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Fuels from excess electricity

EMPA
Materials Science & Technology

Rare metals from scrap computers

Pre-stressing concrete with shape memory alloys

Spinal disc replacement for lifetime

MICHAEL HAGMANN Head of Communications

Thinking in (material) cycles

Dear readers

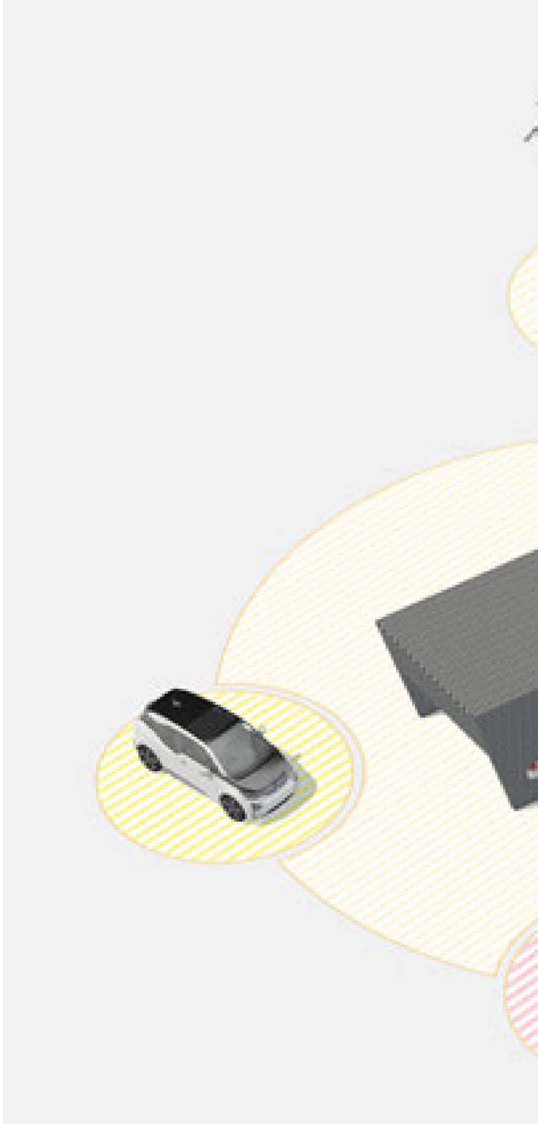
Home and consumer electronics companies launch new products on the market at a breath-taking rate. iPhones, Galaxys and Tablets lure users in with even more features at increasingly shorter intervals – and before you know it, you call the latest little digital gadget your own. Meanwhile, its predecessor is gathering dust in the drawer.

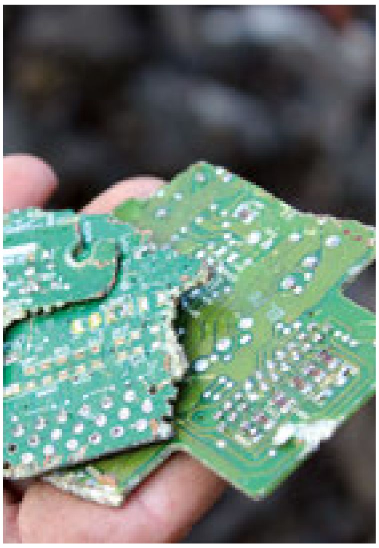
These discarded products harbor all kinds of treasures: around 50 sometimes rare metals, which should really be brought back into the materials cycle so that they don't go to waste and can be reused by the coming generations. This idea is called "urban mining" and has one crucial advantage over the extraction of raw materials from ore mines: the precious metals are up to 30 times more concentrated in our electronic waste. Surely it would be foolish not to use this secondary source of raw materials, wouldn't it? Empa researchers are studying how this can best be accomplished from a technical and economic perspective.

Our latest large-scale project, "Future Mobility", is also about cycles: energy and the fuels of the future, to be precise. Ideally, they should no longer stem from fossil sources but be regenerative. Tapped from renewable energy sources, such as sun and wind, environmentally friendly fuels such as hydrogen and methane can be produced.

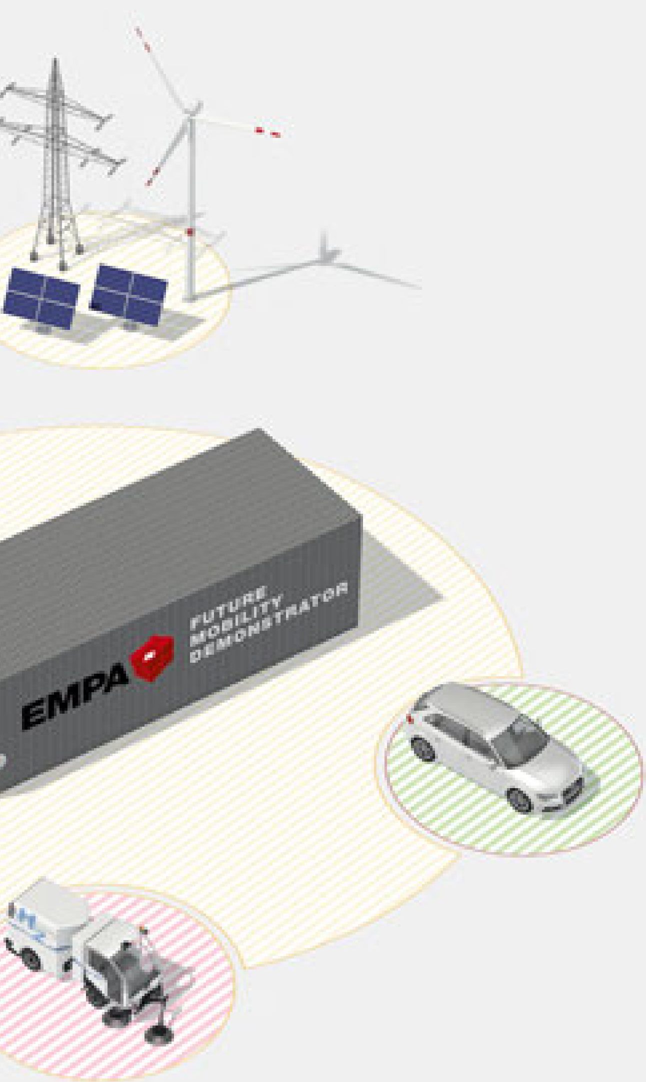
What both topics have in common is a certain throw-away mentality or linear thinking in categories such as raw material extraction, product manufacturing and disposal. The future will happen in cycles; what goes around comes around, as it were. Incidentally, if you want to save on postage and paper, this issue of EmpaNews is also available as an iPad and Android app. Visit www.empa.ch/app for further information and downloads.

