EmpaQuarterly

Research & Innovation #58 | October 17

Batteries of the future

Wellness center with solar power

When robots build houses

Artificial ebony from Switzerland

Empa
Materials Science and Technology

MICHAEL HAGMANN Head of Communications

It's all so electrifying

Electricity is THE single energy currency of the future. Already today, our army of little electronic helpers and gadgets – and thus many of us – are helpless without full batteries. In the future, the increasing electrification of our lives, such as in mobility, on the one hand, and the development of alternative energy forms such as wind and solar power, which both directly yield electrical energy, on the other will boost our dependency on electricity even further.

And rightly so. After all, electricity is extremely versatile to use and can be converted into other energy forms. In other words, electricity is a core element of our future energy system, which needs to be more sustainable and a lot more flexible than today's, which is based on petroleum, coal and uranium.

There is a drawback, though: compared to gasoline and natural gas, electricity can only be stored to a certain extent, especially over longer periods. As we all know, every battery eventually runs down, even if we haven't used the tablet for an eternity. New, more efficient and longer-lasting electricity storage systems are therefore a must. To preserve all that summer solar power for wintertime, for instance. Empa is working flat out on this, as this issue's Focus (from p. 10) vividly reveals.

However, with all the euphoria surrounding electricity we should bear in mind that unfortunately you can't tell how an electron flowing out of the socket actually came about. There are many ways to generate electricity – some more sustainable, others less clever. If we really want to do something for the environment, it is not enough to merely switch to electricity; we should be using the "right" electricity.

Enjoy reading!

Focus:

Batteries of the future

Cover
Lithium ion batteries are flammable and the price of the raw material is rising. Are there alternatives? Yes: Empa researchers have discovered promising approaches as to how we might produce batteries out of sea salt or scrap metal or render them fireproof with the aid of non-flammable solid materials. Pages 10–24. Photo: iStockphoto.

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Sweating efficiently

There is a growing need in our society for fitness and wellness, which generally incurs environmental costs and swallows up large quantities of energy. At NEST, the Empa and Eawag research and innovation building, a global innovation will be put into operation on 24 August: a fitness and wellness facility powered entirely by solar energy and the power generated by its users` physical exercise. The Swiss-Liechtensteinian building technology association, suissetec, made a significant contribution to the facility`s development.

left
The Finnish sauna, the steam bath and the bio-sauna each can host four to five people. The waste heat from the Finnish sauna is recycled by means of a novel CO_2 heat pump and reused in the other sauna cells. This produces an energy cascade from hot to cold.

right
The north side of the two-story sauna module is quadruple-glazed. The heat insulation is just as good as in a solid wall but the incident, indirect light heats up the unit.

TEXT: Stephan Kälin / PICTURE: Empa

The Solar Fitness and Wellness Unit's concept has two purposes: to substantially reduce the energy consumption of wellness facilities, and to produce the remaining energy by itself. It is part of NEST, the modular research and innovation platform on the Empa campus in Dübendorf, and it is enthroned on the building's uppermost platform. Two glass facades, each around eight meters high, are its eye-catching exterior features. But the architectural design by architect Peter Dransfeld is also spectacular on the inside: in the interior space, which is open throughout, three ellipsoids hover below the ceiling. They house two saunas and a steam bath. Under the wellness modules, a range of fitness equipment invites you to work out. Soon, this equipment will be used by the staff of both research institutes, Empa and Eawag.

At NEST, research, industry, and the public sector work together in order to test new technologies, materials, and systems in the fields of construction and energy under real-world conditions. NEST is designed as a "living lab" – which means that its flats and office spaces are actually used, while simultaneously serving as experimental environments for innovation. This means that, even in the case of Solar Fitness and Wellness, the experience of using the wellness facilities is still a means to an end: "Our objective is to be able to meet an energy-intensive need such as wellness entirely through renewable energy," explains Peter Richner, Deputy Director of Empa and Strategic Manager of NEST.

Only the practical test will show whether the energy objectives that have been set can be achieved. And the objectives are ambitious: "We want to operate the facility with one sixth of the energy that it would need with conventional operation," says Mark Zimmermann, Innovation Manager for NEST. More specifically: the aim is to reduce the 120,000 kWh of electricity that the Finnish sauna, the bio-sauna, and the steam bath would normally swallow up each year

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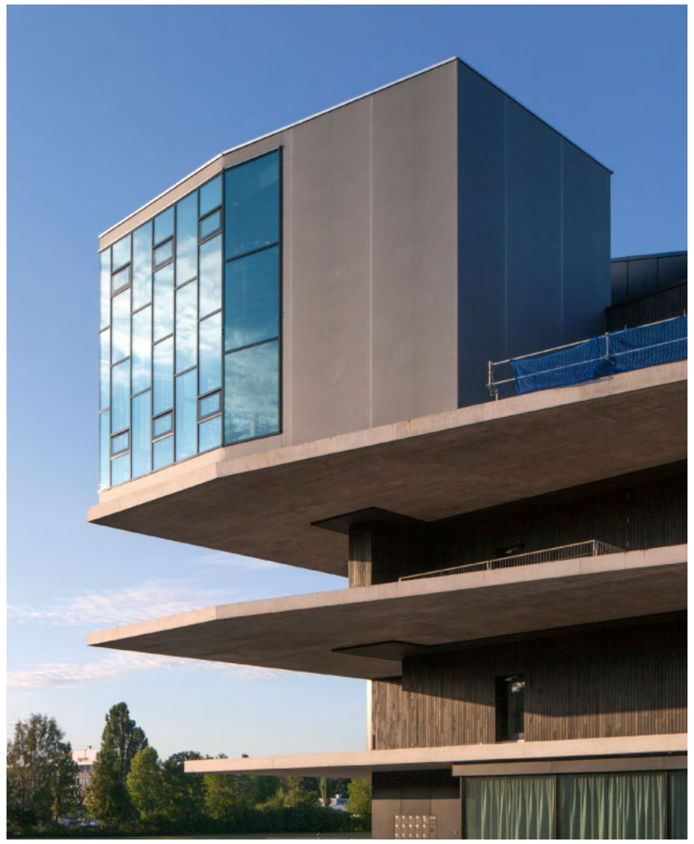


1

2

1
The Solar Fitness & Wellness unit is situated on the northeastern side of NEST on the Empa campus in Dübendorf

2
The unit was designed by architect Peter Dransfeld. The three sauna modules hang spectacularly from the ceiling. As a result, the waste heat from the sauna modules remains in the room.

3
Empa CEO Gian-Luca Bona (next to the hot stones) and his deputy, Peter Richner (with the microphone), at the inauguration of the new NEST unit on 24 August 2017.

to a figure of 20,000 kWh. This massive reduction is to be achieved by using a high-temperature CO_2 heat pump (see box) from the company Scheco, which can generate temperatures of up to 130°C. For efficient operation, the generated heat must be used over as great a range of temperatures as possible. To this end, the respective heat levels required for the different wellness modules are coordinated as a cascade. The heat is stored in layers in a large tank and made available for each of the various uses: 120°C for the Finnish sauna, 90°C for the steam generator in the steam bath, 70°C for the bio sauna, and finally 50°C and 30°C for the showers and the heating, respectively. The underlying energy concept was developed jointly by Empa researchers, the NTB International University of Applied Sciences and Technology at Buchs, and Lucerne University of Applied Sciences and Arts.

Heat efficiently, avoid losses

Using the CO_2 heat pump to generate heat reduces electricity consumption by around two thirds on its own. Moreover, additional heat and moisture recovery from the sauna and steam bath means that ventilation losses can be reduced by at least 50%. “There is also a control system that responds to actual bookings of the wellness modules and only heats them up when necessary,” explains Zimmermann. In addition, improved heat insulation ensures minimal heat losses.

In order to make optimal use of the north facade as well, it is fitted with an eight-meter-quadruple glazing from the company Glas Troesch. With an insulation value of 0.3 W/(m2·K), in the winter semester this facade achieves a more favorable heat balance than a highly insulated wall five times thicker, while also providing a high level of comfort and daylight.

On the facade and on the roof, three photovoltaic installations provide the remaining electricity, which amounts to around 20,000 kWh on average per year, via solar generation. The bifacial glass-glass modules from the company Meyer Burger convert sunlight on both the front and rear sides into electrical energy – reflected by the roof’s material and the facade’s white cladding. In addition to the photovoltaic installations, there is also a solar thermal system for warm water. And, last but not least, the fitness facility users contribute to energy production by using fitness equipment that generates electricity. So, after working out hard in a training session, you can relax in the sauna with a clear conscience. //

3

Printing instead of laying bricks

The NEST unit DFAB HOUSE is a unique architectural project. Not only was it designed and planned digitally, it is also being built digitally using robots and large-scale 3D printers.

