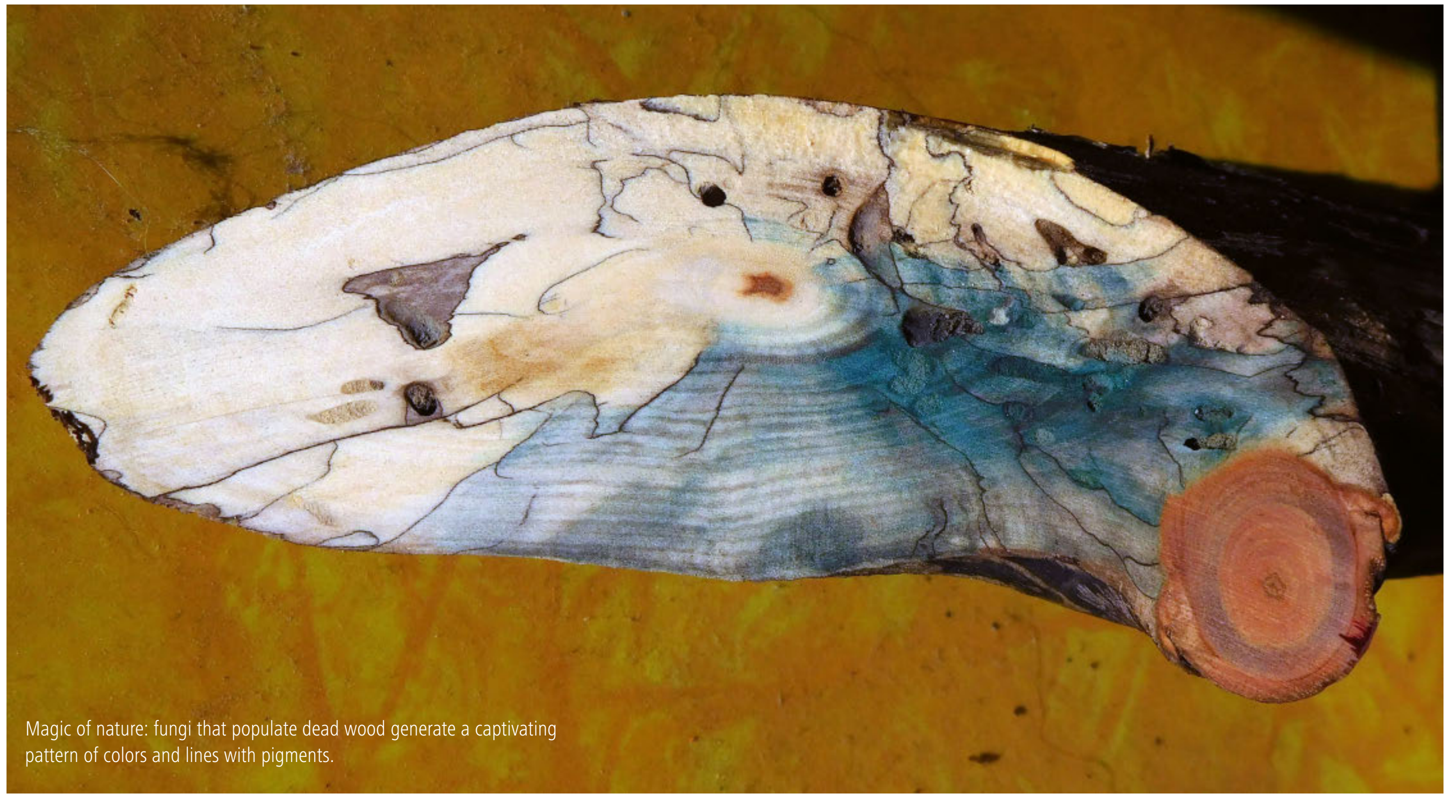
“We were able to identify fungi growing in nature and analyze them in the laboratory to select those with the most favorable properties as wood finishers,” says Hugh Morris, a scientist in Empa’s Applied Wood Materials lab in St. Gallen. For example, the brittle cinder fungus and the Turkey-tail when matched with each other leave black lines caused by the pigment melanin and at the same time bleach the surrounding wood thanks to the fungal enzyme laccase. “This creates a pattern with a particularly strong contrast in the wood” explains Hugh Morris.