Enjoy reading!





Cover
Part of the facade of Empa's Future Mobility Demonstrator. This scientific project will show, how excess electricity from photovoltaics and wind energy plants can be converted to fuel.



Focus

Future Mobility – fuel for tomorrow's cars

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A new source of raw materials: prosperity trash

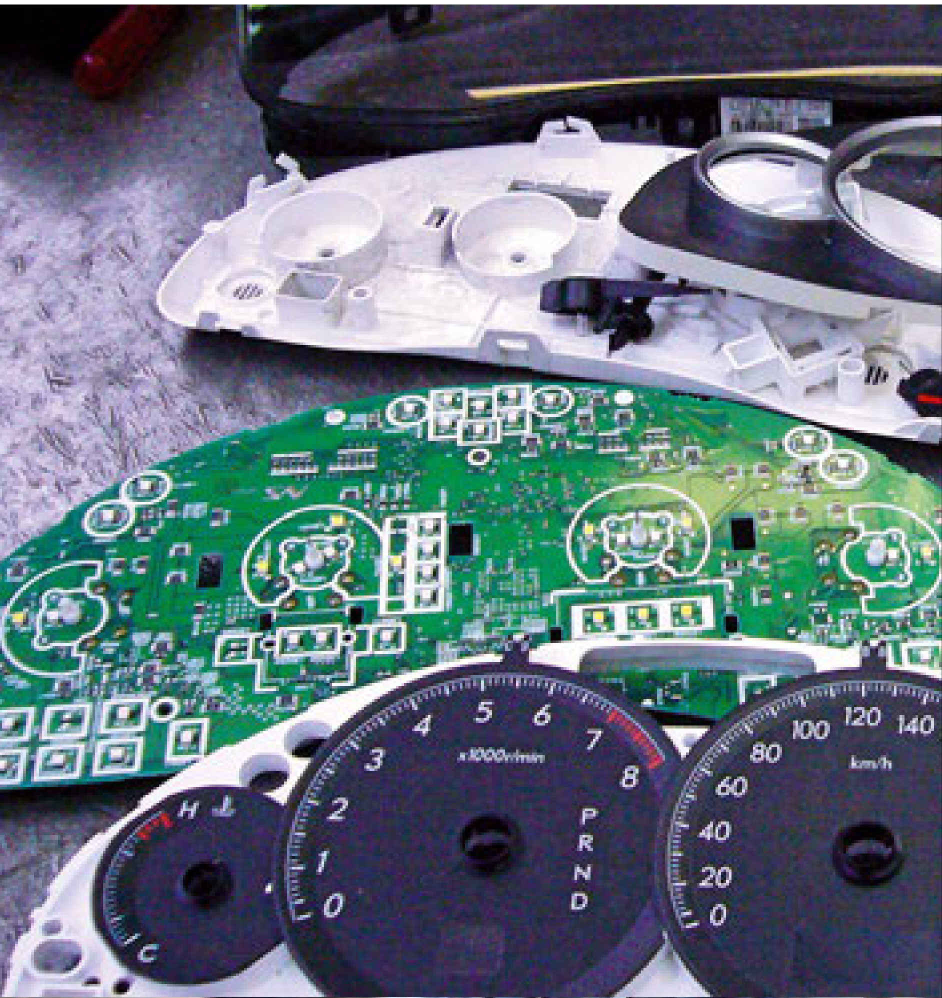
A constant wave of new functions on cell phones and home electronics soon renders them obsolete – and turn working devices into e-waste. Empa is addressing the issue of so-called secondary raw-material extraction or "urban mining", as it is commonly referred to – namely, the transformation of consumer waste into a source of raw materials.

TEXT: Anna Ettlin / PICTURES: Empa

The demand for materials for highly specialized applications is on the rise. Take electronics, for instance, which are becoming increasingly smaller and more powerful: an ordinary cell phone contains around 50 different metals, including some rare ones such as tantalum, indium, platinum and palladium. And many are classed as critical: for geological, political or technical reasons, their long-term availability is unsure and could even become severely limited in future.

The focus in the procurement of these critical metals is increasingly shifting towards "urban mines", namely discarded products, which harbor the coveted materials. Electrical and electronic devices often contain much higher concentrations of valuable materials than even the most productive mines. All too often, however, high costs and the technical complexity of the recycling process stand in the way of the systematic exploitation of these urban mines.

Empa is conducting research in various areas of urban mining. First of all, the institute is investigating which metals are found in which devices and components and in which quantities. Then: which recycling processes produce the highest possible yield? And is this reclamation worth it from an ecological and economic perspective? Three current projects illustrate the range of the research. For instance, Empa researchers are studying the prerequisites for recycling the extremely rare metals indium and neodymium in Switzerland. A second project is devoted to an urban mine that has lain fallow thus far: car electronics. And the results should eventually benefit developing countries, which have to deal with growing mountains of sometimes hazardous e-waste.