TEXT: Stephan Kälin / PICTURE: NCCR Digital Fabrication

A flash of light, a soft hiss – followed by applause for the robotic protagonist: in early May 2017, the construction robot "In Situ Fabricator" made the first symbolic weld seam for the unit DFAB HOUSE at NEST. Robots that build walls and 3D printers that print entire formworks for ceiling slabs – digital fabrication in architecture has developed rapidly in recent years. As part of the National Center of Competence in Research (NCCR) Digital Fabrication, architects, robotics specialists, materials scientist, structural engineers and sustainability experts from ETH Zurich teamed up with business partners to bring several new digital building technologies from the laboratory to practice. The construction is taking place on the topmost platform of NEST, Empa and Eawag's modular research and innovation building, where researchers are able to test new construction and energy technologies under real-life conditions. NEST offers a central support structure with three open platforms, where individual construction projects – known as innovation units – can be installed.

Digitally designed, planned and built

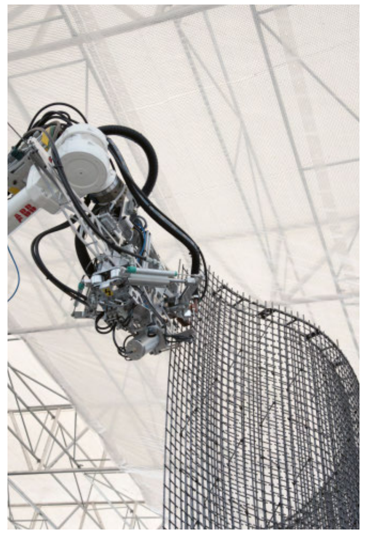
The DFAB HOUSE is distinctive in that it was not only digitally designed and planned, but is also being built using predominantly digital processes. With this pilot project, the researchers want to examine how digital technologies can make construction more sustainable and efficient, and increase the design potential. Design and planning of individual components were digitally coordinated, and the components are now manufactured on site according to this data. As a result, the conventional planning phase is no longer needed. As of summer 2018, the three-story building with an overall square footage of 200 square meters will serve as a residential and working space for Empa and Eawag guest scientists and NEST partners.

Four new building methods put to the test

At the DFAB HOUSE, four construction methods are being transferred from research to architectural applications for the first time. Construction began with the Mesh Mould technology, which received the Swiss Technology Award in 2016; it was developed by an interdisciplinary team and could fundamentally alter future construction with concrete. Here, the two-meter high construction robot In situ Fabricator plays a central role; it moves autonomously on caterpillar tracks, even in a constantly changing environment. A steel wire mesh fabricated by the robot serves both as formwork and reinforcement for the concrete. Thanks to the dense structure of the steel wire mesh and the special composition of the concrete mix, the concrete stays inside the grid and does not pour out.

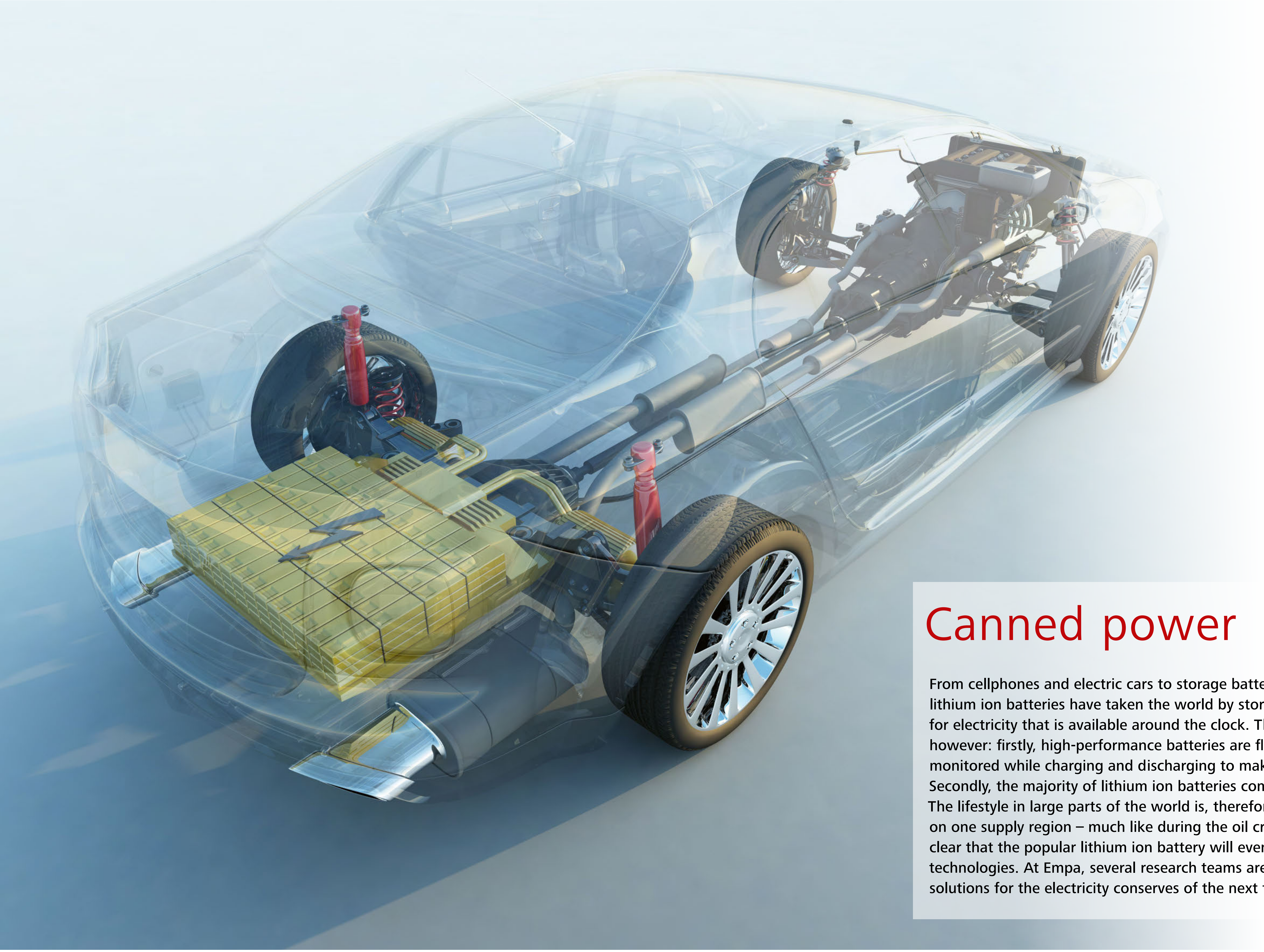
This results in a double-curved, load-bearing wall that will be the architectural hallmark of the open-plan living and working area on the ground floor. A Smart Slab will then be installed – a statically optimized and functionally integrated ceiling slab, the formwork of which is manufactured using a large-scale 3D sand printer.

Smart Dynamic Casting technology is being used for the façade on the ground floor: the automated robotic slip-forming process can produce tailored concrete façade posts. The two upper floors with individual rooms are being prefabricated at ETH Zurich's Robotic Fabrication Laboratory using Spatial Timber Assemblies; cooperating robots will assemble the timber construction elements. //



top
The robot welds the reinforcement for the unit's double arched supporting wall. The reinforcement is simultaneously the concrete formwork: special concrete is poured in later on, seeps only a few millimeters through the lattice and eventually completely encases it.

bottom
The two-story unit "DFAB HOUSE" is currently being erected on the northwestern side of NEST, next door to the Solar Fitness & Wellness unit. The suspended ceiling is 3D-printed from sand.