Depending on the combination of fungal species, the lines are wild and impetuous or almost geometric. The researcher is convinced that the fungi can even, in time, be trained to write words in the wood. The gentle bite of the fungi that are used in the Empa laboratory is particularly favorable: Despite their pronounced talent for drawing, the selected candidates hardly gnaw their substrata. “Although fungi generously supply the wood with pigments, the wood retains its stability and shape,” says Hugh Morris.

However, the fact that the artistic process can be controlled and geared towards the desired result is not only owing to the type of fungus, the researchers also developed a process, with which the wood is ready for processing within weeks. One of the reasons for this rather fast processing is that the selected fungal species are able to grow in the wood with considerably lower moisture levels. This means that the raw material does not have to be dried long, costly or energy-intensive before being processed into furniture.

Together with the industry partner Koster Holzwelten AG, the researchers are now in the process of implementing an efficient and ecologically sustainable production method. This also includes the use of regional wood. “Beech wood is a hardwood that is common in Switzerland but appears uninteresting to furniture designers,” explains Managing Director Jakob Koster. With marble wood from local beech trees, however, it is possible to offer sought-after products on the Swiss timber market with an annual volume of around 3 billion Swiss francs.

In addition to furniture, parquet floors and kitchen fronts, marble wood can also be used for decorative objects and musical instruments. Unique pieces have always been created from patterned wood. With the new technology, spalted wood can now be produced faster, more sustainably and with the desired marbling. //



Magic of nature: fungi that populate dead wood generate a captivating pattern of colors and lines with pigments.

Marbled wood from the lab: depending on the kind of fungi used, the course of the pattern in the wood can be controlled.

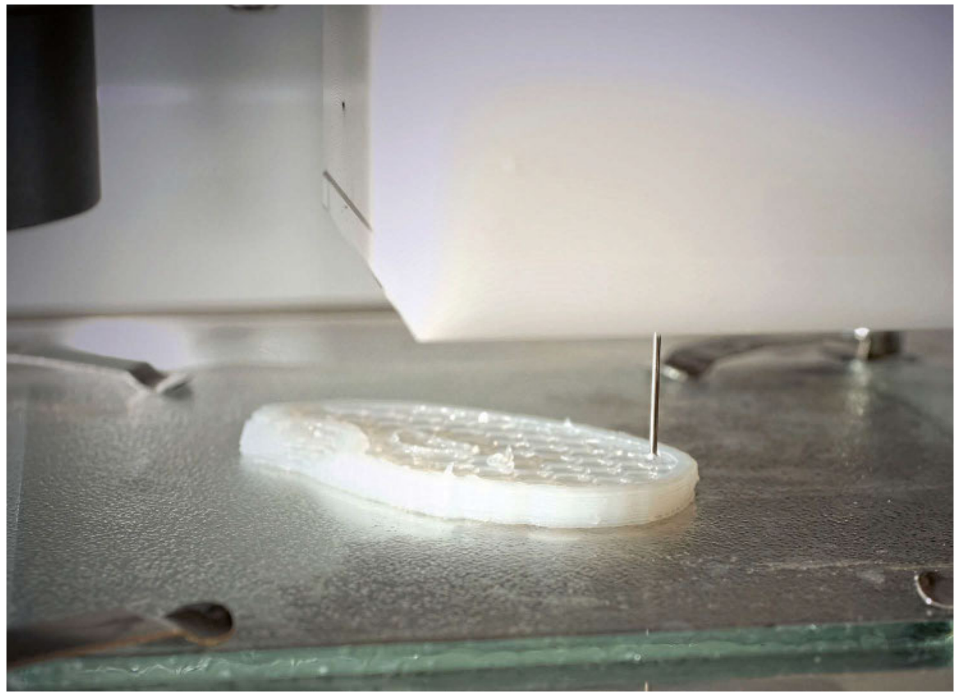
Ears from the 3-D printer

Cellulose obtained from wood has amazing material properties. Empa researchers are now equipping the biodegradable material with additional functionalities to produce implants for cartilage diseases using 3-D printing.