Too good for the scrap press

The fact that cell phones and computers are recycled is almost taken for granted in Switzerland nowadays. In modern households, however, electronics are no longer solely found in the office or living room, but also in the garage: in cars. Every year, 100,000 cars are scrapped in Switzerland – and the same number is exported and eventually ends up on the scrap press abroad. And all of them are jam-packed with electronics: GPS and stereo systems to increase comfort; numerous sensors and chips to monitor safety and energy consumption. Back in 2010, electronics already constituted a third of every new car's material value. This proportion will continue to rise with the increasing "electrification" of transport.

Consequently, a modern car contains about as many metals as a cell phone, including some rare elements such as gallium and the rare earth metals dysprosium and lanthanum. "Of the roughly 50 different metals, up to 20 could be recovered," says Rolf Widmer from Empa's Technology and Society Lab. Today, recycling is primarily limited to three metals: iron, aluminum and copper. All the others are lost when the disused cars are scrapped.

Empa is looking for solutions together with the Federal Office of the Environment (FOEN), the Foundation Auto Recycling Switzerland (SARS), the Association of the Official Car Collection Proprietors (VASSO) and other industrial partners. "First of all, we want to characterize the cars as an urban mine," explains Widmer. This should improve the management of this valuable source of raw materials. Although, according to Widmer, the recycling infrastructure is already in place for the second largest urban mine in Switzerland, consumer electronics, this is not yet the case for car recycling. The Empa researcher sees enormous potential here: "Could car recyclers learn from electronics recyclers? Might car electronics even be incorporated into electronics recycling by dismounting them on their way to the scrap press?"

The project, which should answer these questions, is currently under preparation and an international collaboration is already in the pipeline; other countries also want to improve their recycling of car electronics because the rolling urban mine is growing increasingly fruitful as transport becomes "smarter".

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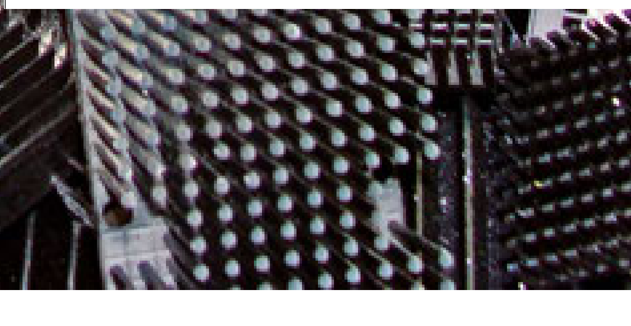
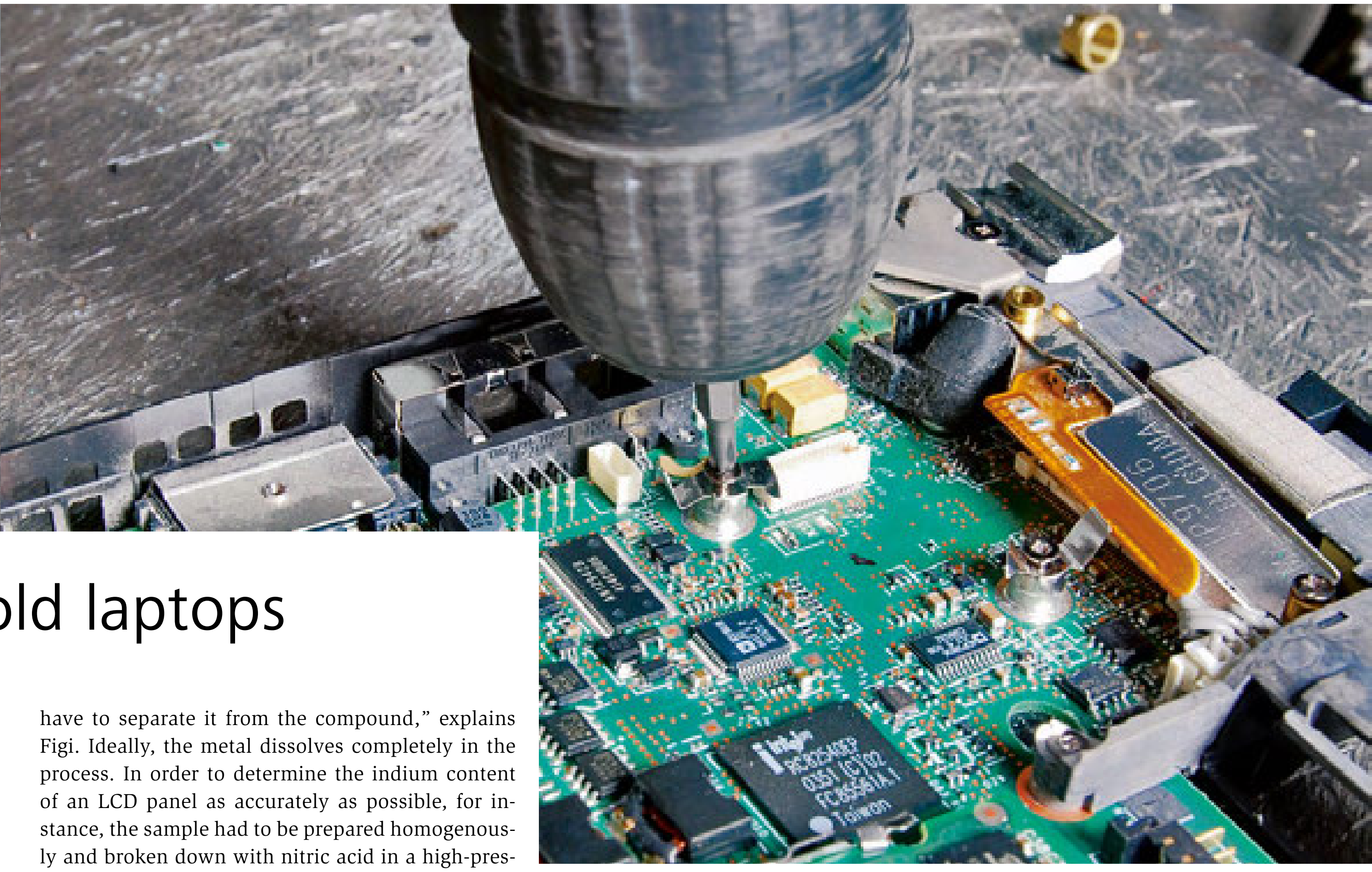
Rare metals from c

