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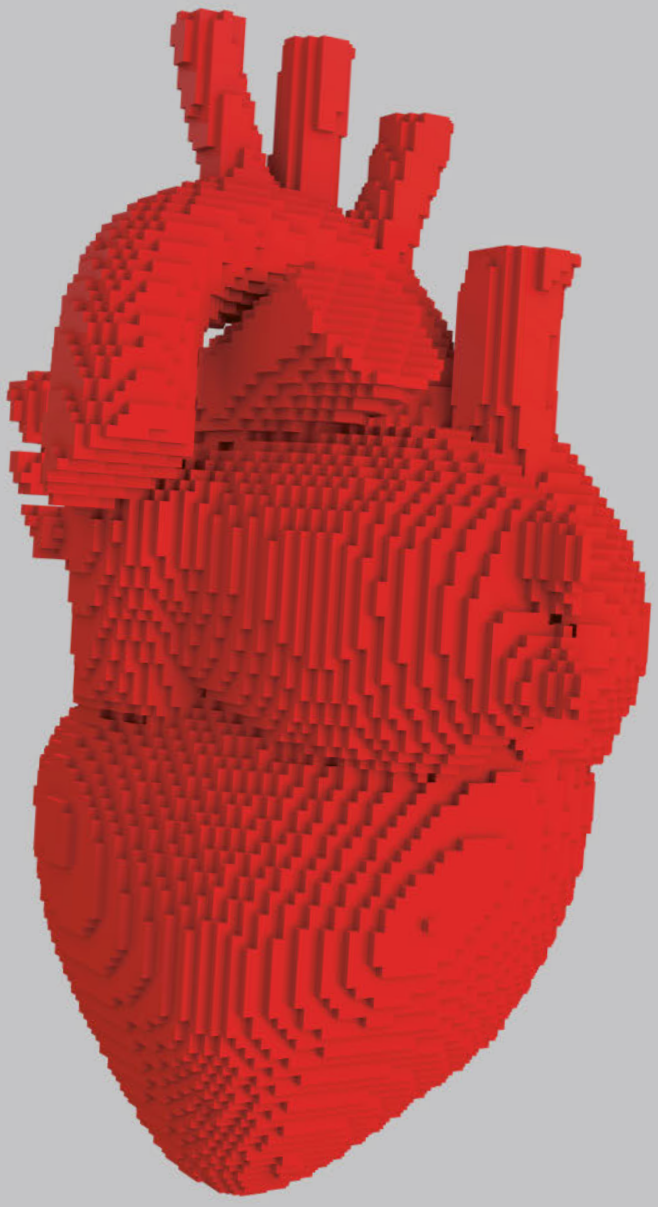
FOCUS

HEALTH MADE TO MEASURE



NANOCELLULOSE SKIN SENSORS
INVISIBILITY CAP FOR HEART IMPLANTS
INNOVATIVE MATERIALS AGAINST BIOFILMS

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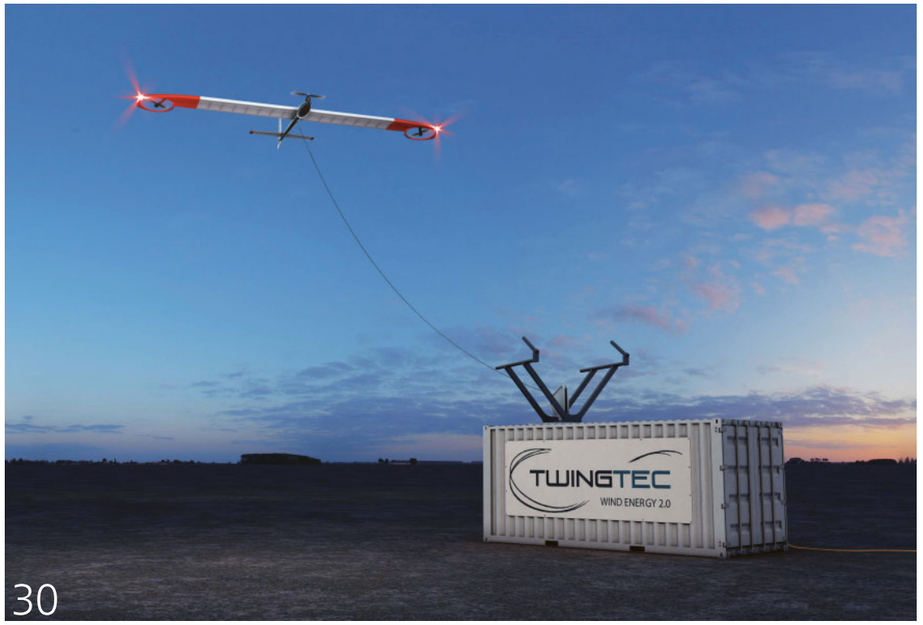

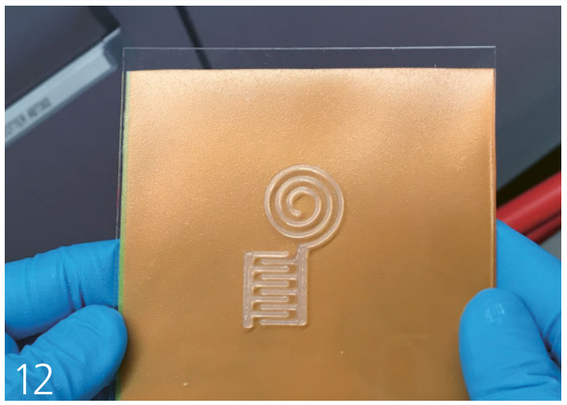

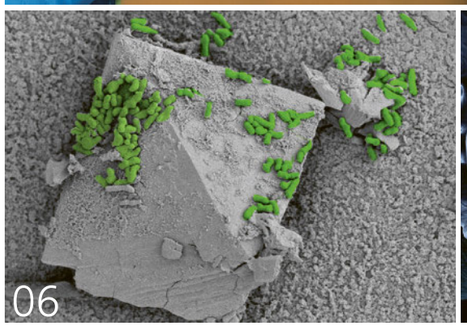

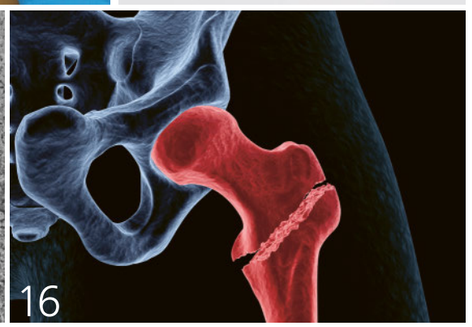

Photos: istock, Twingtec, Empa

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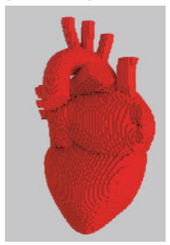

How will we remain healthy and efficient for as long as possible in the future? In this issue, you can find out how Empa contributes to this.
Image: istock

Photo: istock

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MATERIALS FOR THE MEDICINE OF TOMORROW

Dear readers,

When the term "medicine" comes to mind, most of us probably think of drugs, syringes, surgery and the like. "Materials" most likely doesn't make it to the top of the list. Yet modern medicine is highly dependent on innovative materials with novel properties if it is to keep the promises of personalized health care.

This is precisely where Empa comes into play. Because new materials and technologies are our core business – of course also in the medtech sector. We work closely with cantonal and university hospitals, for instance in Berne, Zurich and St. Gallen. As the current issue of "Empa Quaterly" shows the close interaction between materials scientists and physicians yields astounding results.

Whether it is developing new biomedical materials with antibacterial properties against so-called biofilms – an urgent topic not just since the current antibiotic crisis –, novel artificial heart pumps for patients with heart failure, a foam that improves wound healing and prevents scarring, or new skin sensors for diagnostics: The topics we are working on are as diverse as the challenges our partners face in clinical practice day in, day out.

What is true for the medtech sector, however, can also be said for energy research: New materials are not everything, but without new materials, everything is nothing.

Have fun reading, and see you at the next issue!!

Yours, MICHAEL HAGMANN

Photo | ICD/ITKE University of Stuttgart

DESIRABLE DEFORMATION
Since may 2019 there is a unique wooden building in the Remstal near Stuttgart: a tower made of self-formed spruce boards. The method, which has been developed at Empa and ETH Zurich, uses the natural swelling and shrinking of wood under the influence of moisture and thus enables a new and unexpected architecture for the construction with the renewable and sustainable resource of wood.

Further information on the topic is available at:
www.empa.ch/web/s604/urbach-tower

THE MOST SUCCESSFUL FLAT SHARE IN THE WORLD

Biofilms are enormously resistant accumulations of germs, which can cause serious problems, especially in hospitals. Like a single large creature, they can spread within wounds or colonize implants or biomedical products. With novel materials and surfaces researchers intend to combat the sturdy pathogens.