TEXT: Andrea Six / PICTURES: Empa

It all starts with an ear. Empa researcher Michael Hausmann removes the object shaped like a human ear from the 3D printer and explains: «In viscous state cellulose nanocrystals can easily be shaped together with nother biopolymers into complex 3-dimensional structures using a 3D printer, such as the Bioplotter.” Once cross-linked, the structures remain stable despite their soft mechanical properties. Hausmann is currently investigating the characteristics of the nanocellulose composite hydrogels in order to further optimize their stability as well as the printing process. The researcher already used X-ray analysis to determine how cellulose is distributed and organized within the printed structures.

A 3-D- printed ear: Empa researcher Michael Hausmann uses nanocellulose as the basis for novel implants.



Using the bioplotter, the viscous nanocellulose hydrogel can be printed into complex shapes.

At this point in time the printed ear is entirely and solely made of cellulose nanocrystals and a biopolymer. However, the objective is to incorporate both human cells and therapeutics into the base structure in order to produce biomedical implants. A new project is currently underway, looking into how chondrocytes (cartilage cells) can be integrated into the scaffold to yield artificial cartilage tissue. As soon as the colonization of the hydrogel with cells is established, nanocellulose based composites in the shape of an ear could serve as an implant for children with an inherited auricular malformation as for instance, in microtia, where the external ears are only incompletely developed. A reconstruction of the auricle can esthetically and medically correct the malformation; otherwise the hearing ability can be severely impaired. In the further course of the project, cellulose nanocrystals containing hydrogels will also be used for the replacement of articular cartilage (e.g. knee) in cases of joint wear due to, for example, chronic arthritis.

Once the artificial tissue has been implanted in the body, the biodegradable polymer material is expected to degrade over time. The cellulose itself is not degradable in the body, but biocompatible. However, it is not only its biocompatibility that makes nanocellulose the perfect material for implant scaffolds. “It is also the mechanical performance of cellulose nanocrystals that make them such promising candidates because the tiny but highly stable fibers can extremely well reinforce the produced implant,” said Hausmann.

Moreover, nanocellulose allows the incorporation of various functions by chemical modifications into the viscous hydrogel. Thus, the structure, the mechanical properties and the interactions of the nanocellulose with its environment can be specifically tailored to the desired end product. “For instance, we can incorporate active substances that promote the growth of chondrocytes or that sooth joint inflammation into the hydrogel,” says the Empa researcher.

And last but not least, as raw material cellulose is the most abundant natural polymer on earth. Therefore, the use of cellulose nanocrystals not only benefits from the mere elegance of the novel process but also from the availability of the raw material.

The white nanocellulose ear lies glossy on the glass carrier. Just out of the Bioplotter, it is already robust and dimensionally stable. Hausmann can give the go-ahead for the next steps. //

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

Fireproofing made of recycled paper

Scientists at Empa teamed up with isofloc AG to develop an insulating material made of recycled paper. It is ideal for prefabricated wooden elements and even multistory timber houses, and protects the construction against fire. What's more: the additive it contains is harmless to humans, animals and the environment.

TEXT: Rainer Klose / PICTURE: Empa

Franziska Grüneberger looks contented; clutching a nondescript cube made of grey flakes in her hand the researcher in the laboratory for applied wood materials has achieved her goal: Very little chemistry went into the cube, but no shortage of technical expertise. The tiny object is "living" proof that giant mountains of waste paper can be transformed into a valuable, fireproof insulating material – a big step to save fossil fuels. Not that anyone could tell just by looking at it.

The secret lies in what the recycled paper fiber cube doesn't do: crumble. This very property is important to offer long-term protection against fire for load-bearing elements on timber houses. Precisely this firmness, however, is hard to achieve in the industrial production of insulating layers. "We're not dealing with insulating mats here, which workers have to cut to size and shape and slot into the components," explains Grüneberger. "Instead, the recycled paper fibers are automatically blown into a cavity until it is filled completely." For reasons of cost, this blowing has to take place as easily and as fast as possible, which is why the fibers need to flow well at this point. As soon as they are in the cavity, however, they should keep their shape to protect the construction in case of a fire. Ultimately, the machine-blown insulation should be hard and fill the form in the component like an insulating panel fitted by hand. Only in this way can they stave off the heat of a fire for long enough and prevent the construction from burning down too fast.