In Switzerland, electronic devices contained around two tons of indium and more than 80 tons of neodymium in 2009. Indium is found in LCD monitors, for instance, and neodymium in hard drive and speaker magnets. By now this figure is bound to be even higher. Nonetheless, neodymium and indium, like many other critical metals, are yet to be recycled.

Empa is investigating whether it is worth doing something about this on behalf of the Federal Office of the Environment (FOEN) and the electronics manufacturer association Swico in the project e-Recmet, which places technical, organizational, economic and ecological factors under the microscope. “The project provides specific implementation recommendations for Swico,” says Heinz Böni, Head of Empa’s Technology and Society Lab. “It plugs major knowledge gaps that are also extremely important beyond Switzerland.”

Before the profitability and feasibility of recycling can be examined, you need to know exactly how much metal there is in the devices. Hence, Renato Figi from Empa’s Analytical Chemistry Lab devised new, standardized analytic methods for indium and neodymium. “In order to determine a metal’s exact concentration in a sample, we usually





old laptops

have to separate it from the compound," explains Figi. Ideally, the metal dissolves completely in the process. In order to determine the indium content of an LCD panel as accurately as possible, for instance, the sample had to be prepared homogenously and broken down with nitric acid in a high-pressure reactor at a temperature of 280°C and a pressure of 135 bar – a procedure with around 20 variable parameters that all had to be tested individually. According to Figi, however, it was worth the effort: "We now have a method that can be reproduced wherever you have the necessary lab equipment at your fingertips."

With the project on the brink of completion, Heinz Böni takes stock: "It's technically feasible to recycle indium and neodymium. And from an ecological perspective, it is even more favorable than their primary extraction from mines." So far so good, but: "Ultimately, the recycling costs will also come into play," he goes on. And these are currently higher than the market price of the metals. With a little help from the advance recycling fee, however, which Swiss consumers pay when they buy any device, we could already cover it today. "That would be a truly groundbreaking step," says Böni, "both in Europe and worldwide."

Video
Valuable scrap: recycling rare metals (in German)

http://youtu.be/53i8_BtDOg4

Indium

Use	Thin films, solders and alloys, composite materials, semi-conductors
Price per kilo	Approx. 700 CHF
Amount mined per year	Over 500 tons
Estimated reserves	11,000 tons
Concentration in primary mine	1 – 100 grams per ton
Concentration in components (LCD panel)	140 – 220 grams per ton
Amount contained in flat screens in Switzerland in 2009	2.1 tons

Neodymium

Use	Hard drives, engines, speakers, MRI
Price per kilo	Approx. 90 CHF
Amount mined per year	21,500 tons
Estimated reserves	110 million tons
Concentration in primary mine	1.2 – 17.6 kg per ton
Concentration in components (neodymium magnets)	320 – 640 kg per ton
Amount contained in hard drives and speakers in Switzerland in 2009	84 tons

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Fairness in recycling

Many of our raw materials come from developing countries. Standards and related labels guarantee the sustainability of their extraction. For instance, there are Max Havelaar bananas and fair-trade-certified goldmines. But gold is not just mined; discarded cell phones contain the precious metal in a form that is roughly 30 times more concentrated. Like many secondary raw materials, gold is recycled – even in developing countries. However, there are no standards or labels for reclaimed gold or copper, their reclamation is uncontrolled and done with methods that pose a hazard to both humans and the environment.

Consequently, Empa and the State Secretariat for Economic Affairs (SECO) have been working on a more sustainable e-waste recycling concept since 2003. The original “Swiss eWaste Program” managed to instigate improvements in India, South Africa, Colombia and Peru. The follow-up program “Sustainable Recycling Industries” (SRI), which is supposed to support the establishment of a sustainable e-waste recycling system in seven developing countries – now also including Ghana, Egypt and Brazil – over a period of four years was launched last year. Eco-inventory data centers are also being set up in India, South Africa, Egypt and Brazil. India is focusing on hazardous additives, such as flame retardants in recycled synthetic materials, while the disposal of old refrigerators is the priority in South Africa.

Contracts with the most important partners were signed recently. Now the realization is set to begin. Thanks to various projects, SMEs in the recycling sector should be given the incentive and opportunity to work more sustainably. As project leader, Empa brings its scientific expertise to the table, such as in the monitoring of pollutants, lifecycle analysis (LCA) and testing the efficiency and environmental burden of methods. “Despite the low costs and with the simplest of means,” says Rolf Widmer, “it’s quite a challenge to get the monitoring and analysis of pollutants up and running.”