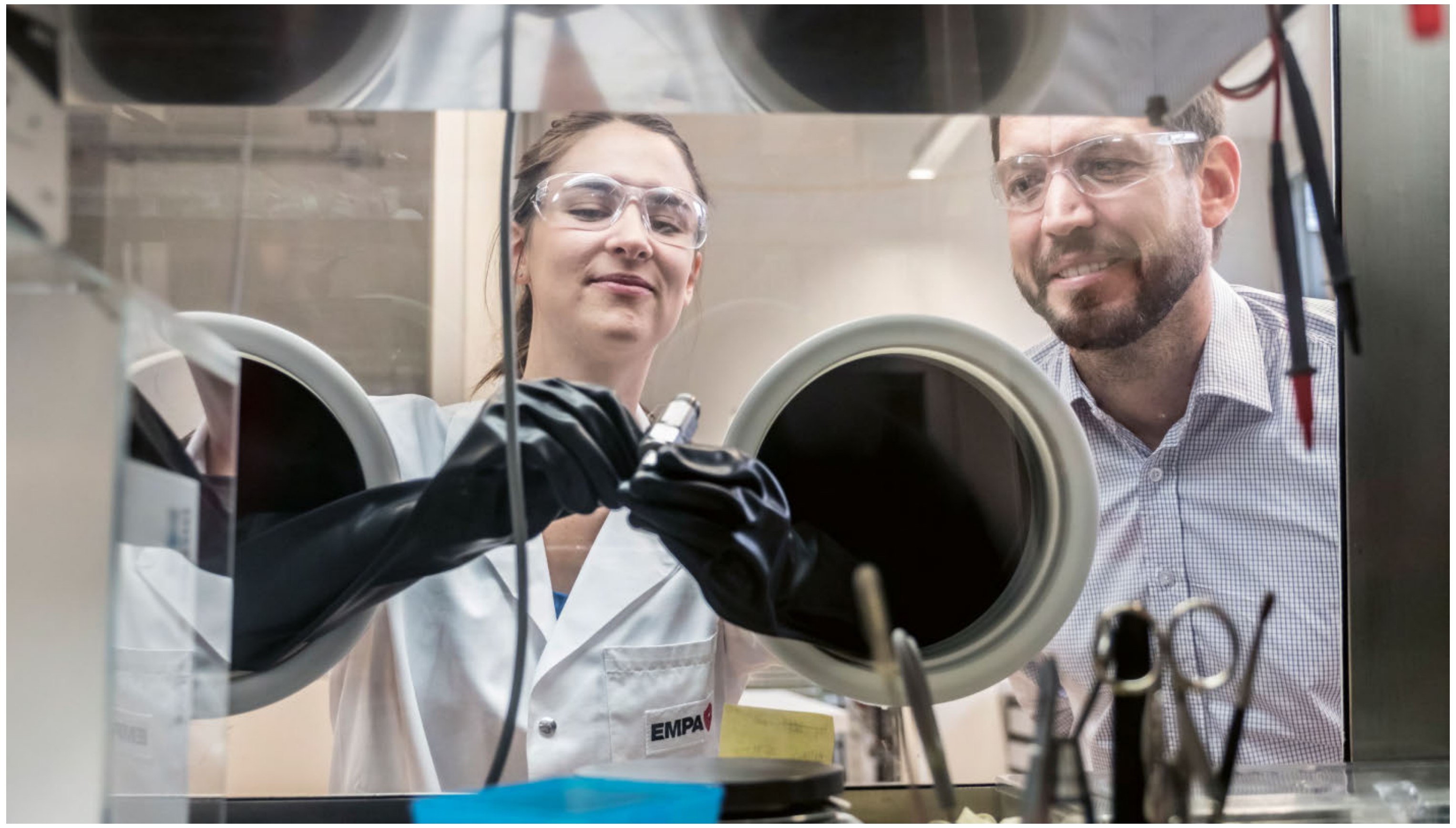


Canned power

From cellphones and electric cars to storage batteries for apartment blocks: lithium ion batteries have taken the world by storm – and stoked the demand for electricity that is available around the clock. This poses two problems, however: firstly, high-performance batteries are flammable and have to be monitored while charging and discharging to make sure nothing happens. Secondly, the majority of lithium ion batteries come from China these days. The lifestyle in large parts of the world is, therefore, increasingly dependent on one supply region – much like during the oil crisis in the 1970s. It is clear that the popular lithium ion battery will eventually be replaced by new technologies. At Empa, several research teams are investigating potential solutions for the electricity conserves of the next few decades.

The hot topics in battery research

Battery research is a broad field. Therefore, it is important to define the research objectives as precisely as possible. Empa researcher Corsin Battaglia explains where we are heading.



Where the prototype of a new battery is born: Marie-Claude Bay and Corsin Battaglia work in a "glove box" as the components need to be shielded from oxygen.

TEXT: Rainer Klose / PICTURE: Empa

Battery research is currently a hot topic. For Empa's battery researchers, this means they have to hold their own among the stiff international competition. Therefore, it is crucial to exactly define the direction, in which the research is supposed to head. After all, batteries need to fulfil very different criteria depending on the desired application – whether it be as a stationary solar power storage system for a mountain cabin or as a battery to power a sports car.

Swift and safe charging

In order to construct electric cars with a greater range, batteries with a higher charge density are required. At the same time, they have to withstand large charging currents if they are to be recharged rapidly at, say, highway rest stops. However, quick charging is not without risks, especially at low temperatures: Tree-like entities made of metallic lithium – known as dendrites – can form in the battery. These electrically conductive metallic deposits can cause a short circuit in the cell and, in the worst-case scenario, even set the battery on fire. Modern fast-charging systems thus check the temperature of the battery before the charging current flows. Battery researchers are on the lookout for performance-enhancing ingredients for batteries without compromising their safety.

The crux with critical raw materials

Lithium ion battery technology has largely defined our society in the last few years. Since its commercial launch in 1991, it has been instrumental in the laptop, smartphone and tablet revolution. In recent years, however, the roaring success of lithium ion batteries has also triggered such a steep increase in the demand for the raw materials needed to build the batteries that, a few years ago, the European Commission classed cobalt and graphite as critical raw materials, for instance.

Unfortunately, for the time being cobalt cannot easily be replaced as it facilitates both high charge densities (i.e. a lot of energy in a small volume) and high charge cycle stability for the battery (i.e. many charging and discharging processes, hence a long battery lifetime). Batteries that are used in electric cars today are very similar to those found in our electronic devices such as tablets and smartphones, which is why the demand for cobalt and graphite is set to keep on rising in years to come.

All over the world, the search is well underway to find substitute materials that are cost-effective and in abundant supply but do not have any technical drawbacks. Empa was involved in the development of a vanadium-based battery, for instance, which is currently being commercialized by the Swatch subsidiary Belenos.

Price is key – for stationary devices

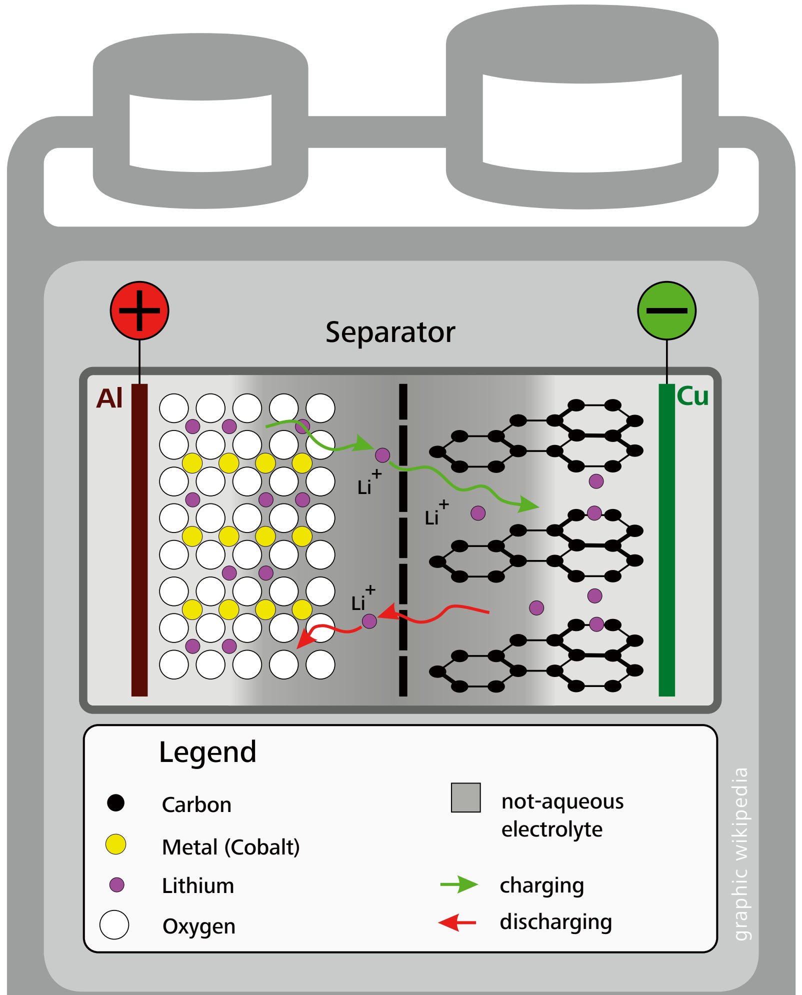
An increasing amount of solar and wind power is to be stored locally to place less of a strain on the power grids. For these "large" batteries, short charging times and a high power density is less important as the battery can be a lot heavier and bulkier in a basement than in a smartphone or in the undercarriage of a car. In contrast, the price and the operating costs throughout the system's lifetime are crucial as the battery has to compete with other energy storage systems.