This is no mean feat: "We had to search for a virtually magical binder for the isofloc cellulose fibers that are already established on the market – a material that ideally works from one second to the next," says Grüneberger. She clicks her fingers like a magician; all that's missing is a mumbled «abracadabra».

A tour de force of chemistry

The project in collaboration with isofloc, a manufacturer of insulation materials, began in the spring of 2017. Franziska Grüneberger and her colleague Thomas Geiger started looking for suitable binding agents – a tour de force of chemistry, as soon became apparent. After all, only those who venture confidently into this terrain will strike gold.

The first constraint: For use in sustainable timber construction, the binding agent must be non-toxic – a substance that can come into contact with humans permanently without causing any problems. Auxiliary materials from the textile, paper, cosmetics and food industry – or substances from nature – make strong candidates. The second constraint: the desired binding agent needs to be affordable and available in abundance.

"Together with Willi Senn, isofloc's development engineer, we launched a series of experiments and combined the insulating fibers with different additives," recalls Grüneberger. In parallel, they searched for the right "starter's gun" to bind the fibers within the blink of an eye. Heating with steam? With infrared radiation? Using magnetic induction? At long last, they found the coveted material from a long string of "suspects": a substance from the food industry. Lab experiments at Empa and isofloc in Bütschwil also displayed a reliable bond between the cellulose flake structure during a fire.

Upscaling and fire test

But does this also work on a large scale? An upscaling test furnished the evidence: The flakes were blown into several wooden frames, alongside an identical cavity with flakes without the novel additive, and fitted using the customary technique. Now it was time to head to the fire lab at VKF ZIP AG, where the wooden frames were exposed to flames at temperatures of 800 to 1,000 degrees for an hour. The wooden frame was not supposed to burn through at any point, nor should any red-hot flakes fall out. The new insulation material stood the test and protected the construction reliably, while the flakes without the additive fell out of the wooden frame for lack of adhesion.

Jon-Anton Schmidt, Head of Application Technology at isofloc AG, explains the advantages: "Fitting the insulating material in loose form saves an enormous amount of time. With the additional advantage of dimensional stability and the associated effectiveness for fire safety, we can achieve protection that is on a par with glued mineral wool mats. This makes this ecological and efficient insulation even more interesting for the construction industry."

New generation of industrial insulating systems

The final development step is now taking place at isofloc, where mechanical technicians and engineers have to develop a new generation of blow-in machines from the existing prototypes that meet the repeatability and quality control requirements. The dosage of the binding agent is crucial here. It needs to be adhered to and monitored in narrow tolerances throughout all production steps.

By isofloc's reckoning, the new insulation will hit the market together with the corresponding blow-in machines in around a year's time. Mountains of waste paper will then be turned into a valuable insulating material that not only helps save vast quantities of fossil fuels during production and use; as the only loose insulating material on the market it can also be used industrially for effective fireproofing. //

Optimizing energy flows

Interdisciplinary, interconnected and oriented towards a sustainable future: these words describe Kristina Orehounig just as aptly as they describe the Empa laboratory "Urban Energy System", which she is heading since February 2018. She has chosen an unusual path to her current scientific discipline – but that is precisely what she sees as an advantage in her day-to-day research.

"There's a great team spirit in my group. That's a big plus on the road to discovery."

TEXT: Karin Weinmann / PICTURES: Empa

Focus on technology: Kristina Orehounig was already drawn to the technical aspects of construction during her architectural studies in Vienna, and she was particularly fascinated by building physics. Nevertheless, she doesn't regret at all that her education wasn't completely straightforward before she found her professional home in the simulation of energy systems: "As an architect, I'm freer in certain ways of thinking. One learns to think holistically and to pursue even ideas that at first appear to be utopian in order to come up with solutions," she explains.

Looking at the big picture

Kristina Orehounig started with the simulation of individual buildings. "But it quickly became clear to me that it was not enough to look at a building in isolation." That's why she expanded her focus to the boundary conditions. This includes, for example, the microclimate that surrounds a building. She went from individual buildings to areas and districts until she finally ended up at entire cities. "Fortunately, I like interconnected thinking – I like the challenge of keeping an eye on the big picture, but still plunging into the depths of the material at some central points."