Industrialized countries like Switzerland are reliant on raw materials – increasingly on secondary ones, too. “Therefore, it’s also important for these to be produced sustainably,” stresses Empa researcher Heinz Böni. Results from the individual countries will thus be pooled regularly at the Global Roundtable for Responsible Recycling, based upon which a sustainability standard will then emerge for secondary raw materials.

Video
Empa’s knowhow for better recycling in India (in German)

http://youtu.be/RMuGAmwgX1o

Collecting light with arti

All over the world researchers are investigating solar cells which imitate plant photosynthesis, using sunlight and water to create synthetic fuels such as hydrogen. Empa researchers have developed such a photoelectrochemical cell, recreating a moth's eye to drastically increase its light collecting efficiency. The cell is made of cheap raw materials – iron and tungsten oxide.

TEXT: Rainer Klose / PICTURES: Empa

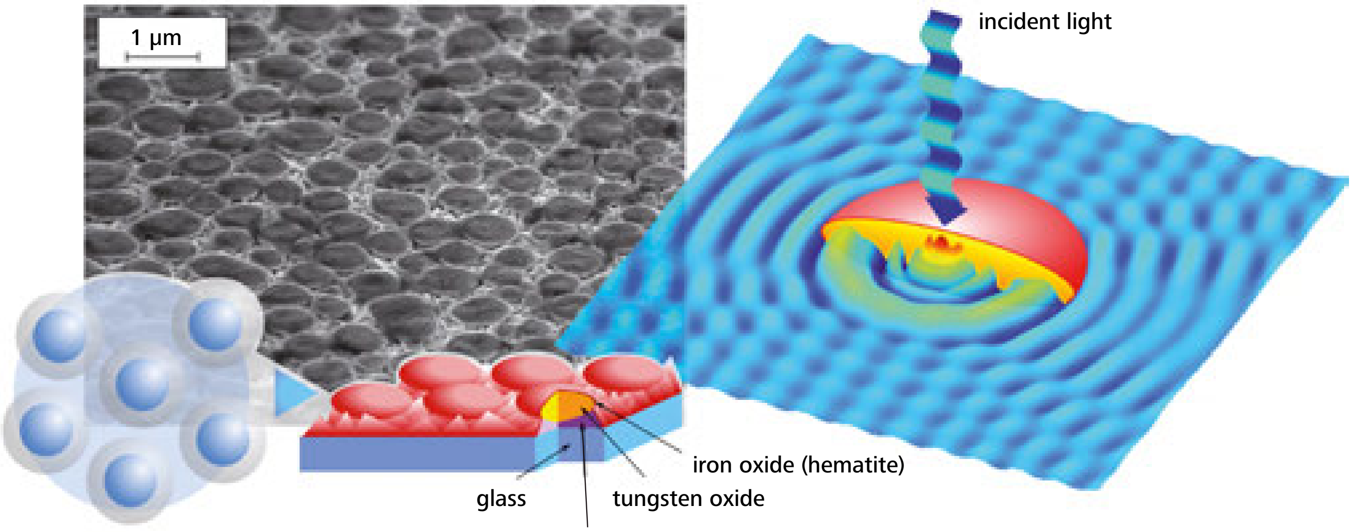
Rust – iron oxide – could revolutionise solar cell technology. This usually unwanted substance can be used to make photoelectrodes which split water and generate hydrogen. Sunlight is thereby directly converted into valuable fuel rather than first being used to generate electricity. Unfortunately, as a raw material iron oxide has its limitations. Although it is unbelievably cheap and absorbs light in exactly the wavelength region where the sun emits the most energy, it conducts electricity very poorly and must therefore be used in the form of an extremely thin film in order for the water splitting technique to work. The disadvantage of this is that these thin-films absorb too little of the sunlight shining on the cell.

Microspheres to collect the sunlight

Empa researchers Florent Boudoire and Artur Braun have now succeeded in solving this problem. A special microstructure on

1
Florent Boudoire tests the functioning of his photoelectrode in a sunlight simulator.

2
How the “moth eye solar cell” is created, and how it collects light.



ficial moth eyes

the photoelectrode surface literally gathers in sunlight and does not let it out again. The basis for this innovative structure are tiny particles of tungsten oxide which, because of their saturated yellow colour, can also be used for photoelectrodes. The yellow microspheres are applied to an electrode and then covered with an extremely thin nanoscale layer of iron oxide. When external light falls on the particle it is internally reflected back and forth, till finally all the light is absorbed. All the entire energy in the beam is now available to use for splitting the water molecules.

In principle the newly conceived microstructure functions like the eye of a moth, explains Florent Boudoire. The eyes of these night active creatures need to collect as much light as possible to see in the dark, and also must reflect as little as possible to avoid detection and being eaten by their enemies. The microstructure of their eyes especially adapted to the appropriate wavelength of light. Empa’s photocells take advantage of the same effect.

In order to recreate artificial moth eyes from metal oxide microspheres, Florent Boudoire sprays a sheet of glass with a suspension of plastic particles, each of which contains at its centre a drop of tungsten salt solution. The particles lie on the glass like a layer of marbles packed close to each other. The sheet is placed in an oven and heated, the plastic material burns away and each drop of salt solution is transformed into the required tungsten oxide microsphere. The next step is to spray the new structure with an iron salt solution and once again heat it in an oven.

“Capturing light” simulated on the computer

Now, one could interpret these mixing, spraying and burning processes as pure alchemy – a series of steps that is eventually successful by pure chance. However in parallel to their practical experiments, the researchers have been running calculations modelling the process on their computers and have thus been able to simulate the “capturing of light” in the tiny spheres. The results of the simulation agree with the experimental observations, as project leader Artur Braun confirms. It is clear to see how much the tungsten oxide contributes to the photo current and how much is due to the iron oxide. Also, the smaller the microspheres the more light which lands on the iron oxide underneath the tiny balls. As a next step the researchers plan to investigate what the effect of several layers of microspheres lying on top of each other might be. The work on moth eye solar cells is still in progress! //

Running on sun

Empa is in the midst of establishing the Future Mobility Demonstrator on its Dübendorf campus. Various technologies should reveal how excess electricity can be economically converted into fuel in the most sensible way. After all, this could save considerable amounts of fossil fuels.