Apart from studies aimed at understanding and improving the behavior of current lithium ion batteries, Empa's research also concentrates on developing completely new concepts for batteries and exploring their potential – a long and oftentimes tedious process, as Corsin Battaglia, head of Empa's Materials for Energy Conversion lab, points out: "Once a new battery system has proved itself in the lab, there is still a long way to go. It often takes years before we have a product or concept that's ready for the market. It's our job to speed up this process."

Research at the materials level is accompanied by life cycle assessments (LCA) to improve the battery's recyclability, for instance, or compare different technologies in terms of their environmental impact throughout the battery's life cycle. //

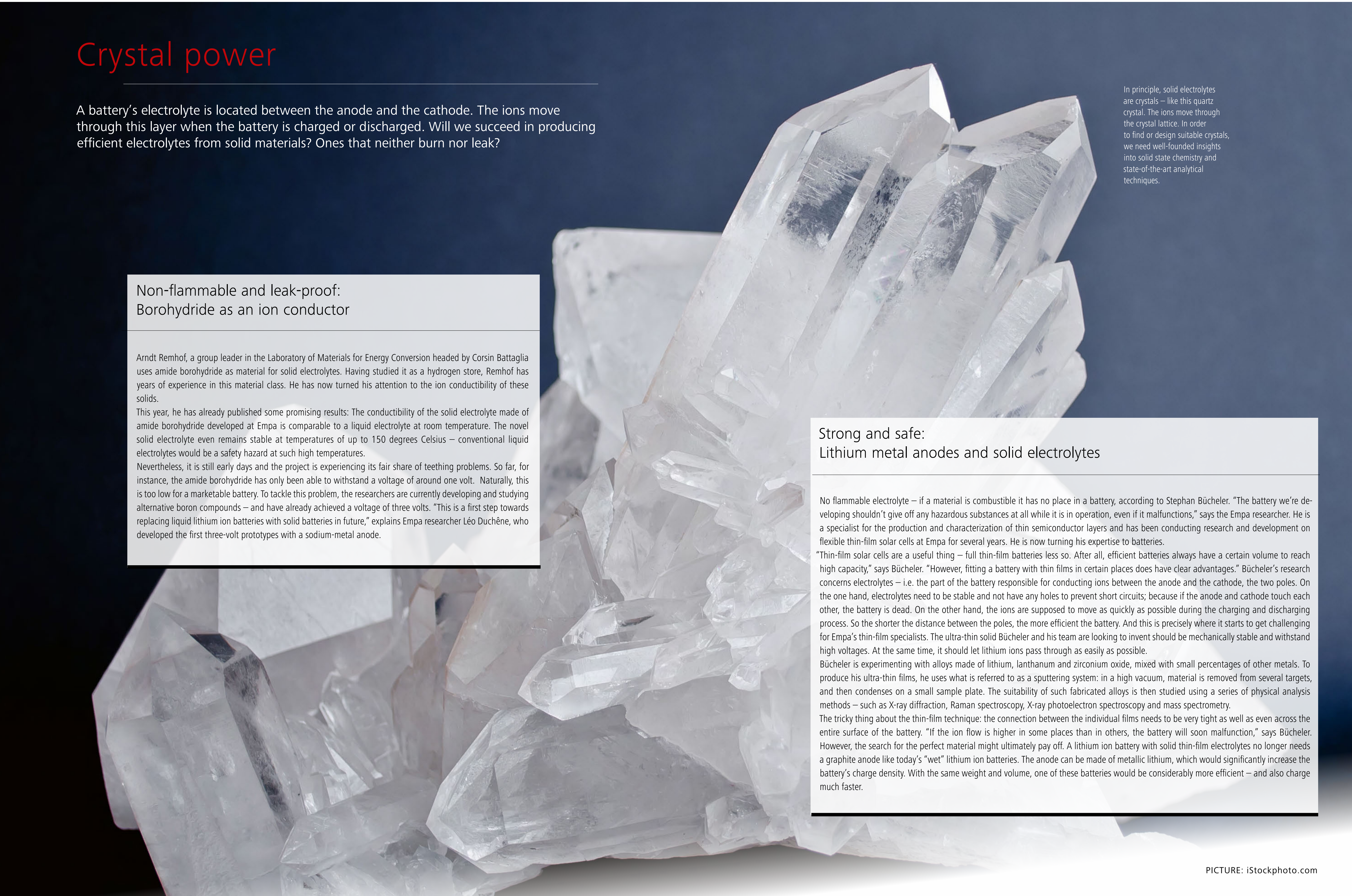
Lithium ion batteries – how they work

The lithium ion battery is all around us. It provides sufficient power for smartphones, toys, kitchen appliances and hobby tools. Electric cars, boats or even planes, however, need a bit more. How does it work?



The original lithium ion battery consists of an anode made of graphite and a cathode made of cobalt oxide. Between the cathode (positive pole) and the anode (negative pole), a liquid ensures that the lithium ions are able to move inside the battery. This liquid consists of fluorophosphate salts dissolved in an anhydrous organic solvent, such as dimethyl carbonate, and is flammable. In a charged state, the lithium ions sit between the graphite layers. As soon as the battery provides electricity, the lithium ions move through the electrolytes to the cathode, where they slip into the structural holes in the cobalt oxide and remain there permanently.

In a charged state, the lithium ions are located in the cobalt oxide. As the battery charges, they move back into the graphite.



Crystal power

A battery's electrolyte is located between the anode and the cathode. The ions move through this layer when the battery is charged or discharged. Will we succeed in producing efficient electrolytes from solid materials? Ones that neither burn nor leak?

In principle, solid electrolytes are crystals – like this quartz crystal. The ions move through the crystal lattice. In order to find or design suitable crystals, we need well-founded insights into solid state chemistry and state-of-the-art analytical techniques.

Non-flammable and leak-proof: Borohydride as an ion conductor

Arndt Remhof, a group leader in the Laboratory of Materials for Energy Conversion headed by Corsin Battaglia uses amide borohydride as material for solid electrolytes. Having studied it as a hydrogen store, Remhof has years of experience in this material class. He has now turned his attention to the ion conductibility of these solids.

This year, he has already published some promising results: The conductibility of the solid electrolyte made of amide borohydride developed at Empa is comparable to a liquid electrolyte at room temperature. The novel solid electrolyte even remains stable at temperatures of up to 150 degrees Celsius – conventional liquid electrolytes would be a safety hazard at such high temperatures.

Nevertheless, it is still early days and the project is experiencing its fair share of teething problems. So far, for instance, the amide borohydride has only been able to withstand a voltage of around one volt. Naturally, this is too low for a marketable battery. To tackle this problem, the researchers are currently developing and studying alternative boron compounds – and have already achieved a voltage of three volts. "This is a first step towards replacing liquid lithium ion batteries with solid batteries in future," explains Empa researcher Léo Duchêne, who developed the first three-volt prototypes with a sodium-metal anode.

Strong and safe: Lithium metal anodes and solid electrolytes

No flammable electrolyte – if a material is combustible it has no place in a battery, according to Stephan Bücheler. "The battery we're developing shouldn't give off any hazardous substances at all while it is in operation, even if it malfunctions," says the Empa researcher. He is a specialist for the production and characterization of thin semiconductor layers and has been conducting research and development on flexible thin-film solar cells at Empa for several years. He is now turning his expertise to batteries.

"Thin-film solar cells are a useful thing – full thin-film batteries less so. After all, efficient batteries always have a certain volume to reach high capacity," says Bücheler. "However, fitting a battery with thin films in certain places does have clear advantages." Bücheler's research concerns electrolytes – i.e. the part of the battery responsible for conducting ions between the anode and the cathode, the two poles. On the one hand, electrolytes need to be stable and not have any holes to prevent short circuits; because if the anode and cathode touch each other, the battery is dead. On the other hand, the ions are supposed to move as quickly as possible during the charging and discharging process. So the shorter the distance between the poles, the more efficient the battery. And this is precisely where it starts to get challenging for Empa's thin-film specialists. The ultra-thin solid Bücheler and his team are looking to invent should be mechanically stable and withstand high voltages. At the same time, it should let lithium ions pass through as easily as possible.