After six years as a researcher and lecturer at ETH Zurich, Orehounig has headed the laboratory "Urban Energy Systems" at Empa since February 2018. Its name says it all: the laboratory conducts research into networked energy systems with the aim of massively reducing the energy requirements and CO_2 emissions of buildings and neighborhoods. More than 20 researchers from different disciplines are working together to achieve this goal: The disciplines represented are civil engineering, mechanical engineering, electrical engineering, architecture, environmental technology and the relatively new field of industrial ecology, which deals with material and energy flows through industrial systems.

You can feel Orehounig's enthusiasm for energy topics – and research in general. Is there enough time for it, in addition to the management tasks involved in leading a research group? "To be honest, at the beginning I was afraid that the management part would become too large. But fortunately there is a great team spirit in the group – even though we recently merged several labs. Everyone has his or her area of expertise and at the same time all team members are very open-minded. The result is a great interdisciplinary team that works together very well." This even allows her to continue giving lectures at ETH Zurich for the Master's program "Integrated Building Systems". During her time at ETH Zurich, she helped to set up and coordinate this program.

From simulation to reality

At first glance, simulating energy systems in buildings, neighborhoods and cities sounds somewhat abstract. But when you listen to Orehounig, you quickly notice that the researchers are dealing with very real – and urgent – challenges. After all, the energy demand of buildings accounts for more than 40% of the total energy demand in Switzerland – and according to the Swiss Energy Strategy 2050 this must change. The Swiss Competence Center for Energy Research on Future Energy-Efficient Buildings & Districts (SCCER FEEB&D), which is headed by the Urban Energy System, has set itself the goal of reducing the ecological footprint of buildings in Switzerland by a factor of three by 2035.

Kristina Orehounig has been running the Urban Energy Systems lab at Empa since February 2018. Previously, she was a researcher and lecturer at ETH Zurich.

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To this end, Orehounig's team is working together with cities and municipalities on energy concepts in which the researchers can use their simulations to help clarify specific issues. For example: Is it still worth operating a gas network? Wouldn't a thermal network make more sense? Or a combination of the two? "We receive many enquiries for such projects," says Orehounig. However, there is not enough capacity to handle all of them – even if it is planned to expand the team to around 30 people. "When selecting projects, a central criterion is whether it advances our research or whether we encounter a new exciting question. Our most important research goal is to scale up the simulation platform we have developed: At the moment, we are mainly simulating neighborhoods, but in the future we want to simulate entire cities."

The platform will soon make the leap from research to industry – and a new start-up is to be created to enable energy companies and engineering consultants to use Empa's modelling tools to design and optimize energy systems for entire neighborhoods.

And it can be even more real. Orehounig: "The 'Energy Hub', ehub for short, at NEST makes it possible to verify at least part of our research work on a real neighborhood – and of course to make it visible." This is also an essential point for their research partners: "Most people would like to carry out a project involving the ehub – and thus demonstrate what is possible in the real world."

Global impacts wanted

After almost a year as head of the laboratory, Orehounig has now settled in well – and is already making plans for the future: "In addition to scaling our models, 'Big Data' is an important keyword. We want to measure more, for example with smart meters. We want to combine these data with the simulations. Another goal is to include mobility, for example through move, the Empa demonstration platform for sustainable mobility. One possibility, for example, is to use electric vehicles as intermediate storage for solar electricity."

One doctoral student is also already working on a goal that is particularly close to Orehounig's heart: to enable developing countries to have a renewable energy future. "The global impact of our research is important to me. And there is great potential in developing countries in particular: if the rapidly increasing energy consumption there is covered by fossil energy, then we have no chance of stopping climate change. Here our tools can help predict future energy consumption and implement long-term, sustainable planning." //

Mercury bound

Another European Space Agency (ESA) satellite was launched last October: BepiColombo, who is since heading for Mercury – with Empa technology on board. Empa coated and soldered individual components meticulously for time-of-flight mass spectrometer sensors. Empa expertise will also be embarking on future ESA missions.

The metal ceramic structure with fitted heaters used in the time-of-flight mass spectrometer on BepiColombo.

TEXT: Cornelia Zogg / PICTURES: ESA, Empa

The destination: Mercury, the innermost planet of our solar system. The space probe BepiColombo, which was named after Giuseppe (Bepi) Colombo, lifted off in October 2018 and embarked on the long voyage to the nearest planet to the sun with a view to mapping it and determining the geological and chemical composition of its surface. One of the instruments on board is a time-of-flight mass spectrometer, individual components of which were developed at Empa.