Text: Andrea Six

BIOFILMS
Sediments on catheters consist of calcium crystals, biofilm material with bacteria, red blood cells and immune cells (greenish). [colored SEM image, 4000× magnification]

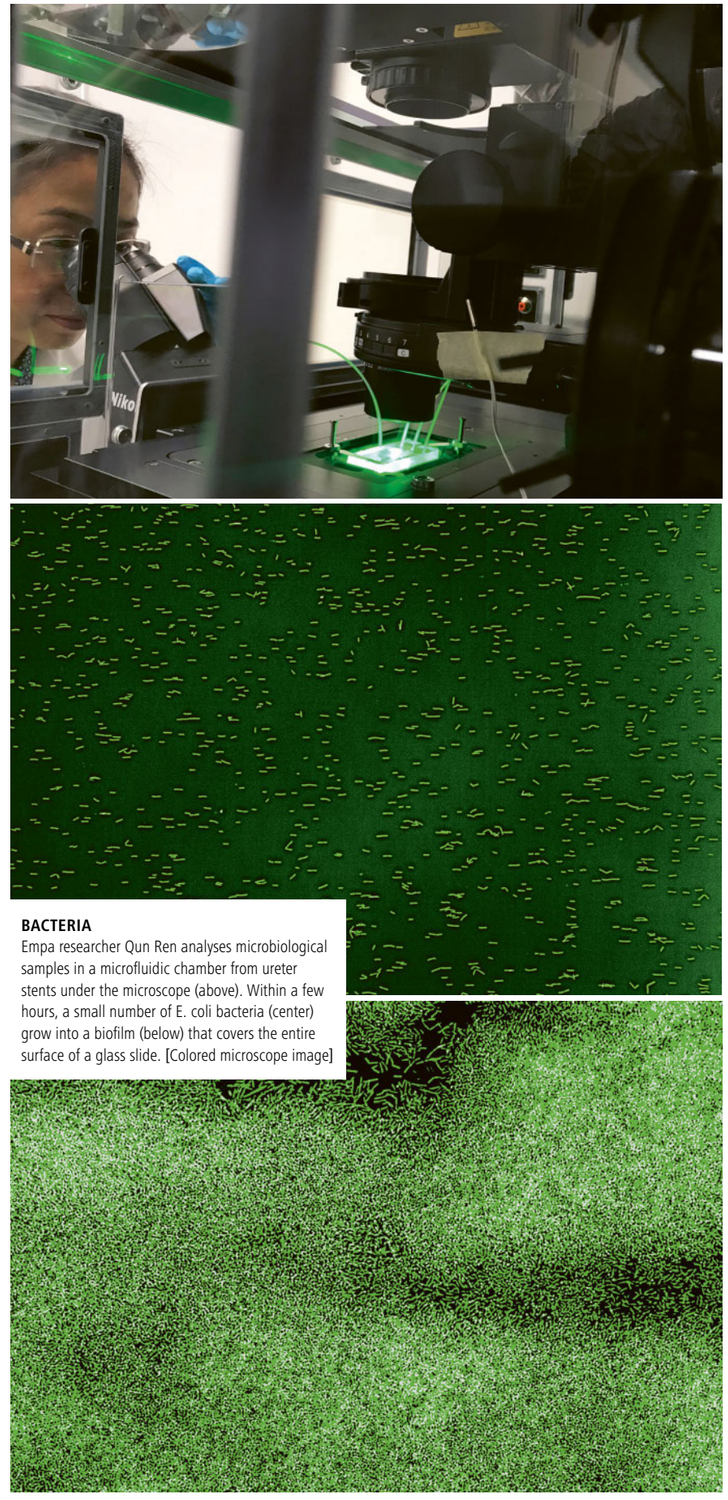
Photo: Empa

Some of us who are hospitalized are feeling worse rather than better. On average, seven percent of all patients in industrial countries are affected by "nosocomial" infections. In intensive care units, the risk increases even more. This can result in serious illnesses and life-threatening blood poisoning.

If patients are treated with invasive medical measures, hospital germs have a particularly easy time of it: If tubes are inserted into the body, for instance to ventilate it, supply it with fluids or drain urine, the infectious agents quickly gain a hold. It is still unclear how these infections can be prevented. A team of Empa scientists and physicians from the Cantonal Hospital of St. Gallen is currently working on a project aimed at reducing the risk of hospital infections.

The focus lies on the analysis of biofilms, accumulations of germs on surfaces that spread in, say, urinary catheters. However, if materials are to be designed to prevent the formation of biofilms, it must first be established how germ growth actually occurs on surfaces. It is simply not possible to develop suitable protective measures against the unknown. And this is where medicine has literally stuck in the dark – because it was largely unknown what exactly grows inside a catheter.

Empa researcher Qun Ren is on the hunt for the secrets inside the polymer stents. Together with the St. Gallen hospital physicians, she investigated samples from ureteral stents of almost 90 patients. The use of a catheter or stent in the ureter is a common procedure, for example in the treatment of kidney stones. "If such a stent is used, however, symptoms and urinary tract infections occur rather frequently," says Ren. This was also seen with the patients she ►



BACTERIA
Empa researcher Qun Ren analyses microbiological samples in a microfluidic chamber from ureter stents under the microscope (above). Within a few hours, a small number of E. coli bacteria (center) grow into a biofilm (below) that covers the entire surface of a glass slide. [Colored microscope image]

Photos: Empa

examined: After a comparatively short period of about 3 weeks in the body, not only calcium crystals (from urine) were deposited in the tubes; the researcher also found bacterial accumulations in the samples. "Biofilms had formed on the surface of the material, from which we could cultivate living bacteria," she says.

THE CREATURE IN THE TUBE

And it is precisely with these biofilms that scientists hold what is probably the world's most successful living being in their hands: Bacterial accumulations embedded in a self-produced slimy matrix that behave like a single organism. And they have been around long before us: Biofilms can already be found in the oldest known fossils of Earth's history. Given their amazing survival strategies it is hardly surprising that they have since persisted and thrived under the worst of conditions such as in urinary catheters.

Thanks to a humid layer of biopolymers, the bacteria living together in biofilms are protected, mobile and connected to each other. They happily exchange useful genetic material, communicate via chemical signals and report to the surface when the deeper layers of the "flat share" suffer from hunger. Antibiotics and disinfectants hardly penetrate the film, and if necessary they send a group of pioneers to a new location and found further colonies, pretty much like a metastatic tumor.

SKILLFUL LIKE A GECKO

What is successful in nature can end badly in hospitals. The aim is, therefore, to develop new materials, for example for stents that reduce the risk of infection. "A key event in the formation of a biofilm is the moment when mobile bacteria attach to a surface," explains Ren. Some of the microorganisms use the same trick as geckos, which can cling to a glass pane upside down: They use van der Waals forces, interactions between their own molecules and those of the surface that is supposed to offer them a new home. Other examples coat the surfaces of tubes and stents with a suitable coating, which helps them to settle on the surface. "In order to fend off bacteria, we must thus prevent the process of attachment," says Ren.

The prerequisite for workable materials and coatings that resist germs is the seamless transfer of research results "from bench to bedside". A material can only prove itself if the analyses in the laboratory are as realistic as possible. Empa researchers have, therefore, developed a multi-part lab model, the conditions of which are as close as possible to those in the hospital.

> "Biofilms were there long before us and they are equipped with amazing survival strategies."

Potential novel catheter mterials are rinsed with liquids in a bioreactor, as in the case of a real urinary stent inside the body. All isolated microorganisms are examined using confocal microscopy, bacterial culture and genetic analysis. At the same time, the material's surface that is covered with calcium crystals is characterized using X-ray analysis. "We can only produce safe and highly efficient new materials that are resistant to bacterial biofilms if we know exactly what these microorganisms are capable of," said Ren.

The samples from the Cantonal Hospital in St. Gallen have now been used to show exactly what happens in the body with catheters made of conventional materials. Since all of these were patients with no signs of infection before the catheter was inserted and who carried the stent for only a short time in their bodies, all isolated biofilms were mild, as could be expected. However, it became clear that certain types of bacteria like to occur together. For example, some patients had harmful enterobacteria in their samples, while others had species of microorganisms such as lactic acid bacteria, which are thought to have a protective effect. The researchers will now investigate how these various "urotypes" are associated with the risk of hospital infection. They are also discussing the possibility of modifying surfaces differently according to certain subsets of patients. In the next step, the team plans to examine samples from long-term treatments and infected patients. ■

Further information on the topic is available at:
www.empa.ch/web/s404/

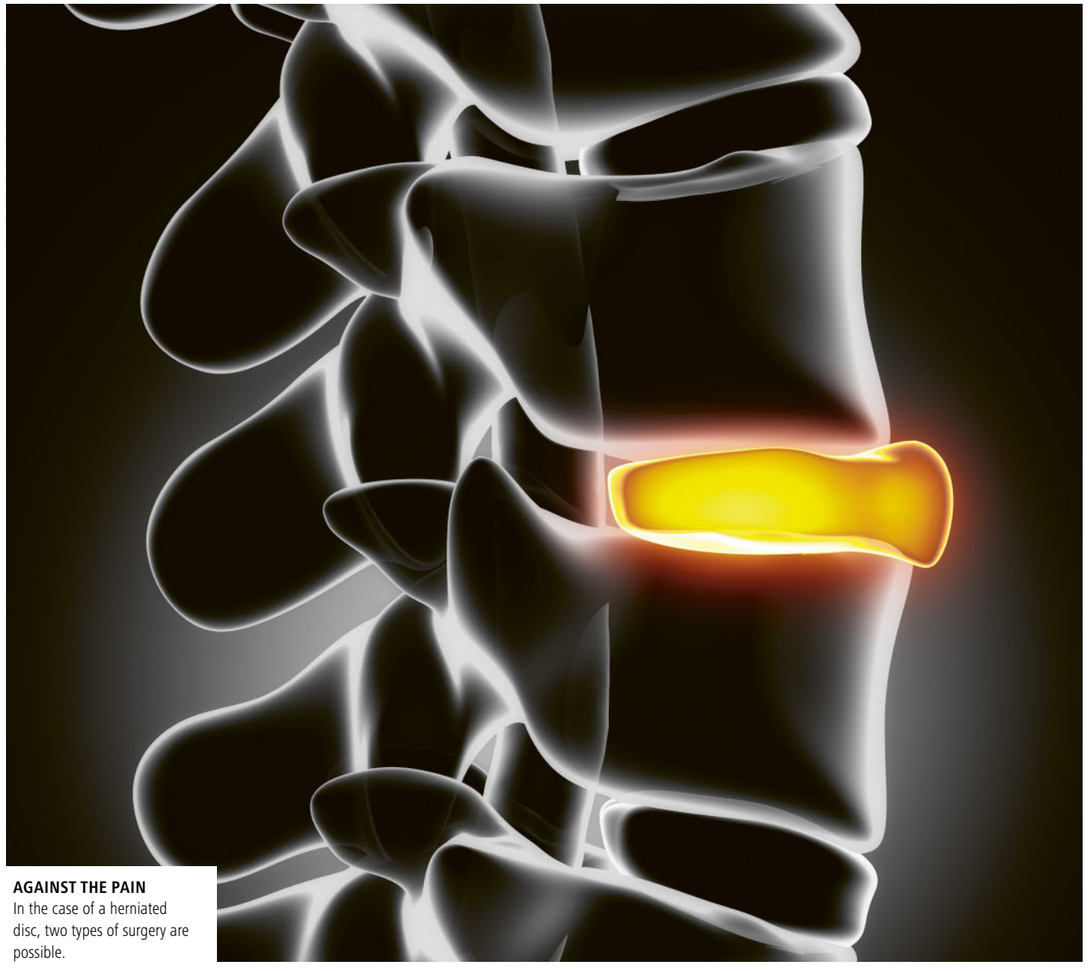


Photo: istock

AGAINST THE PAIN
In the case of a herniated disc, two types of surgery are possible.