Bücheler is experimenting with alloys made of lithium, lanthanum and zirconium oxide, mixed with small percentages of other metals. To produce his ultra-thin films, he uses what is referred to as a sputtering system: in a high vacuum, material is removed from several targets, and then condenses on a small sample plate. The suitability of such fabricated alloys is then studied using a series of physical analysis methods – such as X-ray diffraction, Raman spectroscopy, X-ray photoelectron spectroscopy and mass spectrometry.

The tricky thing about the thin-film technique: the connection between the individual films needs to be very tight as well as even across the entire surface of the battery. "If the ion flow is higher in some places than in others, the battery will soon malfunction," says Bücheler. However, the search for the perfect material might ultimately pay off. A lithium ion battery with solid thin-film electrolytes no longer needs a graphite anode like today's "wet" lithium ion batteries. The anode can be made of metallic lithium, which would significantly increase the battery's charge density. With the same weight and volume, one of these batteries would be considerably more efficient – and also charge much faster.

PICTURE: iStockphoto.com

Battery research – where is it heading?

Starting with the familiar lithium ion batteries, researchers are moving in all directions. All the components of the battery are being studied: the cathode (positive pole), the anode (negative pole) and even the electrolyte, through which the ions move. Current and future battery types at a glance.

Known battery types

Lithium ion battery

See page 13

+ high energy density
+ established technique
– flammable if treated wrongly
– limited lifespan
– ingredients from China (supply security)

Research on:

– cathode material without cobalt (from China)
– non-flammable electrolyte liquids
– better performance and reliability
– lower production costs

Molten salt battery

See page 19

+ long lifespan
+ many charging/discharging cycles
+ ingredients easily obtainable
– operating temperature 300 °C
– needs to be charged/heated daily

Research on:

– solid electrolytes
– better performance and reliability
– lower production costs

Research on new battery types

Graphite cathode, metal anode

See page 21

+ sodium, aluminum, magnesium possible
+ cathode made of low-cost waste graphite
+ easy to assemble, large quantities
– every metal needs special chemistry

Lithium metal anode with thin-film electrolyte

See page 15

+ higher energy density than lithium ion batteries
+ non-flammable
+ does not release any toxins in the event of accidents / breakdowns
– production at around 500 °C
– ingredients have to be resistant to high temperatures

Lithium ion battery with solid electrolyte

see pages 14 and 20

+ non-flammable
+ sodium or magnesium possible instead of lithium
+ simple production (pressed powder)
– mechanical stress ages battery
– optimum electrode material still unknown

PICTURE: iStockphoto.com

Sea salt instead of scarce raw materials

Lithium is becoming scarce and cannot be found in all regions of the world. A battery made of sodium and chloride ions would be the solution. The ingredients are found in seawater. And that is (virtually) everywhere.

Safe and salty:
The aqueous sodium battery

As we keep reading, lithium ion batteries in smartphones and laptops can go up in flames every now and so often. This triggered a spectacular recall campaign for the Samsung Galaxy Note 7 in 2016, delayed the production launch for the Chevrolet Volt and Opel Ampera in 2012 and caused eight million Sony laptop batteries to be recalled in 2006. The reason: lithium ion batteries contain a flammable liquid. And the oxygen released from the cathode fans the flames even further.

Wouldn't it thus be a smart idea to substitute the flammable electrolyte for an aqueous (and thus non-flammable) solution? The problem: water can only withstand voltage differences of no more than 1.23 volts because it disintegrates at higher voltages. A customary lithium ion battery cell supplies around 3.7 volts – i.e. three times as much.

Ruben-Simon Kühnel and David Reber from Empa's Materials for Energy Conversion lab have now found a way round this problem. They produced an extremely concentrated solution of a special sodium salt, sodium bis(fluorosulfonyl)imide, or NaFSI for short. More than seven kilograms of this salt can be dissolved in a liter of water. The viscous, salty solution survives voltage differences of up to 2.6 volts. Thus, according to the researchers, this now means a water-based battery is within reach. And they have already assembled one: initial experiments with sodium titanium and sodium vanadium electrodes yielded a wealth of promising results.

The sodium water battery would also solve another problem: the global stocks of lithium that can be mined easily are limited. Sodium, on the other hand, is readily available in sea salt and table salt from salt mines. Likewise, all other raw materials for this battery are available in large quantities.

Hot and reliable:
The molten salt battery

Another path towards low-cost, yet safe batteries is the sodium nickel chloride battery, aka the molten salt or zebra battery. The first batteries of this type were already developed in 1985, but were overshadowed by the successful lithium ion batteries. Unjustly, according to Corsin Battaglia, head of Empa's Materials for Energy Conversion lab. This battery works at an operating temperature of 300 degrees, but is extremely well insulated. As a result, the energy required to keep it warm remains within limits. "Compared to lithium ion batteries, this battery has major advantages as a stationary storage battery: Being made of nickel and table salt, it doesn't need any cobalt or graphite and doesn't loose power, even if kept fully charged – and unused – for longer periods."

Many telecommunications companies thus already rely on backup power batteries of this type. These batteries can even be used in extreme climatic conditions: due to their good thermal insulation, it doesn't make a difference whether they have to supply electricity on a hot summer's day at Zurich Airport or on a cold winter's night in the Swiss Alps.

Switzerland leads the way in the development of these batteries, which are produced by the company FZSoNick SA in Stabio. Empa is collaborating with the company to improve the ceramic electrolytes for this type of battery. The salt melt and the liquid sodium anode have to be separated by a alumina ceramic material, which is also able to conduct ions. The anode and cathode in this battery thus consist of molten substances – the electrolyte comprises a ceramic layer that separates these melts. If the researchers succeed in improving this ceramic electrolyte, the battery's performance and lifespan will increase.

Electro-pioneer

The electric car Think City was constructed in Finland and the US and also sold in Switzerland between 2008 and 2012. It had a range of up to 160 km and was powered by a 24-kWh molten salt battery with an operating temperature of 260 to 360 degrees Celsius. The Think City remained on the fringes of the car industry, however: fewer than 3,000 cars were produced before the manufacturer went bankrupt in 2011.

PICTURE: iStockphoto.com, wikipedia

Robust batteries made of scrap

Lithium is growing scarce? Don't worry. We can build low-cost, long-lasting batteries from waste graphite and metals that are in plentiful supply. Such as aluminum from disused planes.

Inexpensive and safe: Magnesium or sodium instead of lithium

Researchers from Empa have teamed up with scientists from the University of Geneva, the Paul Scherrer Institute (PSI) and the Henryk Niewodniczański Institute of Nuclear Physics in Poland on a research project, "Novel Ionic Conductors". The latest studies headed by Empa researcher Arndt Remhof (see also p.19) reveal that sodium and magnesium are just the ticket for developing new, pure solid-state batteries. Functional sodium-based prototype cells have already yielded highly promising results. What's more, the electrolyte is non-toxic, non-flammable and remains chemically stable, even above 300 degrees, which makes it particularly safe. In parallel, the team headed by Hans Hagemann at the University of Geneva devised a more cost-effective technique for producing the new solid electrolytes.

Meanwhile, the team has also developed a solid electrolyte for magnesium. Previous research projects in this field can be counted on one hand. Although setting magnesium in motion is difficult, it is all the more interesting: it is light and available in abundance But more importantly, a magnesium ion has two positive charges, whereas lithium only has one. Essentially, this means that it stores almost twice as much energy in the same volume.

"These initial projects were primarily proof-of-concept studies," says Empa researcher Elsa Roedern. "We are still a long way from having a complete and functional prototype, but we have taken the first important step towards achieving our goal."

Low-cost and long-lasting: Aluminum battery with graphite as a cathode

Kostiantyn Kravchykworks in the group of Maksym Kovalenko. This research group is based atat both ETH Zurich and in Empa's Laboratory for Thin Films and Photovoltaics. The two researchers' ambitious goal at the Empa branch is to make a battery out of the most common elements in the Earth's crust – such as magnesium or aluminum. These metals offer a high degree of safety, even if the anode is made of pure metal. This also offers the opportunity to assemble the batteries in a very simple and inexpensive way and to rapidly upscale the production.

In order to make such batteries run, the liquid electrolyte needs to consist of special ions that do not crystallize at room temperature – i.e. form a kind of melt. The metal ions move back and forth between the cathode and the anode in this "cold melt", encased in a thick mantle of chloride ions. Alternatively, large but lightweight organic anions, which are metal-free, could be used. This does come with a problem, though: where are these "thick" ions supposed to go when the battery is charged? What could be a suited cathode material? By way of comparison: in lithium ion batteries, the cathode is made of a metal oxide, which can easily absorb the small lithium cations during charging (see p.13). This does not work for such large ions, however. In addition, these large anions have an opposite charge to the lithium cations.