TEXT: Christian Bach & Rainer Klose / PICTURE, ILLUSTRATION: Empa

Just how much one terawatt hour is

Switzerland's entire energy consumption in 2010 amounted to 253 terawatt hours (TWh), almost 60 TWh of which went on electricity. Just for comparison: the Leibstadt nuclear power plant produces around 10 TWh a year.
1 TWh of renewable excess electricity converted into methane could replace almost 60 million liters of petrol, and 70,000 gas vehicles could thus run CO_2-neutrally.

The Future Mobility Demonstrator will be built on the Empa campus in Dübendorf, and it will look like this. The project is planned to start in autumn 2014.

Switzerland has a substantial amount of "fallow" energy reserves. For instance, around half the local biomass (primarily slurry, dung, waste wood and bio-waste) goes unused, as an Empa study reveals. Converted in biogas plants, this would yield around 6 terawatt hours (TWh, see box) of bio-methane per year. On top of this there will be another 5 to 9 TWh of temporary excess electricity in the spring and summer months through the scheduled expansion of solar and wind-power until 2050. Photovoltaic plants, however, primarily produce maximum amounts of electricity at lunchtime and in good weather. And these electricity supply peaks can't always be put to good use.

With the large-scale project Future Mobility, Empa is looking to demonstrate how these home-grown energy can be used to replace imported fossil energy sources. A demonstrator will be constructed on Empa's Dübendorf campus that enables Empa and its industrial partners to develop the necessary concepts and test their practicality by working with real-world users.

Future Mobility – what exactly is it all about? The mobility of the future will increasingly have to rely on renewable energies, which is why drive concepts capable of using this energy are now in the spotlight: gas, electric and fuel-cell vehicles – all drives that Empa has been investigating and developing for years together with its partners in the ETH Domain and in industry. The idea behind the large-scale project: if the unused "domestic" energy could be exploited systematically, way over 1 million gas, electric and fuel-cell vehicles could drive around practically CO_2-neutrally, which would slash Switzerland's carbon dioxide emissions by over 4 million tons, which would match perfectly the Swiss contribution to the Kyoto-protocol.

The main challenge here isn't to process this energy and make it available; it's the economics of the entire system. Future Mobility should reveal how such plants have to be sized and operated, and which applications they need to be combined with to become a success – both in ecological and economic terms. After all, if the idea is also supposed to catch on in the real world one day, both of these requirements need to be fulfilled. //