DECISION-MAKING MADE EASY

A herniated disc is painful – and the most frequent cause of spinal surgery. But is the selected treatment always the right one? New research results show that the clinical criteria – the comparison of two static images – are often not sufficient to make the best decision for the patient.

Text: Karin Weinmann

Sudden back pain is often caused by a herniated disc. The intervertebral discs are a kind of buffer between the vertebrae and are heavily strained over the years. If they become brittle and break, parts of the tissue can extend outwards and press on the nerve or the spinal canal. This can cause severe pain. The lumbar spine is particularly often affected. The herniated disc often shrinks again on its own with the support of pain and inflammation inhibiting medication, but in more severe cases surgery is necessary.

RELIEVE OR STIFFEN?

There are basically two types of surgery that can be considered for a herniated disc:

One option is to remove the exuded disc mass in order to reduce the pressure on the nerve or the spinal canal. Thanks to microsurgery, this is now a minimally invasive procedure.

The second option is to fuse the affected vertebrae. Screws are inserted into the vertebral bodies and the two affected vertebrae are permanently fused with a metal construction. This is necessary when the vertebrae are strongly displaced against each other during movement. However, stiffening is a riskier, highly invasive procedure – and often the problem only shifts as a result: the following intervertebral discs are subjected to greater stress as a consequence and can also yield.

In order to decide which operation is necessary, doctors rely on X-ray images. Usually one image is taken in the upright state and another in the forward bent state. If the affected vertebrae shift strongly towards each other or even twist, fusion is necessary – if not, decompression can suffice. However, various studies have shown that this comparison of two static images is often not sufficient as a basis for a decision: up to one third of the patients who receive the simpler operation have to undergo subsequent surgery. At the same time, it can be assumed that not all patients in whom the vertebrae were fused required this surgical procedure. The problem: The images only show the initial and final state of the vertebral position – and not what happens during the movement itself.

DYNAMIC
The movement patterns of unstable intervertebral discs differ from patient to patient.

Photo: istock

DYNAMIC MOVEMENT PATTERNS ARE CRUCIAL

Researchers from the Mechanical System Engineering Lab at Empa and the Department of Orthopaedic Surgery at the University of Pittsburgh were now able to show that the vertebrae do not move linearly during movement. On the contrary: "Depending on the patient, very different move-ment patterns appeared," explains Empa researcher and co-director of the project, Ameet Ai-yangar. For the study, which won the ISSLS Prize in Bioengineering Science in 2018, the researchers produced dynamic images of seven patients with herniated discs and seven control subjects in the same age group in a continuous X-ray image while slowly tilting their upper bodies forward. From the images, the researchers calculated how the vertebrae moved in the sagittal axis of rotation and flat to each other. The results are remarkable:

It would be expected, as was confirmed in most of the healthy controls, that the sagittal angle of rotation and the vertical displacement increase uniformly during movement.

Paradoxically, however, in one patient, the vertebrae first shifted in the opposite direction to the movement and then back to the center – so while the initial and final positions looked as if the vertebrae were stable, the movement showed great instability. For this individual, decompression alone would not have been of much use, but fusion would have been necessary. The clinical analysis would have massively underestimated the instability in this person. This can be seen in the figures: if the researchers only compared the initial and final values of the images, a displace-ment value of just 0.4 mm was found. In the movement itself, however, the researchers observed a value of 4.6 mm – more than 11 times the traditionally calculated value.

> "Crucial are not the initial and final states, but how vortices shift relative to each other."

In other cases, vertebrae hardly shifted – however at first did rotate strongly into opposite direction and back again. Only in two of the patients did a movement take place that roughly met expectations. Overall, each of the examined patients achieved a maximum displacement of at least 1.8 mm. In the clinical calculation, however, a displacement of less than 0.4 mm was calculated for three of the seven patients.

TECHNOLOGY NOT YET PART OF CLINICAL ROUTINE

This shows that the current basis for decision-making on the type of operation is often insufficient – a dynamic assessment of the damage would be necessary. So simply replace the static X-ray machines with dynamic ones and the problem is solved? Unfortunately, it's not quite that simple: the technology required to create the dynamic images – socalled "Dynamic Stereo X-Ray" (DSX) systems – only exists in a few locations worldwide. And the calculations of the movements are very complex. "At the moment, the technology only exists in the research stage. However, we are in the early stages of transition – one day the devices could become part of everyday hospital life," explains Aiyangar. Until then, the researcher suggests, it might at least make sense to create and compare several X-ray images in different static states instead of just two images in end positions.

THERAPY INSTEAD OF SURGERY?

Aiyangar already has more ideas: He wants to investigate the benefit of therapy for herniated discs. 200 different muscle strands are involved in the movement and stabilization of the back. It is impossible to measure them all at the same time in order to find out which therapy offers the greatest benefit. "Modeling the complex system could contribute a lot to correct early intervention," says Aiyangar. With the right therapy, it is hoped, surgery could even be avoided altogether. ■

Further information on the topic is available at: www.empa.ch/web/s304/biomed

FLEXIBLE
Empa researcher Gilberto Siqueira demonstrates the newly printed nanocellulose circuit. After a subsequent drying, the material can be further processed.

Photo: Empa

WOOD ON OUR SKIN

Physiological parameters in our blood can be determined without painful punctures. Empa researchers are currently working with a Canadian team to develop flexible, biocompatible nanocellulose sensors that can be attached to the skin. The 3D-printed analytic chips made of renewable raw materials will even be biodegradable in future.

Text: Andrea Six

The idea of measuring parameters that are relevant for our health via the skin has already taken hold in medical diagnostics. Diabetics, for example, can painlessly determine their blood sugar level with a sensor instead of having to prick their fingers. Empa researchers, together with scientists from Canada, have now produced a novel flexible sensor that lies on the skin surface and is biocompatible because it is made of nanocellulose.

A TRANSPARENT FOIL MADE OF WOOD

Nanocellulose is an inexpensive, renewable raw material, which can be obtained in form of crystals and fibers, for example from wood. However, the original appearance of a tree no longer has anything to do with the gelatinous substance, which can consist of cellulose nanocrystals and cellulose nanofibers. Other sources of the material are bacteria, algae or residues from agricultural production. Thus, nanocellulose is not only relatively easy and sustainable to obtain. Its mechanical properties also make the "super pudding" an interesting product. For instance, new composite materials based on nanocellulose can be developed that could be used as surface coatings, transparent packaging films or even to produce everyday objects like beverage bottles.

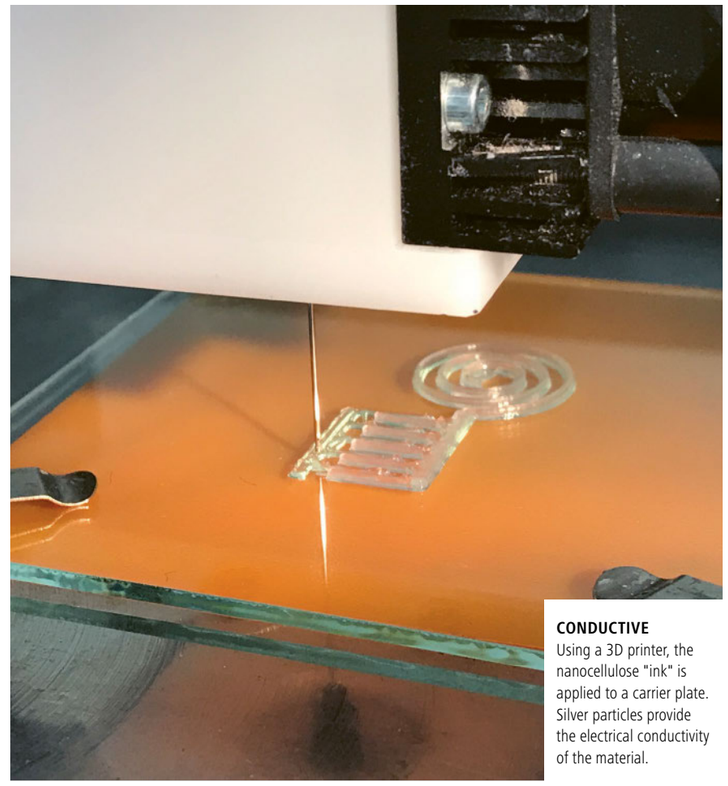
> "All in all, the tiny biochemistry laboratory on the skin measures only half a millimeter in thickness."