To solve the problem, Kovalenko's team had a trick up their sleeves: the researchers turned the principle of the lithium ion battery upside down. In conventional Li-ion batteries, the anode (the negative pole) is made of graphite, the layers of which (in a charged state) contain the lithium ions (see p. XY).In Kovalenko's battery, on contrary, the graphite is used as acathode (the positive pole). The thick anions are deposited in-between the graphene layers. In Kovalenko's battery, the anode is made of metal.

Kravchyk made a remarkable discovery while searching for the "right" graphite: he found that waste graphite produced in steel production, referred to as "kish graphite", makes for a great cathode material. Natural graphite also works equally well – if it is supplied in coarse flakes and not ground too finely or into folded, non-flake shapes. The reason: the graphite layers are open at the flakes' edges and the thick anions are thus able to slip into the structure more easily. The fine-ground graphite normally used in lithium ion batteries, however, is ill-suited for Kovalenko's battery: by grinding the graphite particles, the layers become creased like crumpled-up paper. Only small lithium ions are able to penetrate this crumpled graphite, not the new battery's thick anions.

The graphite cathode battery constructed from steel production "kish graphite" or raw, natural graphite flakes has the potential to become highly cost-effective. And if the first experiments are anything to go by, it is also long-lasting. For several months, a lab system survived thousands of charging and discharging cycles. "The aluminum chloride – graphite cathode battery could last decades in everyday household use," explains Kravchyk and adds "similar demonstrations, but further increased battery voltages, without compromising capacities, and of even lighter elements are on the way and will offer further increase in energy densities from current 60 Wh kg^{-1} to above 150 Wh kg^{-1}"

PICTURE: iStockphoto.com

A marketplace for energy

The energy grid is becoming increasingly complex: decentralized energy producers require storage possibilities, such as large stationary batteries, to guarantee our power supply even with an increase in heavily fluctuating energy sources like solar and wind power. A project at Empa's research and technology platform ehub (Energy Hub) is analyzing how energy flows can be regulated intelligently and in real time.

TEXT: Karin Weinmann / PICTURE: iStockphoto.com

Switzerland's power supply is on the brink of a major transformation: instead of a few large-scale power plants, a growing number of small, decentralized producers are feeding electricity from biomass, wind power and photovoltaics (PV) into the grid. Especially in wind power and photovoltaics, the amount of energy that is fed in is subject to heavy temporal fluctuations depending on the weather. Storage devices are used to keep the grid stable and guarantee an uninterrupted power supply. This makes the power grid of the future far more complex: instead of centrally regulating the major power plants in such a way as to produce just as much energy as is needed, the decentralized generators will have to store energy at times when it is not required. To maintain the equilibrium between numerous extra energy suppliers and storage systems on the energy grid and avoid overexerting the power lines, energy flows have to be optimized by means of "smart" regulation.

In a project at Empa's energy demonstrator in Dübendorf, researchers are now testing a new possibility to combine the grid, power suppliers, consumers and storage systems in a smart way on an urban district level. The goal is to find out how renewable energy can boost the grid's stability and be exchanged between districts in an optimum way.

The idea, developed at EPFL in Lausanne, involves viewing the power grid as a trading floor of sorts: every participant can offer or request energy with a desired price tag attached. An intelligent control system manages energy flows in such a way as to minimize the overall costs of the system.

How much does it cost to charge?

Take the example of a stationary storage battery: if it is fully charged, it doesn't make much sense to pump in more electricity – so charging the battery even more becomes expensive in this "energy marketplace". At the same time, the battery serves as an energy source – drawing energy becomes cost-effective. Once the battery charge has dropped to a few percent, however, it will be cost-effective to re-charge but expensive to discharge. In this energy marketplace, every participant has their own agent, irrespective of whether they are producers, consumers or storage systems. This agent translates the device's current needs into a common language and forwards this inform-ation to a hub, which is responsible for a sub-grid. This hub has its own intelligence: it monitors the grid, collects the needs and offers from all participants in "its" sub-grid and calculates how the energy flows ought to be conducted ideally – at a rate of ten times per second. A neutral energy exchange has thus been created.

This also allows special circumstances to be taken into account: if electricity production fluctuates heavily in a short period of time, for instance, it makes more sense to charge and discharge a supercapacitor instead of straining a battery with numerous charging and discharging cycles, which would age it quite rapidly. In this case, the cost of charging the battery is considerably higher than charging the supercap – and so the energy will flow to the latter.

Flexible and freely expandable

One advantage of the idea is that the system can also be expanded flexibly in future: if new storage possibilities, producers or consumers join, they merely require their own agent to translate their needs and offers – and they are already part of the energy marketplace.

Empa is testing this concept in ehub's energy system. The energy demonstrator, which supplies the research building NEST and the mobility demonstrator move with energy, combines thermal and electrical energy components. These include a photovoltaic plant, heat and cold storage units, a hydrogen cycle, heat pumps and supercondensers as well as batteries, which are combined with each other in various grids. Each of these sub-grids is regulated by its own hub.

In future, the system should also work on a larger scale. And the researchers have already worked out how: in a district, a hub combines the resources available and the sub-grid it monitors into a virtual resource with a single, "accumulated" cost function. The next hub on the level above would thus receive rather simple information. Not only could such an energy marketplace include individual districts, but also cities, regions or even the whole country. //

Video
COMMELEC - arranging energy sources and storage facilties in a virtual marketplace. (EPF Lausanne)
https://youtu.be/Kw2kwdfAU2M

… as black as ebony

Like many tropical wood types, ebony is an endangered species that is tricky to use, such in instrument manufacturing. Despite strict trade regulations, ebony stocks are plummeting. A substitute is urgently needed. And this is where the Empa spin-off Swiss Wood Solutions comes in. Its product, "Swiss Ebony", consists of modified Swiss maple, which boasts the same properties as ebony – a sustainable and entirely legal solution.

TEXT: Cornelia Zogg / PICTURES: Empa, iStockfoto.com

A young violinist touches down in Berlin, his fine, expensive instrument in his luggage and eager to get on stage the next evening. He is stopped at customs. An hour later, he leaves the airport – short of his violin, which has been confiscated.

Like many violins, the young musician's instrument has a tailpiece and fingerboard made of ebony, a tropical wood that is on the CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) list of protected wood species. Hence, ebony may only be imported if the legal provenance of the material can be proven to customs authorities. Besides the raw material, some of the 183 CITES countries also regulate finished products, such as musical instruments. As a result, many musicians are reluctant to travel with their instruments as getting them through customs is too risky. Numerous instruments have already been impounded.

However, travelling isn't the only problem. Anyone who deals in these instruments may be liable for prosecution if they are unable to prove the legal provenance of the material. Even offering such products on an internet platform may end up being reported.

A Swiss alternative to endangered tropical wood species

Back to our budding violinist: he would like to continue the tour with his fine instrument. And naturally he doesn't want to have any trouble with customs authorities. Moreover, he wants to be sure that he can sell his valuable instrument legally if need be. But he doesn'thave a certificate stating the provenance of the wood his violin is made of. His violin manufacturer tells him that only ebony will do: the tropical wood's hardness, good workability and excellent sound properties make it just the ticket for violin-making.

Besides, its elegant dark color is a real eye-catcher. Beech or Swiss maple aren't a patch on it. Or are they? Researchers from Empa's Laboratory for Applied Wood Materials and the Chair of Wood Materials Science at ETH Zurich co-founded the start-up Swiss Wood Solutions and discovered a way to modify Swiss wood species so they exhibit the properties of endangered tropical wood species such as ebony or grenadilla. (The latter is primarily used to make clarinets and oboes.)

Swiss maple from sustainable forestry is cut and soaked in an aqueous solution. The timber is then dried and compressed using a hot-press, which enables the wood properties that are so important to instrument manufacturers to be tailored. To make a clarinet, for instance, you need a lower wood density than for violin finger boards. The color and sound conduction speed also differ, as Oliver Kläusler, CEO of Swiss Wood Solutions, explains: "Our technique enables us to determine these parameters ourselves, which means a violin maker can fine-tune the instrument very precisely."

Even better than the original

The spin-off is not the first company to specialize in tropical wood alternatives. There are already similar materials, such as wood and synthetic composites or carbon materials. Therefore, in the spring of 2017, Kläusler conducted sound tests with professional musicians and music students to compare these materials directly. The encouraging result: Swiss Ebony came in joint first with real ebony.