Hans-Rudolf Elsener from Empa's Joining Technology and Corrosion lab co-developed and built a heatable metal ceramic structure in a complex process. The coated silicon wafers mounted on it convert neutral particles into charged ones. Thanks to the Empa heaters, this conversion is far more efficient than without them as deposits of organic substances combined with cosmic radiation would irreversibly damage the coated little plates. The regular heating ensures that the instrument's measurement sensitivity will not be compromised.

Lack of space in Space

As space probes need to be lightweight and the space on them is limited, weight is cut wherever possible, even on the tiniest of components. Take the heated structure for the European and Japanese space mission to Mercury, for instance. Screws and wiring are problematic and waste space. Therefore, the components need to be soldered, which causes additional difficulties. Elsener joined the heater structure made of titanium and aluminum oxide ceramics with gold germanium in a vacuum furnace. In doing so, he had to be careful not to damage the various heater components during the soldering process.

Ceramics are extremely heat-sensitive, and soldering materials with different thermal properties causes high mechanical tensions that can damage or even destroy components. Therefore, Elsener begins by coating all the components in the metal ceramic structure so that he can solder at far lower temperatures thanks to the coating. The components thus survive the soldering pro-

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cess unscathed. This calls for a complex interplay between material knowhow and manual dexterity.

Successful, long-standing collaboration
Elsener prints, coats and solders the delicate ceramic parts on behalf of the University of Bern, and can fall back on many years of experience. After all, besides BepiColombo, more missions are on the horizon. For instance, Elsener also made ceramic heaters for the ESA missions CHEOPS and JUICE (see box below), and they will also be installed in the upcoming LUNA mission. The finished ceramic heaters are merely 20x15 millimeters in size and 1.3 millimeters thick, which requires the utmost precision. They are produced in a well-oiled collaboration between Empa and the University of Bern where Elsener is also in charge of fine-tuning the heaters. The University of Bern already called upon Empa's expertise and Elsener's skilled craftsmanship for the components for the Rosina mass spectrometer for the successful ROSETTA mission that landed on the comet Churyumov-Gerasimenko in 2017. //

BepiColombo

The four-part space probe BepiColombo set off for Mercury on 20 October 2018 and is expected to provide a comprehensive description of the planet with clues to its history. BepiColombo was developed in a joint venture between ESA and the Japanese space agency JAXA. Until it arrives on Mercury, the probe will conduct a swing-by maneuver past Earth (2020) and two swing-by maneuvers past Venus (2020/2021), followed by six swing-by maneuvers past Mercury itself before BepiColombo can enter the planet's orbit in 2026. The mission is scheduled to end in 2027.

CHEOPS

CHEOPS should be ready for lift-off in early 2019 and help in the search for potentially habitable planets in other solar systems. The satellite measures the brightness of stars, which decreases slightly when an exoplanet passes its parent star. The size of the exoplanet can be determined from the decrease in brightness during one such transit. Institutes from 11 European countries participate in the CHEOPS mission. The satellite itself was constructed at the University of Bern. Hans-Rudolf Elsener produced the five heaters used on CHEOPS in his lab at Empa.

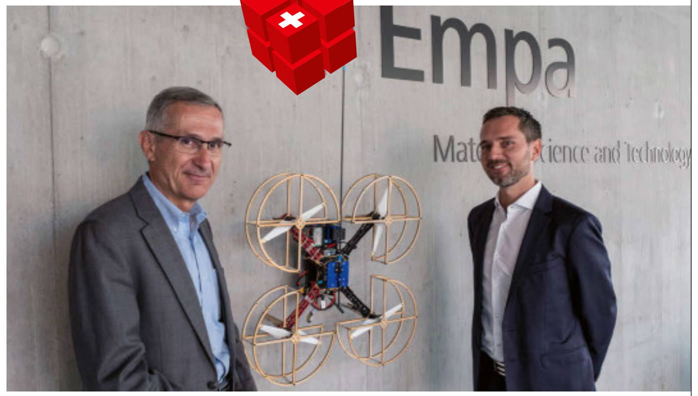
JUICE

The launch of the Jupiter mission JUICE is scheduled for June 2022. The space probe's objective is to research the Galilean moons of the planet Jupiter and will lift off from Centre Spatial Guyanais with an Ariane 5 rocket. Empa heaters will support the Particle Environment Package (PEP), which is a particle spectrometer to measure neutral and charged particles. En route to Jupiter, JUICE will conduct swing-by maneuvers past Earth, Venus and Mars before eventually reaching its destination in seven and a half years. Once there, JUICE will then spend three and a half years collecting data.