Researchers at Empa's Cellulose & Wood Materials lab and Woo Soo Kim from the Simon Fraser University in Burnaby, Canada, are also focusing on another feature of nanocellulose: biocompatibility. Since the material is obtained from natural resources, it is particularly suitable for biomedical research.

With the aim of producing biocompatible sensors that can measure important metabolic values, the researchers used nanocellulose as an "ink" in 3D printing processes. To make the sensors electrically conductive, the ink was mixed with silver nanowires. The researchers determined the exact ratio of nanocellulose and silver threads so that a three-dimensional network could form.

JUST LIKE SPAGHETTI – ONLY A WEE BIT SMALLER

It turned out that cellulose nanofibers are better suited than cellulose nanocrystals to produce a cross-linked matrix with the tiny silver wires. "Cellulose nanofibers are flexible similar to cooked spaghetti, but with a diameter of only about 20 nanometers and a length of just a few micrometers," explains Empa researcher Gilberto Siqueira.



CONDUCTIVE
Using a 3D printer, the nanocellulose "ink" is applied to a carrier plate. Silver particles provide the electrical conductivity of the material.

Photo: Empa

The team finally succeeded in developing sensors that measure medically relevant metabolic parameters such as the concentration of calcium, potassium and ammonium ions. The electrochemical skin sensor sends its results wirelessly to a computer for further data processing. The tiny biochemistry lab on the skin is only half a millimeter thin.

While the tiny biochemistry lab on the skin – which is only half a millimeter thin – is capable of determining ion concentrations specifically and reliably, the researchers are already working on an updated version. "In the future, we want to replace the silver particles with another conductive material, for example on the basis of carbon compounds," Siqueira explains. This would make the medical nanocellulose sensor not only biocompatible, but also completely biodegradable. ■

Further information on the topic is available at:
www.empa.ch/web/s302

DECEPTIVELY REAL

The human heart still poses great challenges to modern medicine. More than ten million people in Europe suffer from heart failure, and quite a few of them need a donor organ. Artificial heart pumps are used to bridge the waiting time, but complications are not uncommon. The "Zurich Heart" project, in which Empa is a partner, is developing solutions.

Text: Cornelia Zogg

Photo: istock

For many patients with heart failure, an artificial heart pump is a lifesaver – but one that often causes side effects. There is a risk of blood clots or a rejection of the foreign material, which can lead to severe immune responses. Researchers at Zurich University Hospital, together with col-leagues from the University of Zurich and ETH Zurich, therefore launched the "Zurich Heart" project back in 2011. The project involves physicians, engineers, biologists and materials scientists with the aim of developing common heart pumps further and at the same time co-ming up with new solutions to eradicate existing risks. Researchers from various universities and research institutes – including Empa – are working on new approaches in around ten subprojects.

EMPA INVOLVED IN SEVERAL PROJECTS

Several Empa teams are part of Zu-rich Heart and are working on a new generation of heart pumps that will be "camouflaged" in such a way that human immune cells cannot distinguish them from a real heart. Natural blood vessels – including the heart – are lined on the inside with endothelial cells that regulate the exchange between blood and the body's tissues. An artificial heart pump must thus have a surface, on which the body's own endothe-lial cells can settle. This tissue surface fools the blood into believing that it is not an artificial organ but a real heart. Researchers led by Eduardo Mazza, head of Empa's Experimental Continu-um Mechanics lab, professor at ETH Zurich and co-project leader of Zurich Heart, have succeeded in developing a membrane that offers optimal condi-tions for the colonization of endothelial cells. This membrane not only provides a suitable basis for the necessary cells, but also dampens the natural pumping movement – if the contractions are too strong, cells can hardly hold on to even the most temptingly prepared surface and are washed away by the blood.

HEXAGON SOLUTION

Aldo Ferrari, a researcher at ETH Zurich and Empa, has developed a substrate with a special structure that makes endothelial cells feel comfortable on the membrane so that they can hold on to it. Like a honeycomb, individual hexa-gons line up in a row and offer the cells an optimal space to nest in them and not be washed away. The method has proven successful; the researchers were able to confirm in both in vitro and in vivo experiments that the cells adhere to the membrane even after several pumping movements and thus provide a potential solution for the development of more biocompatible heart pumps. Despite these successful initial trials further challenges remain, however. The aim is to not only coat the membrane but also the entire inner surface of the pump with the hexagonal structure.

> "The surface of the tissue is pretending to be a real heart."

NEXT STEPS ALREADY INITIATED

Zurich Heart is now entering its second phase. "We want to translate some of the solutions devel-oped within Zurich Heart into clinically relevant products," says Mazza. This could take several years, though, so Zurich Heart has no time limit. The first generation of PhD students involved in Zurich Heart have now completed their theses and produced numerous publications and pa-tents with positive feedback. "With our hybrid membrane project, we have come much further than we had originally expected," says Mazza. With his team he is already planning the next steps: The longterm behavior of such an "endothe-lialized" heart pump has not yet been investigated, and Mazza now wants to address this issue. After all, such a heart pump has to withstand several mil-lion beats. "Our motivation has increased even further in recent years", Mazza concludes. He is confident that the upcoming projects will yield important knowledge as well as practical solutions for and around the human heart. ■

Further information on the topic is available at:
www.empa.ch/web/s604/zurich-heart

WHY DO BONES FAIL?

Can analytical methods from materials science help us better understand human bones? A research team at Empa in Thun is pursuing precisely this approach.

Text: Karin Weinmann

Osteoporosis is a widespread disease. Every third woman and every fifth man are affected by bone loss with advancing age. A frequent consequence of this is a fracture of the femoral neck – a painful injury that massively impairs the quality of life of those affected. Patients must reckon with longterm loss of mobility. Long bed rest and the associated often poor general condition even lead to an increased mortality rate.

The disease causes a loss of bone mass due to an imbalance in the natural remodelling process in the tissue and changes in bone quality. These changes affect the microstructure, density of microcracks and tissue properties.

Bones have an extremely complex structure. If, for example, a thigh bone is sawed open, it can be seen that it consists of a hard outer layer and a porous filling. Under the microscope, cylindrical structures of concentric lamellae are visible inside the hard shell, arranged around central blood vessels. These individual lamellae are only a few thousandths of a millimetre thick and consist of a type of natural fibre composite material: collagen fibres in which mineral particles are embedded, embedded in a protein-containing mineral matrix. The higher the mineralization, the stiffer and more fragile the bone. This hierarchical structure allows the bones to be robust and resistant despite their relatively low density. When bones fracture, it is therefore not sufficient to consider only the density and structure of the bone at the macro level – mechanisms in all scale ranges are responsible for the fracture.

MATERIAL ANALYSIS FOR BONE

A research group at Empa in Thun led by Jakob Schwiedrzik aims to gain a better understanding of bone failure at the lamella level. "If one only considers bone density, as is usually the case in clinical practice today, the risk of fracture for patients can be predicted relatively well on average. In individual cases, however, the results may differ considerably and the effective fracture risk may be incorrectly assessed," explains Schwiedrzik. "We hope that our research will enable us to make more accurate predictions for each individual patient in the future".

The researchers are using methods that are actually at home in materials research: They subject even the smallest samples of bone material containing only a single lamella to tensile and com-pression tests. They are investigating how the material fails and how the measured properties are related to the underlying microstructure. In microstructure analysis, Raman spectroscopy and transmission electron microscopes are used – highly complex instruments that make it possible to precisely observe structural changes in the test objects.

"At the moment, the production and testing of a single bone sample still requires a great deal of time – especially for tensile tests," explains Schwiedrzik. To do this, samples with a defined geometry must first be produced from the material used using a focused ion beam. In order to be able to analyze more samples in less time in the future and to enable statistical evaluation of the experiments, a large part of the current work consists of automating the sample heart position and developing our own measurement setups.

> "When bones break, it is not enough to look only at density and structure at the macro level."

PERSONAL DIAGNOSIS

The question of how the methods developed can be used for clinical studies is exciting. A project is currently underway involving researchers from the Inselspital Bern, the University of Bern, ETH Zurich and Empa. Bone material from patients who have received a hip implant is being investigated. This material will be analysed on several length scales. The aim is to collect data on micromechanical properties, microstructure, cell activity and metabolism and to correlate these with clinical findings and patient data using machine learning. The resulting database will make it possible to quantify the bone quality of a patient and include it in the diagnosis. ■

Further information on the topic is available at: www.empa.ch/web/s206

THE WAY TO SCIENTIFIC INDEPENDENCE

How does a young researcher get his own research group? Of course, an exciting research idea is needed – but if it doesn't fit into an existing topic, it can be difficult. The Ambizione Programme of the Swiss National Science Foundation (SNSF) is designed to help young researchers take the first step towards scientific independence and establish their own research group and research area.

The Empa research group led by Jakob Schwiedrzik has also become possible thanks to an Ambizione grant. The research topic combines two fields of knowledge of the young researcher: As a mechanical engineer, he is interested in the development of filigree measuring instruments – bone has been a central topic for him since his diploma and doctoral theses. The grant covers three years of research for Schwiedrzik and one doctoral student.

FEMORAL NECK FRACTURE
The femoral neck fracture is a frequent consequence of osteoporosis. Empa researchers are using test methods from materials analysis to investigate when the microstructure of bones fails.

Photos: istock

SCARS: GONE WITH THE FOAM

Poorly healing wounds and severe scarring are more than just a cosmetic problem; they can significantly impair a person's mobility and health. Empa researchers have now developed a foam that is supposed to prevent excessive scarring and help wounds to heal quickly. An essential ingredient: the yellow ginger tumeric.