The violin manufacturer Boris Haug from Suhr used the material to make tailpieces for professional instruments, which were then played for weeks on end. "One musician was reluctant to give our cello prototype back and proposed leaving us her top-notch ebony tailpiece instead," says Kläusler. Her explanation: her cello sounded "sexier" than ever with Swiss Ebony. The ebony substitute can already match its natural role model in terms of price, too. However, Kläusler and his team are looking to slash production costs even further. They also set great store by making the entire production process environmentally friendly and sustainable.
Swiss Wood Solutions is currently on the lookout for investors to launch the product on the market. The development conducted thus far was funded by two grants from the Gebert Rüf Foundation. Moreover, the spin-off has been receiving coaching from various business angles, including experts from the Commission for Technology and Innovation (CTI), Empa's business incubator glaTec and Venture Kick.

More than music

In future, Swiss Ebony might even be used for other lifestyle products, such as watch components, pool cues and knife handles. As talks with potential customers revealed, these markets face very similar challenges to the musical instrument sector. The spin-off is also working on a new method to dye its wooden products, which should open up additional potential applications for the material. "But that's still a pipe dream," says Kläusler. "The immediate goal is to equip musicians with top-quality instruments. Sustainably and ecologically." And orchestras might well be able to head off on world tours again without second thoughts. And with a clear conscience, too. //

top
A violin with a fingerboard made of Swiss Ebony.
Photo: Wilhelm Geigenbau AG, Suhr.

center
The new material: a Swiss Ebony two-by-four made of Swiss maple.

bottom
A Swiss Ebony cello tailpiece – still undyed but already boasting the physical properties of ebony.
Photo: Wilhelm Geigenbau, Suhr.

Clear-cut ideas

Tanja Zimmermann joined Empa's Board of Directors in September. She runs the new Functional Materials department – another step up in a successful career that began in Empa's Wood lab. Thanks to her inquisitiveness, creativity and an eye for the impossible, Zimmermann helped lift a previously little-known research field onto the international stage

TEXT: Corelia Zogg / PICTURES: Empa

K“Creativity is a basic requirement in research.” Tanja Zimmermann is speaking from experience. Born in Hamburg, she used creative ideas to rehabilitate a research field at Empa. Until only a few years ago, wood was not exactly a fashionable research field – and not just at Empa, either. According to Zimmermann, the general consensus was that everything that you would possibly want to know about wood had already been investigated. As a newly appointed head of the corresponding research lab in 2011, one of her first tasks was thus to convince Empa's Board of Directors of the contrary – and she suc-ceeded compellingly, as a glance at her team's publication list reveals. “In the past, there were three or four journals where wood researchers could publish their results,” Zimmermann says. “Nowadays, we publish in top-notch materials science journals, which I consider a huge success.”

Her fascination with wood and its wealth of possibilities began much earlier, however. Zimmermann looks back on a long, “linear” career at Empa, which all started with a three-month internship during her wood science degree at the University of Hamburg in 1992 – and reached its pinnacle (so far) with her recent appointment as Head of Department. In all these years – she took over the helm of a research group in 2001 and has been running the Applied Wood Materials lab since 2011 – it never occurred to her to leave the institute. For one simple reason: “Empa has always given me every opportunity to move ahead,” she says.

Wood offers countless possibilities

The countless possibilities to develop new wood-based materials were a major motivation for her. Only recently, her team managed to make a 3D ink from nanocellulose, which can be used to produce microstructures with outstanding mechanical properties – a technique that is extremely promising for implants and other biomedical applications. Moreover, as a renewable raw material wood is more ecological and sustainable than conventional 3D printer ink.

Seemingly futuristic projects involving wood are all in a day's work for Tanja Zimmermann. Together with fellow Empa researcher (and ETH Zurich professor of wood materials science) Ingo Burgert and her team, for instance, she initiated the NEST unit “Vision Wood”, a residential unit for Empa students where a wide range of wood applications is currently being tested under real-life conditions. Wood displays a number of sometimes unexpected properties. The student digs, for example, contain antimicrobial, magnetic and fire-resistant wood, but also wood that is fully waterproof – such as for the sinks.

A nanocellulose sponge, which was chemically modified so that (against its “nature”) it only sucks up (large quantities) of oil and no water – an extremely interesting “skill” if one considers its potential use in the environmental sector, such as oil disasters – also stems from Zimmermann's team. And while wood is frequently considered an antiquated building material, the Empa researcher keeps discovering fresh application possibilities. Even the future, she contends, does not consist solely of synthetic materials and metals; the natural and ecological material should (and can) also have a role to play here, as Zimmermann points out. «Perhaps we'll soon have wood that conducts electricity,” she says with a view to possibilities yet to be researched.

Tanja Zimmermann on the balcony of the NEST unit Vision Wood, which was conceived under her supervision. The balcony furniture is made of a novel bamboo fiber and synthetic resin material.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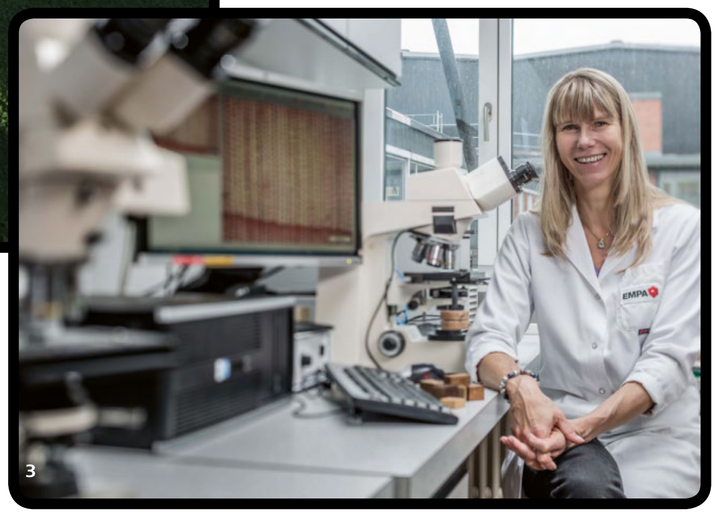
It's all about the right chemistry

Zimmermann also finds herself confronted with wood-related challenges in her private life. Ten years ago, for instance, she and her family moved into a 200-year-old farmhouse, the entire supporting structure is made of wood. Major renovations were necessary before they could move in. And anyone who believes that wood is only exciting for basic research in the lab is very much mistaken. The attic in the half-timbered house – as is typical of such an old building – was infe-sted with insects. "When we sandblasted the whole room, suddenly we could see all the little holes they had eaten into the wood. The company tried to persuade me to fork out an arm and a leg to impregnate the wood with a chemical preservative, but that's absolute nonsense," explains the expert. With the right insulation, i.e. as soon as temperature and moisture conditions are no longer suitable for the wood-eating insects, wood preservatives are redundant anyway.

The research in Zimmermann's team focuses on wood as a natural, renewable resource that's abundant in Switzerland for developing new materials. A key success factor for her: the chemistry between colleagues has to be right. For Zimmermann, a good team spirit is an essential ingredient for a successful research lab. "I'd rather take on ten decent researchers who are a good fit for my team than two socially incompetent hotshots," she says. She also aims to pursue this philosophy in her new position. She believes that a good team only works if everybody pulls in the same direction and supports each other – only then is top-flight research possible. However, for Tanja Zimmermann collaboration is not just essential within a team, but also on other levels. "It's important to me for the various research labs in my department to openly communicate and exchange ideas with each other," she explains. "This creates synergies and new, exciting ideas that are necessary for innovative projects." The new Functional Materials department, she adds, also contains research labs from a wide range of fields, such as building technology, high-performance ceramics, fiber technology, concrete and building chemistry.


3

All aboard

When it comes to ideas for new research projects, the sky's the limit for Zimmermann – provided there is an obvious benefit. "I'd never start a research project just for the sake of it. It should always be based on an idea that has a real benefit for society," says Zimmermann. After all, as a research institution Empa acts as a kind of bridge between research and industry. She lauds the diverse possibilities at Empa. "We have the whole gamut here, from basic research and industrial collaborations to services and consulting," she explains. As Head of Department, she has the opportunity to maintain these different facets, even if she no longer has time to be in the lab herself.