A large arc in the night sky over Kourou: BepiColombo lifted off from the European spaceport in French Guiana on 20 October 2018. Its destination: Mercury.

NEST Aerial Robotics Hub

In the new NEST Aerial Robotics Hub that is co-run by Empa and Imperial College London it is all about research on autonomous drones. Thanks to the collaboration, functional materials can be integrated into robot technology. Novel drones equipped with soft materials are to be developed, for instance. The flying robots will use the research and innovation building NEST in Dübendorf as test ground. The autonomous drones will initially be deployed to simplify building maintenance and to make it more efficient.
The drones are being fine-tuned at the NEST Aerial Robotics Hub under the scientific leadership of robotics researcher Mirko Kovac. What the scientists are particularly interested in: How will the flying robots shape up as permanent "housemates" and what form might a joint ecosystem between humans and robots take?



Empa CEO Gian-Luca Bona (left) and Mirko Kovac, Scientific Director of the new NEST Aerial Robotics Hub, with one of the drones, which will be "living" in NEST in future.

Award for research on vehicle emissions

This year's Swiss Aerosol Award goes to Empa researcher Maria Muñoz for her research on the emission behavior of GDI (gasoline-direct injection) engines. The results of her analyses are alarming: All the vehicles tested – built between 2001 and 2016 – emitted genotoxic exhaust gases. The carcinogenic potential of these exhaust gases was up to 17-times higher than that of the diesel vehicle that was included in the analysis. Due to the chemical composition of the exhaust gases and the high particle emissions, GDI engines, therefore, pose a similar health risk to diesel engines without particle filters.
Like in diesel vehicles particle filters for GDI engines could curb the health hazards of these exhaust gases. In the meantime, legislation has responded: Since 1 September 2018, newly registered GDI vehicles have to comply with the same particle limits as diesel engines. This is virtually impossible without filters. What remains problematic, however, is the fact that all vehicles purchased before then may continue to be driven without filters. And retrofitting does not seem to be on the cards, even though retrofitting older vehicles with particle filters could drastically improve their emission behavior.

Getting rid of sweat at the push of a button

On 15 November 2018 the Swiss sportswear manufacturer KJUS showcased the world›s first ski jacket with an integrated electronic user-controlled membrane. Thanks to the HYDRO_BOT technology developed in collaboration with Empa, the membrane actively pumps out sweat from inside the jacket. This eliminates the problem of chills after skiing, which is normally caused by moisture trapped in the inner clothing, and ensures that skiers hardly use up any energy to stay warm – and thus have more energy for their sport. The core element of the jacket is the innovative HYDRO_BOT technology, in which two functional membranes are integrated in the back zone of the jacket, where the wearer usually sweats the most. The technology consists of three layers: a membrane comprising billions of pores per square meter surrounded by an electrically conductive fabric. By means of a small electrical impulse, the pores turn into micro-pumps that actively conduct moisture away from the body quickly and efficiently. The jacket is extremely easy to switch on and off using the integrated control unit or the iPhone/Android app.

Hands-on hydrogen refueling station

Empa is going mobile: At the Geneva Motor Show in March 2018, Empa researchers explained why hydrogen is the ideal fuel for cars of the future. Visitors to the Swiss Oil Industry Association booth could have a go at refueling hydrogen using Empa technology on a Hyundai iX35 fuel cell car. The «fake» hydrogen refueling station can also be tested at various Swiss exhibitions throughout the upcoming year. The first of these was the building and lifestyle trade fair Nuova ArteCasa in Lugano in October 2018. More appearances are already scheduled. And once again, Empa will be showcasing their mobility concepts of the future in conjunction with the Swiss Oil Industry Association at the Geneva Motor Show in 2019.

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