Text: Andrea Six

SMOOTHING FOAM
Healing of wounds in human skin is a complex process. A novel polymer foam is designed to help heal severe injuries without excessive scarring.

Photos: John Gibbons for Unsplash

A scar on the elbow that is strained with every movement, or a foot, on which a wound simply does not want to close – poorly healing injuries are a common cause of health restrictions. And although millions of people are affected in their everyday lives, the complex process of wound healing is not yet fully understood, let alone controllable. Empa researchers have, therefore, developed a foam that is supposed to be placed in skin wounds to support and optimize the natural healing process. With the "Scaravoid" project, Markus Rottmar and his team in Empa's Biointerfaces lab have taken a step in a new direction. "Traditional treatments target individual factors of wound healing, such as oxygen supply or moisture regulation, and only produce an inadequate tissue response," explains Rottmar. Within "Scaravoid", which is sponsored by the Gebert Rüf Foundation, the healing process is to be understood and supported more comprehensively.

PERFECTLY ORCHESTRATED

It is clear so far that a perfectly orchestrated interaction of numerous individual factors in the body is necessary in order to close a skin injury and transform it into healthy tissue. Cells must be attracted so that a well-dosed inflammation cleanses the wound. In order for the cleaned defect to close, new tissue grows, which is then transformed into functional skin. As astonishing as the body's self-healing powers are, a malfunction can disturb the balance and lead to excessive scarring or inadequate wound closure. In older people or diabetics, for instance, the risk that the complex cascade may be impaired is increased. With "Scaravoid", the Empa team is now intervening at several stages in the process thanks to a biological polymer scaffold that is already approved for certain medical uses. In a high-pressure reactor, the polymer is expanded using supercritical carbon dioxide (CO_2), whereby the pore size can be finely tuned by varying pressure and temperature. Once placed in a wound, the polymer scaffold is to begin its work: With its open-pored architecture, it offers immigrant cells a suitable structure to settle in. Since the foam is biodegradable, the cells disintegrate the polymer structure and produce a new scaffold according to their needs to form a new, functional tissue.

NATURAL BALANCE

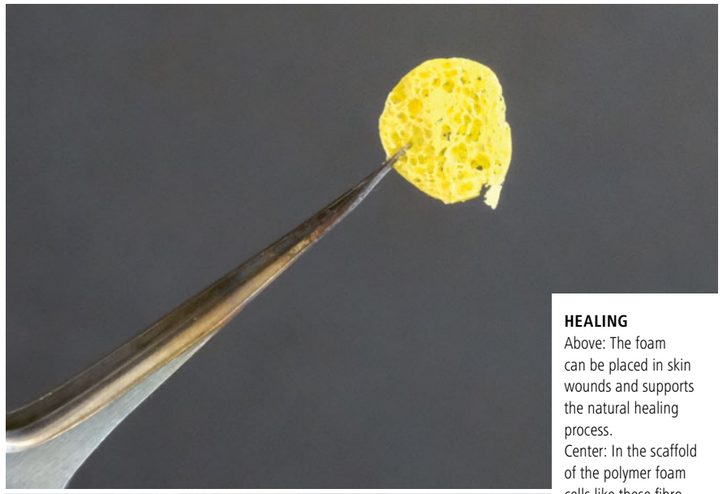
In order to prevent undesired scarring, the polymer scaffold is equipped with a bioactive substance that is supposed to inhibit scarring. The researchers use a substance that is known way better ▶

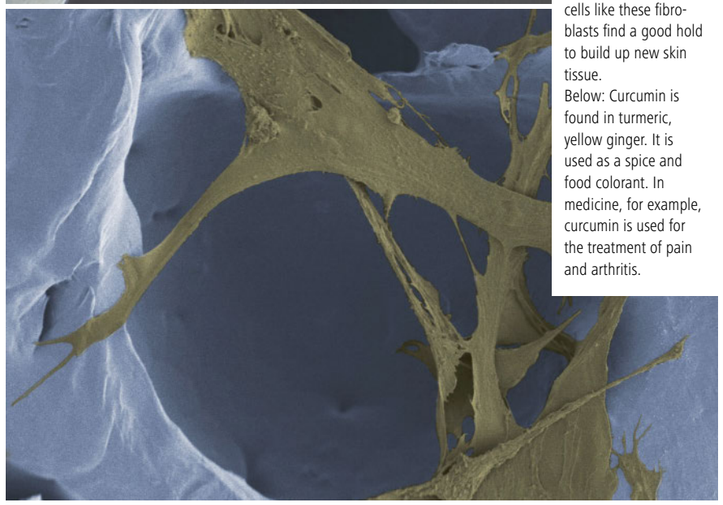
from the kitchen than from the hospital: curcumin. The powder of the turmeric root, also known as yellow ginger, is an E100 additive that dyes foods such as mustard or margarine and contributes to the taste of curry powder. Curcumin, on the other hand, is an interesting pharmacological component because of its anti-inflammatory characteristics. The Empa researchers added curcumin to cell cultures and found that the production of biomarkers typically found in scars is significantly reduced.

"A perfectly orchestrated interaction of multiple factors is necessary to close a wound and transform it into healthy tissue."

In the foam, curcumin is bound inside the scaffold and is gradually released. It controls the behavior and function of the cells that migrate into the scaffold and thus supports the natural balance of wound healing. What is currently being analyzed in lab tests in the form of small polymer discs will be used in clinical trials in the form of larger polymer membranes. The membranes can be cut to size by the physician and placed into the wound. The membranes are intended to optimize wound healing, particularly in the event of serious injuries, such as those following traffic accidents or severe burns. ■

Further information on the topic is available at:
www.empa.ch/web/s404/





HEALING
Above: The foam can be placed in skin wounds and supports the natural healing process.
Center: In the scaffold of the polymer foam cells like these fibroblasts find a good hold to build up new skin tissue.
Below: Curcumin is found in turmeric, yellow ginger. It is used as a spice and food colorant. In medicine, for example, curcumin is used for the treatment of pain and arthritis.

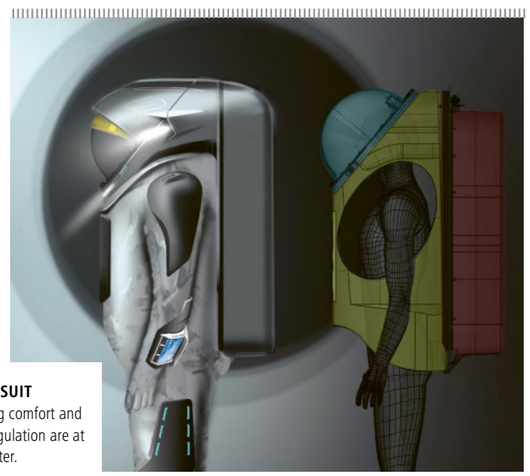
Photos: Empa, Pixabay

EMISSIONS PUZZLE SOLVED

MEASURING STATION
The increase in CFC-11 emissions was noted here: The Gosan measuring station in Korea.

The chlorofluorocarbon CFC-11 is considered to be one of the main substances responsible for the degradation of the stratospheric ozone layer, which protects us from the UV radiation of the sun. Measurements show, that the atmospheric CFC-11 concentration is rising again despite a worldwide ban. But where do they come from? An international research group involving Empa was able to solve this mystery: CFC-11 emissions could clearly be traced back to eastern China. Illegal foam production facilities are suspected.

More information can be found at: www.empa.ch/web/s604/cfc-11



MARS SUIT
Wearing comfort and heat regulation are at the center.

COMFORTABLY TO MARS

In cooperation with Empa, the Austrian Space Forum (ÖFW) is developing the "Serenity" space suit – a prototype for a Mars suit. The two partners have now signed a cooperation agreement to work even more closely together on the development of the prototype. The cooperation focuses on optimizing the wearing comfort and heat regulation system of "Serenity" based on body models developed at Empa.

More information can be found at: www.empa.ch/web/s604/mars-suit

Images: ÖWF/Bernhard Kaliauer Design Studio; Kyungpook National University

EFFICIENCY
Empa researchers break their own world record.

NEW WORLD RECORD FOR FLEXIBLE THIN-FILM SOLAR CELLS

Never before has such an efficient flexible CIGS solar cell been created. Empa researchers achieve an efficiency of 20.8% for the first time – breaking their own record from 2013.

More information can be found at: www.empa.ch/web/s604/cigs-record-2019

HAZARDOUS FOR THE LUNGS

In a unique experiment, Swiss researchers have investigated the effect of exhaust particles from aircraft turbines on human lung cells. The cells reacted most strongly to particles emitted from the ground when the aircraft is idling. It was also found that the cell-damaging effect can only be compared to the effect of particles from petrol and diesel engines to a limited extent.

More information can be found at: www.empa.ch/web/s604/aircraft-particles

PARTICLES
The greatest risk of damage is not at take-off but at idling speed.

POLLUTED
According to various researchers, there is practically no place in the world left free of plastic anymore.

MICROPLASTICS IN FRESHWATER

The term microplastics is familiar to most people, but its dangers are virtually unexplored. Empa researchers have now carried out the world's first risk assessment for microplastics in lakes and rivers. The study concludes that aquatic organisms are not (yet) acutely endangered in Europe.

More information can be found at: www.empa.ch/web/s604/mikroplastik

Images: Flisom, istock, Empa

READY TO RECYCLE?

The number of registrations of electric cars is rising sharply. But where to put old batteries? The association of Swiss car importers, "auto-schweiz", is striving for a recycling solution for the entire industry. Empa experts support it.