She finds plenty to counterbalance her work challenges in her free time, too – she is constantly on the go and finds it hard to sit still. She enjoys doing sports and rides her horse a lot. And she recently started learning to play the guitar. A lack of motivation does not seem to be a problem for her – quite the contrary: she always manages to motivate others with her enthusiasm, which is especially important when promoting and encouraging talented young researchers. "I absolutely love working with people," Zimmermann confesses. There is nothing better than supervising a PhD student and watching the budding scientist grow over the years – both personally and professionally. Although she is bound to miss this direct contact in future, she will still be involved in "people management". Above all, it is an opportunity for her to promote the interdisci-plinary collaboration between the various research labs and bring together the right people for the questions at hand. "It will be interesting to combine the various materials from the research labs in 'my' department and give them unusual functions." //

"Olympic gold" for budding researcher

What started out as a two-week internship at Empa culminated in the GENIUS Olympiad 2018 in the US for Luca Schaufelberger: as the winner of the national competition "Swiss Youth in Science", he represented Switzerland at the Olympic Games for bright minds – and won there, too! His reusable water filters made of nanocellulose thrilled jury committees from here to the other side of the Atlantic.

TEXT: Corelia Zogg / PICTURES: Michael Riechsteiner ("Swiss Youth in Science")

Filters made of chemically modified cellulose nanofibrils are ideal for removing humic acid from polluted water – as a team of Empa researchers headed by Houssine Sehaqui and Tanja Zimmermann had demonstrated. As part of his final high school thesis project during an internship at Empa in early 2017, Luca Schaufelberger from Zofingen Cantonal School then developed a technique to remove the humic acid captured in the filters virtually without a trace. This means that the filters can be reused, a major advantage as they are considerably more ecological than their disposable counterparts. He used an alkaline saline solution, which was so effective that the filter could be cleaned several times and reused with only a slight decrease in efficiency.

Luca Schaufelberger shows President of the Swiss Confederation Doris Leuthard his invention at the national competition "Swiss Youth in Science".

Co-author of two scientific publications – at age 19
The 19-year-old's internship project was so pioneering that his work, combined with Empa's research, spawned two scientific publications. And that's not all: his outstanding high school project also won the "Swiss Youth in Science" award – and an additional prize that entitled him to participate as Switzerland's only entrant in the GENIUS Olympiad 2018 at State University of New York (SUNY) in Oswego, on the shores of Lake Ontario. In this annual competition, high school students from all over the world compete with projects in five environmental categories. Schaufelberger's reusable nanocellulose filter also caused quite a stir there – and won gold in the Science category.

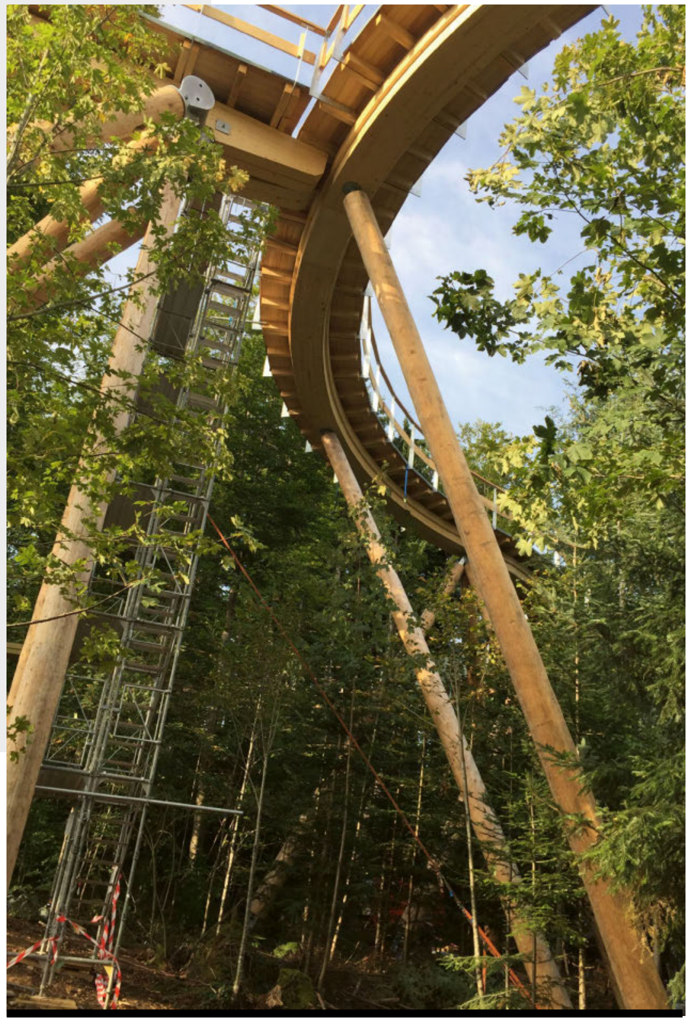
Success within five weeks
Not a bad haul for a five-week internship. Luca's first internship lasted two weeks and enabled him to pave the way for the filter's production under the supervision of Empa researcher Houssine Sehaqui. Within the scope of his project, he returned to Empa and made the nanocellulose filter reusable.

The lab work as well as the trips and presentations in Switzerland and the US gave Luca his first taste of life as a scientist, a path he would like to continue on in future, too. "After my military service, I'd like to study interdisciplinary science at ETH Zurich," he confirms. The topic of sustainability is extremely close to his heart, which is also why he has devoted himself to the topic of water, especially water pollution and recycling. And considering everything that the young researcher has achieved thus far, what he might accomplish after his degree is anybody's guess. //

Strolling safely around tree-tops

A walk through the woods offers only a limited glimpse into this diverse habitat. What happens at dizzying heights in the treetops remains hidden from walkers. From May 2018, however, the Canopy Walk in Neckertal, Toggenburg, will enable visitors to stroll around the forest canopy on filigree wooden structures. To make sure the eight to twelve-meter wooden masts that support the treetop walkway are safe, the wood needs to be protected against pests. This is where the biological wood treatment method developed by Empa spin-off Mycosolutions AG in St. Gallen comes in, as the operators insisted on finding an ecological solution. The canopy walkway is an exciting pilot project for the spin-off from Empa's Applied Wood Materials lab.
The 200 masts made of local spruce were, therefore, treated with an organism that keeps pests at bay. Before they were assembled, the supports were sprayed with a suspension containing fungal spores of Trichoderma harzianum and nutrients, which help the spores to grow. With sugar and urea in their backpacks, the helper organisms immediately begin penetrating the trunks with their fine netting. In future, however, the protective organisms will feed on harmful members of the fungus kingdom.
The fungus hunters from Mycosolutions are well aware that natural processes eventually change wood as a material. "Cracks will appear in the trunks as the wood dries out," says Reto Vincenz, CEO of the Empa spin-off. "So the spruce will be treated to regular wellness spas with the protective spores."
With a desired service life time of 30 to 50 years for these supports, untreated spruce masts would not be able to go the distance. And anyone who uses the wrong wood treatment risks the whole structure collapsing at any minute – as was the case in a similar park in Spain, where the masts had been eaten away within eight years and suddenly came tumbling down.

www.mycosolutions.swiss



Model of a phononic crystal at the first "Design Biennale Zurich". Photo C. Lauchenauer

Designed by Empa: as quiet as a mouse

From mind-numbing clanging to booming building sites – there is no end of sound vibrations that we could really do without. A damping material that is both lightweight and sturdy could make life a lot easier. With this in mind, researchers from Empa have succeeded in producing crystals that are capable of cushioning the irksome noise and vibrations. The next step is to tailor the 3D-printed phononic crystals for use in practice.
Empa's current Designer-in-residence, Christian Lauchenauer, has now teamed up with materials researchers and acoustics experts to sound out the first poten-tial industrial applications. Lauchenauer presented crystalline components for vibration-free microscope feet at the first "Design Biennale Zurich" in September. He also used the crystals to develop partitions for offices, which reveals another advantage of phononic crystals over conventional sound-absorbing materials: as the new material does not need any soft insulating layers, it can be used as a load-bearing structure.

Events (in German)

9. November 2017
Polymerwerkstoffe für technische Anwendungen
Zielpublikum: Industrie und Wirtschaft
events.empa.ch
Empa, Dübendorf

16. November 2017
Entwicklung innovativer Produkte mit Polymeren, Additiven und Beschichtungen
Zielpublikum: Industrie und Wirtschaft
events.empa.ch
Empa, Dübendorf

22. November 2017
Additive Fertigung von Metallen
Zielpublikum: Industrie und Wirtschaft
events.empa.ch
Empa, Dübendorf

24. November 2017
Metallische Gläser – Eigenschaften, Technologien, Anwendungen
Zielpublikum: Industrie und Wirtschaft
events.empa.ch
Empa, Dübendorf

9. Januar 2018
Klebetechnik für PraktikerInnen
Zielpublikum: Industrie und Wirtschaft
events.empa.ch
Empa, Dübendorf

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