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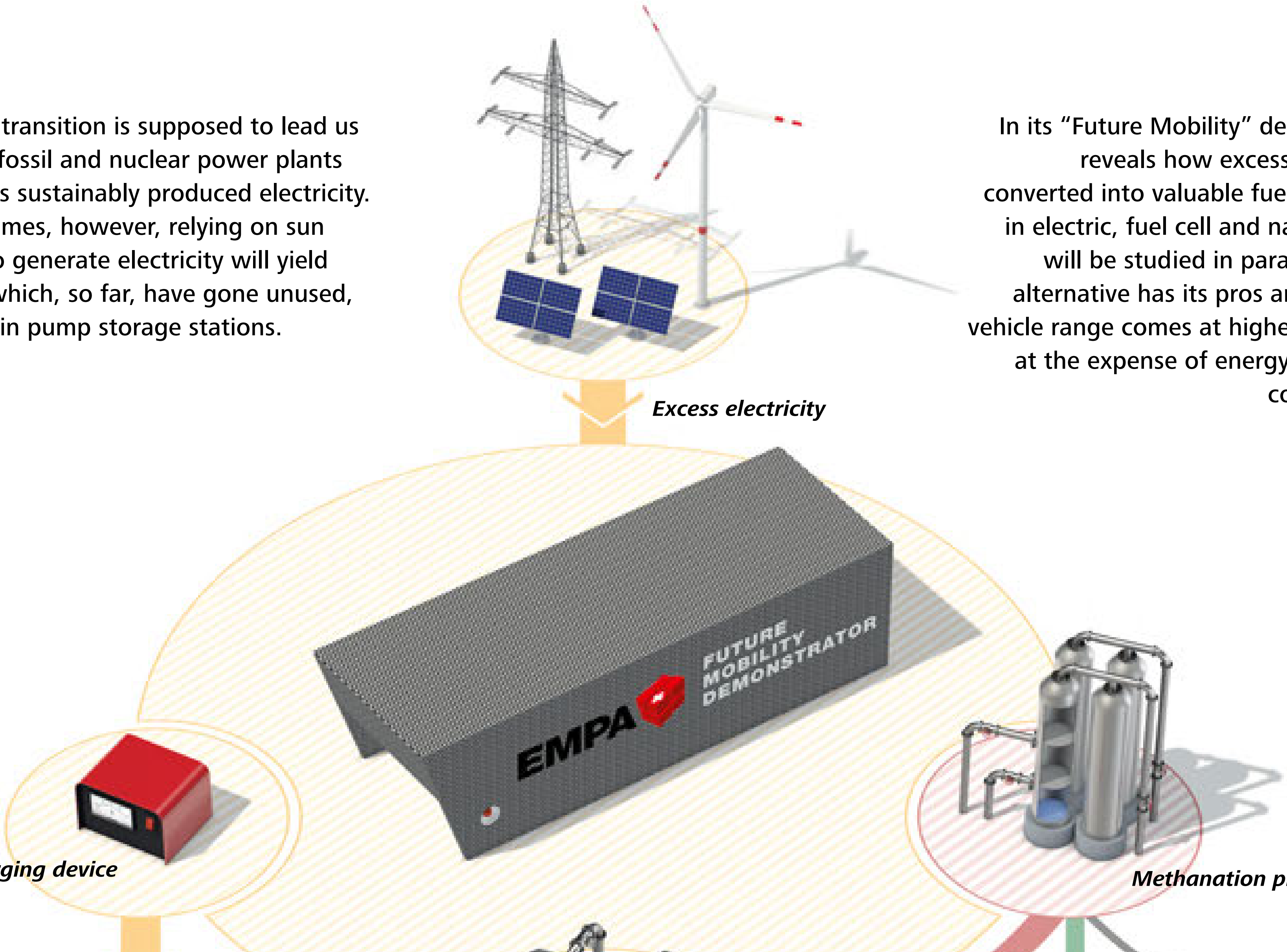
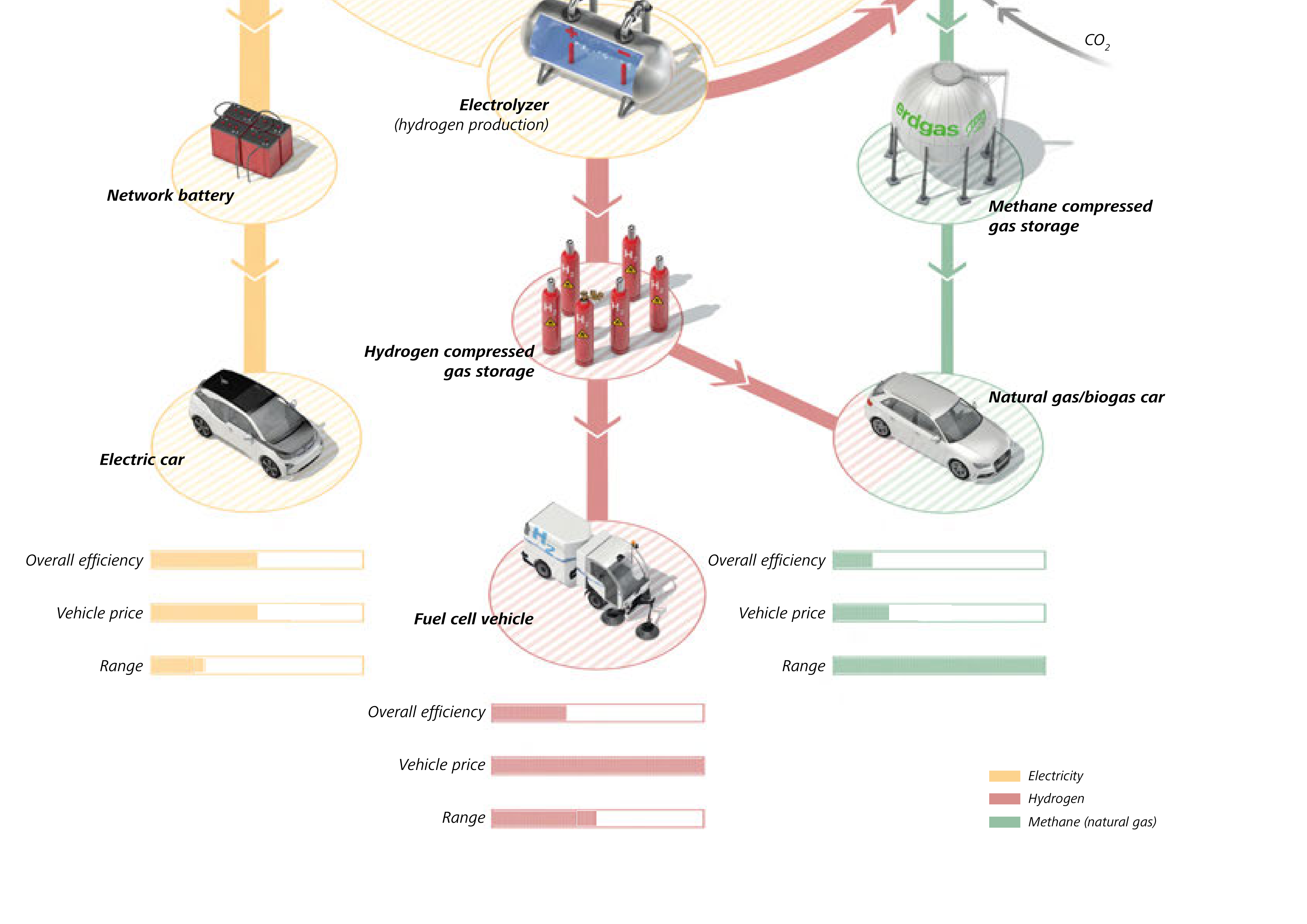
Turning excess electricity into fuel

The energy transition is supposed to lead us away from fossil and nuclear power plants and towards sustainably produced electricity. At certain times, however, relying on sun and wind to generate electricity will yield surpluses, which, so far, have gone unused, or retained in pump storage stations.

In its "Future Mobility" demonstrator, Empa reveals how excess electricity can be converted into valuable fuel. Its consumption in electric, fuel cell and natural gas vehicles will be studied in parallel. Because each alternative has its pros and cons: a greater vehicle range comes at higher vehicle prices or at the expense of energy losses during the conversion process.