Text: Rainer Klose

Photo: istock

Crunching, the serrated metal roller eats its way into the battery modules, crushes the plastic frames, slits the silver foils of the lithium polymer packs, and shreds everything into pieces. The result is a fine powder. If it is successively thrown into several acid baths, salts and oxides are formed, from which new batteries can be built. The YouTube video "Neue Recycling-Methode für Batterien aus Elektroautos", published in May 2019, shows something that had never been seen so far: the shredding of lithium-ion batteries. This process seemed impossible, because these batteries are flammable. A little bit of electrical voltage, a single spark is enough, and everything goes up in flames. The German company Duesenfeld, therefore, completely discharges the batteries and fills the airtight shredder with nitrogen. The flammable electrolyte liquid is evaporated and pumped out before the powder is removed. In this way, 96 percent of all materials in the battery can be recycled.

Around 40,000 electric cars and plug-in hybrids with lithium-ion batteries are currently driving on Swiss roads – just under one percent of the entire vehicle fleet. There will soon be more. In the first three months of 2019, the share of new registrations already rose to 5.3 percent. And this is just the beginning – a whole series of high-performance electric cars will be launched on the market this year: Audi e-tron, Mercedes EQC, Peugeot e-208. These models will meet the Tesla Model 3, which has been leading the registration statistics since March. In 2020, the VW Group will launch its first electric mass-market automobile, the VW iD.3. So it is high time to think about what happens to the batteries when these cars crash or are scrapped at the end of their lives.

A RECYCLING SYSTEM FOR CAR IMPORTERS

The association "auto-schweiz", which represents most Swiss car importers, is well aware of this challenge. In 2018, car importers, therefore, turned to Empa to calculate the cornerstones of a recycling system for car batteries. Empa had already advised other industry associations like Swico on the recycling of electronic devices and computer technology. However, unlike electronic products, no early recycling fee has yet been charged for cars. auto-schweiz is striving for an industry solution and has commissioned the Swiss Auto Recycling Foundation to develop such a solution. Since ▶

1992, this foundation has been responsible for the dismantling and recycling of end-of-life vehicles in Switzerland.

Empa researcher Rolf Widmer and his colleagues from Empa's "Technology and Society" lab have been cooperating with the Auto Recycling Foundation on this project since March 2019. They analyze recycling systems in neighboring countries, examine costs and the ecological footprint and make model calculations in order to estimate the future quantities of old batteries – and, finally, recommend appropriate strategies.

"Traction batteries of vehicles damaged in an accident can burn suddenly and are treated as hazardous goods thus far."

HOT OR COLD RECYCLING?

Most lithium-ion batteries are not cold shredded, as with the Duesenfeld method mentioned at the beginning; instead they are burnt in an oven before being ground. Market leader is the Belgian company Umicore. During hot recycling, the thin copper foils of the battery melt and, together with cobalt and nickel, form an alloy that can be recycled. However, the battery's lithium, graphite, liquid electrolyte and aluminum burn and end up in the slag. They are lost for reuse.

In addition to hot Umicore recycling and cold shredding under inert gas, there are other automated dismantling methods. Batrec Industrie AG, a Swiss battery-recycling specialist, shreds some batteries in a wet environment to prevent fires. The Empa experts will compare all these methods.

THE TRANSPORT PROBLEM

However, the search for the best recycling system is not only about shredding, but also about building a supply chain. "Traction batteries of vehicles damaged in an accident can burn suddenly and have to be transported as hazardous goods in special containers thus far," explains Daniel Christen, Managing Director of the Swiss Auto Recycling Foundation. This is costly and time-consuming. Christen is looking for a cheaper solution to "disarm" batteries and deliver them to disposal companies.

There are already approaches around: Blubox Trading AG in Birrwil, for instance, uses the "Firebox" from a Dutch manufacturer. The Firebox is a freight container with a built-in fire extinguishing system that can hold an entire car or a larger charge of "disarmed" batteries.

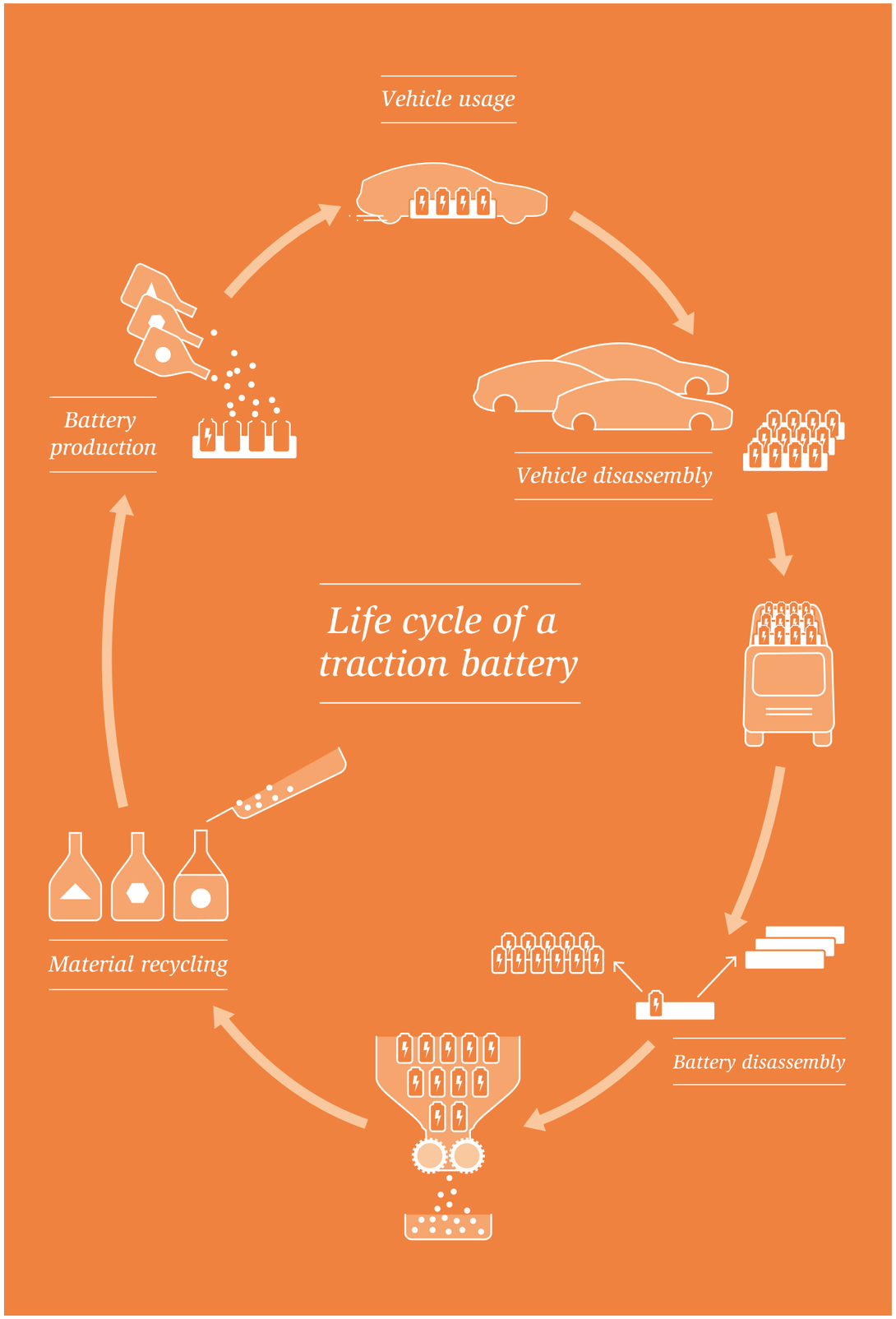
Last but not least, the forwarding agents and car recyclers must be trained so that decommissioned electric cars do not become hazardous. There is already a database for rescue workers that provides this kind of information: On a tablet, the firefighter enters the number of the license plate and can identify an electric car on the spot. The tablet shows, how he has to disconnect the battery. With the same information, electric cars could also be dismantled safely.

MANY QUESTIONS STILL UNANSWERED

Nevertheless, there are still many open questions that need to be answered before a recycling system can be set up. How will the market for used batteries develop? Will it one day be worthwhile repairing exhausted battery packs with new modules and putting them back on the market – similar to refurbished engines or gearboxes? Will old car batteries rather become stationary solar power storage units in their "second life"? How long will it take for decommissioned batteries to reach the recycling companies? Does Switzerland need large recycling capacities at all, or will car manufacturers abroad collect and recycle most of the batteries themselves? Much will depend on the market prices of the raw materials, on the value of lithium, cobalt, nickel and graphite, on the price and performance of new batteries, but also on politics, which can set the framework conditions and issue regulations.

In any case, the good news is: Electric cars are not a recycling problem. All steps of the recycling process are technically feasible. And a number of specialists are already working on it. ■

Further information on the topic is available at:
www.empa.ch/web/s506/



Graphic: Hug & Dorfmüller Design AG

A CLEVER DISTRIBUTION

Our energy system is changing: The permanent availability of energy in the right place at the right time is becoming more demanding. At the same time, digitalization offers us new tools for better controlling energy flows. A new joint energy research platform of ETH Zurich, the Paul Scherrer Institute (PSI) and Empa – ReMaP – aims at contributing to a better understanding of interconnected future energy systems.

Text: Stephan Kälin

On a sunny summer day what do we do with solar power if it cannot be used directly? Which storage solutions can (and should) be used? When does a conversion into hydrogen – or any other energy carrier, for that matter – make sense, and what does this mean for the grid? The megatrends of today's energy research are well known: Energy production is becoming increasingly decentralized. Electricity is becoming more and more important – in mobility but also for heating. Digital solutions for measuring and controlling energy flows and the inclusion of Artificial Intelligence (AI) generate new opportunities for reducing energy consumption and for an optimized distribution.

With these trends in mind, energy researchers at ETH Zurich, the Paul Scherrer Institute (PSI) and Empa are working on the design of a future energy system. In the last few years, the energy research platform "ehub", the mobility demonstrator "move" and the research and innovation building "NEST" have been installed at the Empa campus in Dübendorf. Taken together, these platforms form a living district that allows new technologies to be implemented, operated and validated in a real-world environment. At the same time, PSI in Villigen has created the "Energy System Integration" (ESI) test platform, which also deals with new solutions for storing and converting energy. Led by ETH Zurich's Energy Science Center, these infrastructures will be integrated in a new research platform, ReMaP (Renewable Management and Real-Time Control Platform), and brought to a new level. A digital model of all facilities will make it possible to simulate the researchers' ideas before they are actually implemented. ReMaP was launched at the end of 2018 and is now being developed step by step.

BRINGING NEW CONCEPTS TO THE MARKET FASTER

"By connecting the platforms and combining the research data, we are creating new opportunities for energy research from a systemic perspective," says Philipp Heer, Head of ehub and responsible for the ReMaP project at Empa. "The actual implementation of innovative approaches on the research platform is intended to help these approaches to be established in the energy market more quickly and without risk".

Ten research projects are already underway. One of them, for instance, combines the stationary batteries in NEST with the Power-to-Gas system at PSI In order to investigate the optimum interaction of these storage solutions for surplus electricity. Another project is investigating the question of what an individual energy consumer – such as a tenant – considers more important: his privacy or minimizing his energy expenses. Smart meters and storage devices allow insights into consumer behavior, which can be used to optimize the power grid. A team led by ETH Zurich researcher Gabriela Hug has developed a local energy store with a "protection algorithm". The consumer decides for him-/herself whether he or she wants to optimize energy expenses while at the same time disclosing his/her consumption, or whether he/she wants to protect his/her privacy by having the storage system conceal the energy consumption. This exemplifies how many different levels and interdependencies the transformation of our energy system encompasses and that eventually not only technological solutions but also user acceptance will be crucial. At the end of the day, researchers can only draw conclusions about this "human component" if novel concepts and ideas are implemented in a real-world environment such as the research platforms combined in ReMaP.

ReMaP is supported by the Swiss Federal Office of Energy (SFOE) and the ETH Foundation. ReMaP is open to other universities, research institutes and industry. ■

Further information on the topic is available at:
www.empa.ch/web/s604/remap

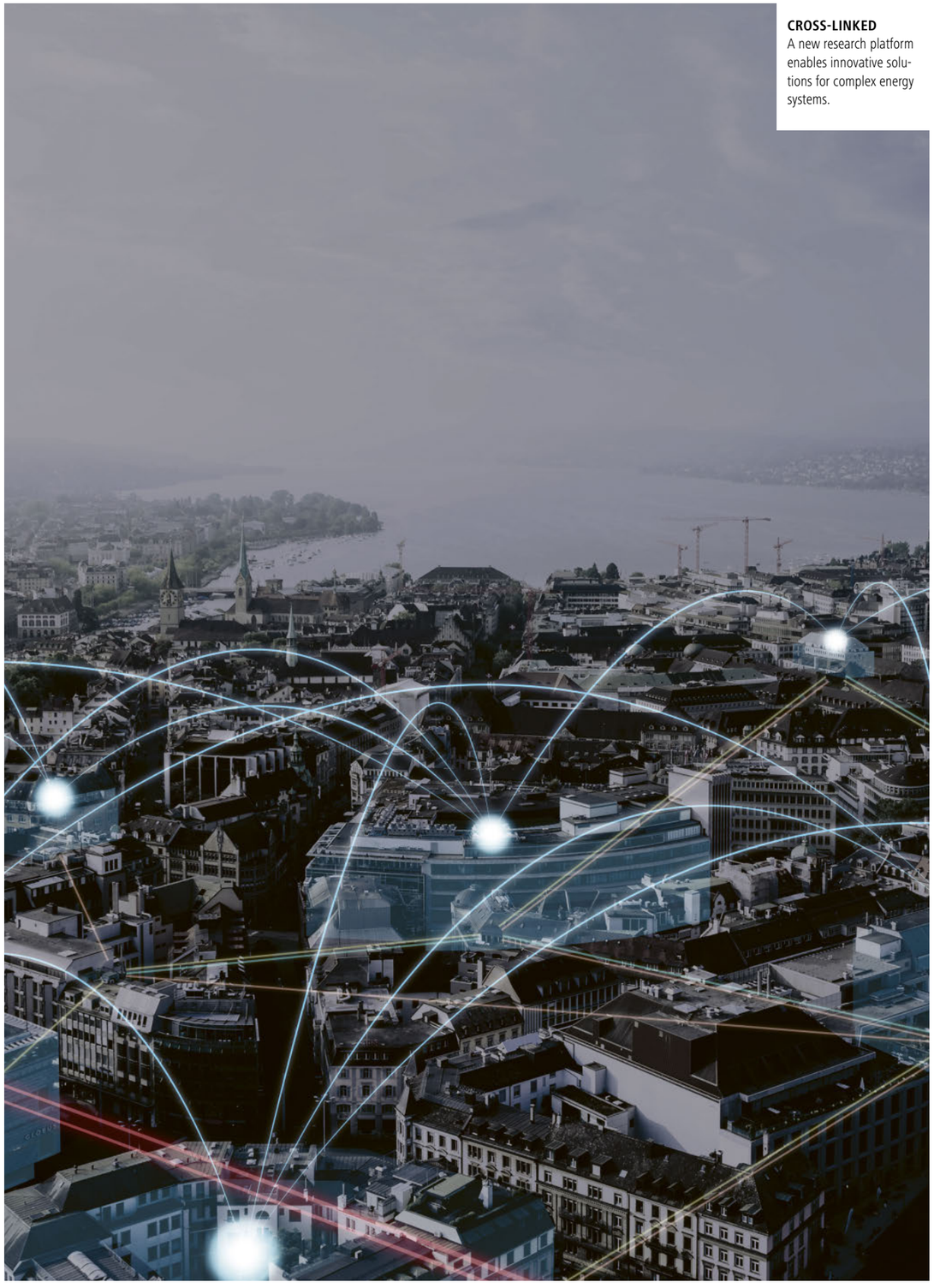


Photo: ikonaut

CROSS-LINKED
A new research platform enables innovative solutions for complex energy systems.

WIND POWER FROM THE SKIES

To harvest wind energy, you don't necessarily need rotors on steel masts – light kites on thin ropes can do the same. The Empa spin-off TwingTec has been researching this technology for some time now. Last autumn, it was possible for the first time to start, generate electrical energy while flying and then land again, all in the specified level of automation. Commercialization is now within reach.

Text: Rainer Klose

Anyone who has ever steered a child's kite knows the feeling: the wind grips the kite and pulls the string. The rope is quickly tensioned, the pulley rotates between the fingers and is difficult to control. The question arises: Could this wild energy not only be used to play, but also to generate electricity?

Rolf Luchsinger has proven that. He is CEO of Empa's spin-off TwingTec, founded in 2013. This makes TwingTec one of the first companies to develop airborne wind power plants – and places it one step ahead of some of its competitors. The young company employs nine people at its headquarters in Dübendorf.

ASCENDING AGAIN AND AGAIN

The idea behind the project is simple, but the practice is tricky: meteorologists know that at a height of 500 meters wind power is up to eight times stronger than at a height of 120 meters – which is the hub height of modern wind turbines. A kite could make use of this strong wind if it screws its way up in circles and pulls a rope from a pulley. A generator that produces electricity is connected to the axis of the rope pulley. As soon as the rope has been unwound, the kite glides back towards the ground station; in the meantime, the rope is wound up and the ascent begins anew. "The big challenge is not flying itself," says Luchsinger. "The problem is to take-off and land automatically. After all, the kite power station should be able to supply electricity without being controlled by humans.

AUTOMATED FLIGHT SUCCESSFUL

IIn autumn 2018, this was exactly what happened on the mountaintop of the Chasseral in western Switzerland. TwingTec prototype T28, a device with a wingspan of three meters, started from its base vehicle, climbed up into the air, circled autonomously for 30 minutes, produced electrical energy and finally landed safely on the launch platform. Now comes the next step: continuous power generation for customers. ▶

TWINGTEC
Successful test flight on the heights of the Chasseral in autumn 2018: TwingTec prototype T 28, a device with a wingspan of three meters, took off independently from its base vehicle, climbed into the air, circled autonomously in the air for 30 minutes, produced electrical energy and finally landed safely again on the launch platform.

Luchsinger's team is currently working on the T29 prototype, which is scheduled to be in operation for a longer period of time at the Chasseral in autumn 2019. T29 will not only automatically take off and land, but will also generate up to 10 kW of electrical power and feed it into the grid. BKW, a utility of Berne, is in charge to transmit the experimental wind power to the first consumers.

The route from the first sketch to the first kilowatt-hour of grid electricity was long and winding. In the beginning, there was the idea of using a kite reinforced with compressed air, similar to kite surfing. Research on a number of prototypes led to a structure with rigid wings. Steering with several ropes was also discarded in favor of a control system with flaps like an airplane. TwingTec uses small rotors for take-off and landing, similar to a drone. In 2014, TwingTec filed a groundbreaking patent for the take-off and landing technology of the energy kite, which has since been approved in several countries.

> "Wind power is not suitable for densely populated areas. Potential customers rather are mining companies, remote settlements and islands."

A glance at the numerous competitors shows just how promising energy kites could soon be. In Europe alone, ten start-ups and several teams from universities and technical colleges are developing solutions for this type of energy generation. They are all members of the Airborne Wind Europe association, which organizes a major conference every two years. The next one will take place in Glasgow in mid-October.

FOUNDER
Rolf Luchsinger, CEO of TwingTec, alongside prototype T 29, which will be feeding electricity into the grid for the first time.

ON THE WAY TO COMMERCIALIZATION

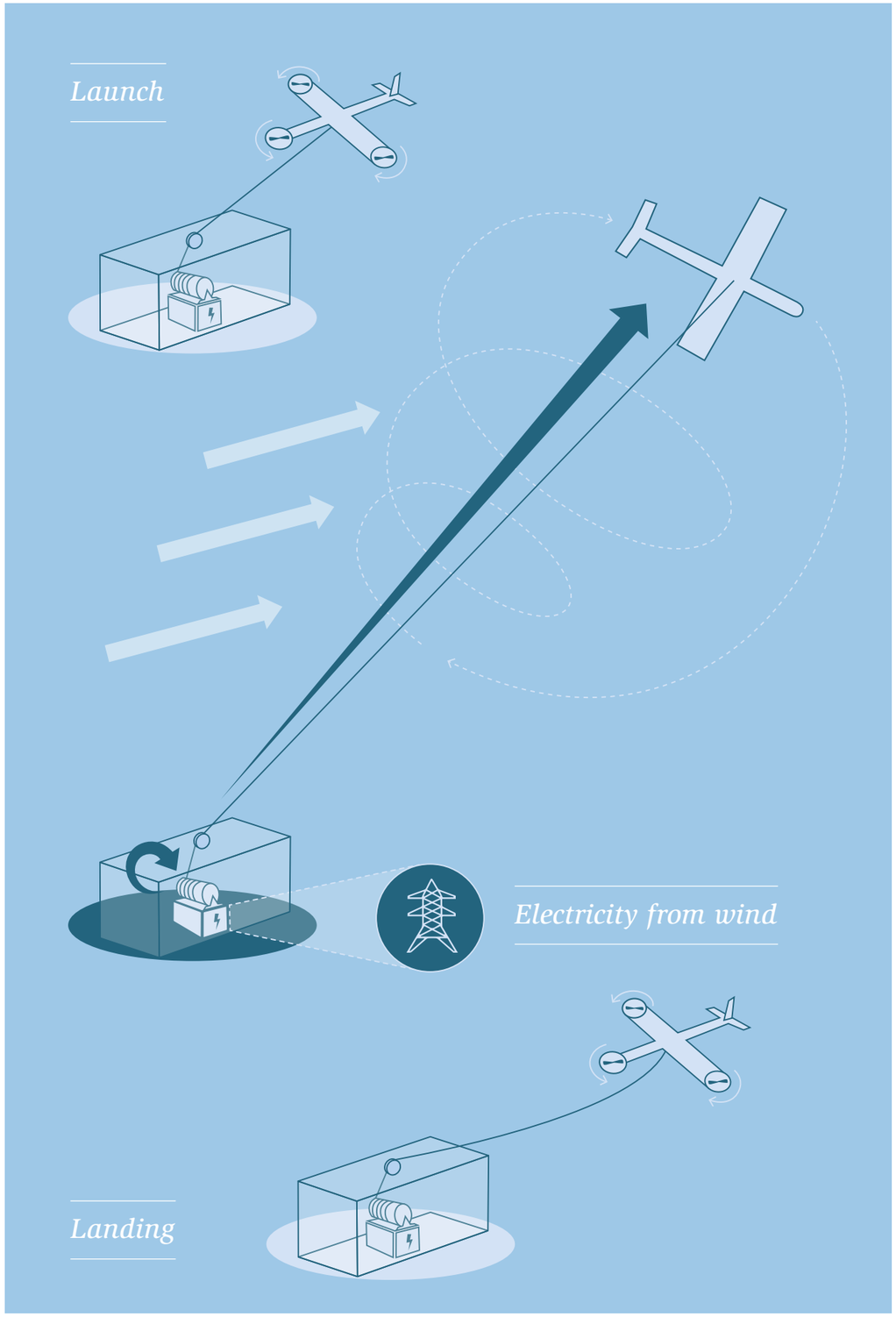
Therefore, TwingTec must not take too much time and is preparing for the next step. The findings from the flight tests with the T29 will soon lead to the first series product: the TT100, an energy kite with a wingspan of 15 meters. Placed on a standard shipping container, the kite is to take off and land automatically and generate up to 100 kW of electrical power – which would be sufficient for 60 single-family homes.

However, in the Swiss mainland you will probably never see energy kites. "Wind power is not suitable for densely populated areas," says TwingTec CEO Rolf Luchsinger. Customers for this sustainable form of energy generation rather live in remote areas. "We are talking to mining companies, mayors of remote settlements and people on islands. Today those places mostly use diesel generators that emit exhaust gases and noise. Besides of that, diesel fuel has to be delivered at great expense to these places." Autonomously working TwingTec kites could save diesel and take over the entire energy production in the medium term. In the long term, however, Luchsinger has even bigger plans: to build floating wind farms on the sea with his energy kites. There is plenty of space and wind, and energy-kites won't bother anyone. This is precisely what wind energy needs to speed up the energy revolution.

A lot of capital will be needed to start series production. Prototype T29, which is to fly on the Chasseral in autumn, got financial support by the Swiss Federal Office of Energy (SFOE). However, private investors and partners from the energy industry are now being sought for the commercialization phase coming up, so that the enormous potential of wind power can finally be exploited in full scale. ■

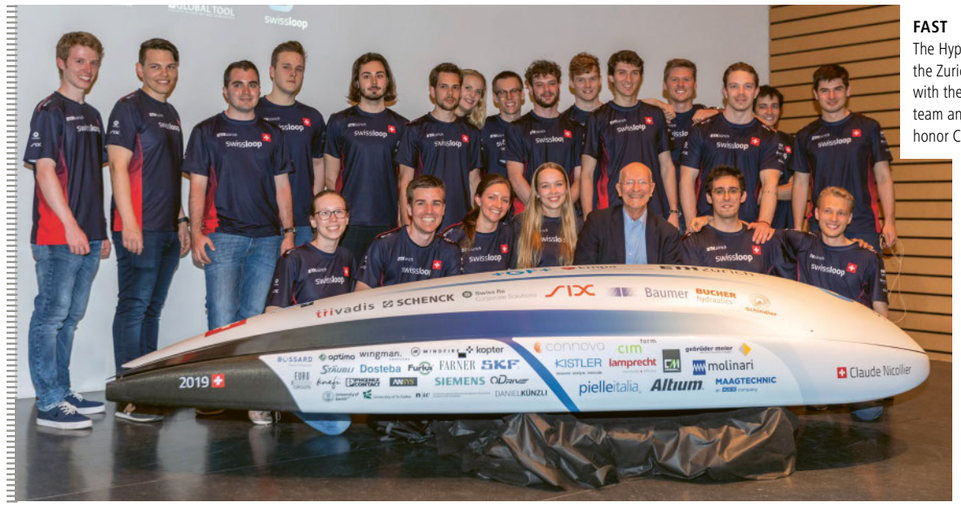
Further information on the topic is available at:
www.twingtec.ch

Photos: TwingTec, Empa



Graphic: Hug & Dorfmüller Design AG

SWISSLOOP RELIES ON CLAUDE NICOLLIER



FAST
The Hyperloop Pod of the Zurich students with the development team and guest of honor Claude Nicollier

On 21 July, Swissloop, an association of students from ETH Zurich and other Swiss universities, will again compete against teams from all over the world at the international Hyperloop Pod Competition in Los Angeles. At Empa, Swissloop presented its completely new Pod to the public for the first time. A great honor for the inventors: Claude Nicollier himself personally took the opportunity to accompany the transport capsule named after him at its inauguration.

www.empa.ch/web/s604/swissloop-pod

TWO NOMINATIONS AND ONE AWARD

For 13 years, the building foundation has been committed to young engineers in the construction industry – including the awarding of the "Building Award" for remarkable and innovative engineering achievements in construction. This year, two Empa projects were nominated for the award in the "Research and Development" category: The shape memory alloy "memory steel" and the modular research and innovation building NEST by Empa and Eawag. The NEST team received the award at the KKL Lucerne.

www.empa.ch/web/s604/building-award

NEST
Carina Doll, Eawag, and Peter Richner, Deputy Director of Empa, accept the Building Award.

Photos: Empa (2), Swissloop

CREATIVE
Still life with fruit spy combines work of art and science.

RESEARCH NEEDS CREATIVITY

Natural science and art are closer than you might think. Empa researchers supplied three works of art for the "Artsci 2019" art and science exhibition at ETH Zurich. The audience and experts were enthusiastic about the imaginative materials researchers. "The fruit spy that came from the cold" by Professor Thijs Defraeye was even awarded the audience prize.

www.empa.ch/web/s604/artsci2019

EVENTS
(IN GERMAN)

26.–28. AUGUST 2019
Tagung: 2nd Swiss & Surrounding Battery Days
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/swissbattery
Empa, Dübendorf

6. SEPTEMBER 2019
Kurs: Klebetechnik für Praktiker
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/klebetechnik
Empa, Dübendorf

12.–13. SEPTEMBER 2019
Tagung: Welcome to nano-scale: from science to health application
Zielpublikum: Wissenschaft und Industrie
www.empa-akademie.ch/nano-scale
Empa, Dübendorf

24. SEPTEMBER 2019
Tage der Technik: Green Engineering – Mit Technik gegen den Klimawandel
Zielpublikum: Öffentlichkeit
www.tage-der-technik.ch
Empa, Dübendorf

25. SEPTEMBER 2019
Kurs: Die Wärmebehandlung, ein "Werkzeug" zur gezielten Einstellung von Eigenschaften
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/waerme
Empa, Dübendorf

Details and further events at www.empa-akademie.ch.

THE PLACE WHERE INNOVATION STARTS.