CO2
Electrolyzer
(hydrogen production)
Network battery
Methane compressed gas storage
erdgas
Hydrogen compressed gas storage
Electric car
Natural gas/biogas car
Fuel cell vehicle
Overall efficiency
Vehicle price
Range
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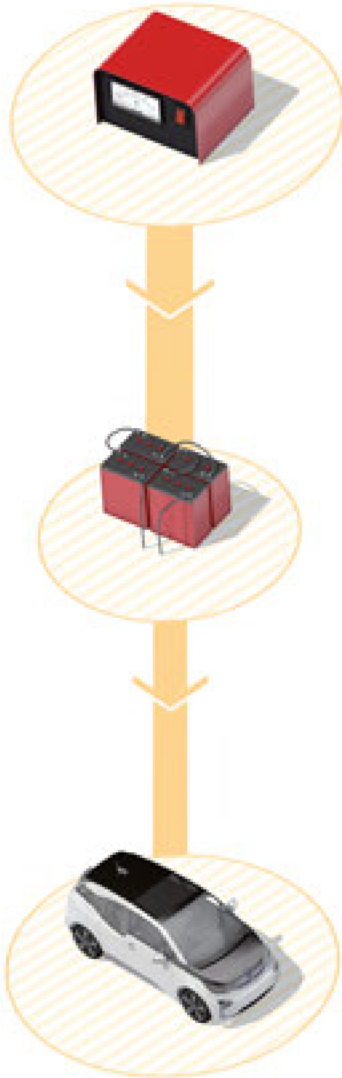
Electricity
Hydrogen
Methane (natural gas)



Midday sun for the rush hour: electric cars

Theoretically, the easiest option would be to power electrical vehicles with excess electricity. Especially in the spring and summer months, large amounts of temporary excess electricity will already accumulate in the near future – unfortunately, mainly during lunch break, when far less electricity is consumed in Switzerland than photovoltaics, wind energy or hydropower plants provide. In other words, the electricity needs to be stored or it will fizzle out unused. In principle, electric vehicles (or their batteries) are just the ticket for the direct storage of excess electricity. However, as many as possible with as empty a battery as possible would need to be hooked up to a charging station precisely at lunchtime – and as few as possible should be driving around, which is hardly possible. Within the scope of Future Mobility, a permanent network battery assumes the role of temporarily storing the excess electricity that typically accumulates during the day. It can then be used to recharge the empty vehicle batteries at night. Batteries have an efficiency level of over 75 % and can also help stabilize the power grid – in other words, smoothen differences between the supply and demand within seconds. The biggest problem right now is the cost of the network batteries, which is why Empa is researching and developing new, cheaper batteries with a higher storage density and lower losses together with ETH Zurich and the Paul Scherrer Institute (PSI).

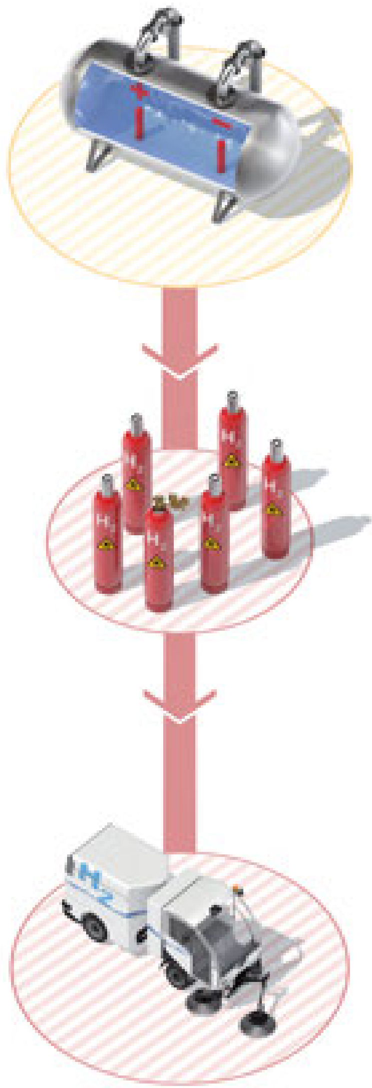
The Swiss Federal Office of Energy (SFOE) predicts a 28 % to 46 % proportion of electric and plugin cars and delivery trucks in Switzerland by 2050, 28 % for heavy utility vehicles and 70 % for motorbikes. These electric vehicles would consume a total of 11 TWh in electricity – the lion's share, namely 6 to 10 TWh, would have to be covered by fossil power plants or energy imports. There would be no advantage compared to using gasoline or diesel powered cars. Within the scope of Future Mobility, Empa researchers are looking to study whether and how the proportion of renewable energy can be increased by using network batteries for Switzerland's future electric fleet.

Catching and storing peak electricity: hydrogen vehicles

An energy transition is inconceivable without hydrogen for electricity storage. This makes hydrogen vehicles interesting. These vehicles have an electric drive, a hydrogen accumulator and a fuel cell that generates power from hydrogen and thus recharges the battery while it is on the move, thus combining rather long ranges with short refueling times. However, the complex technology sends the vehicle prices sky-high. On the flipside, hydrogen-powered cars do not emit any exhaust gases or CO_2, only steam. Empa is developing drive concepts for hybrid vehicles with integrated fuel-cell systems and conducting research into new technologies for hydrogen storage to replace pressure storage and increase the range of hydrogen vehicles even further.

The new Swiss energy strategy assumes that the electricity obtained from today's nuclear power plants will be halved by 2050, with the other half covered by renewable energies. Around 10 TWh should come from photovoltaics – the equivalent of an installed output of around 10 gigawatts (GW). However, Switzerland only needs 6 to 8 GW. In other words, on nice summer's days photovoltaics alone provides between 2 and 4 GW more electrical output than the country's overall demand. One possible solution that is being looked into within Future Mobility is decentralized chemical electricity storage devices: wherever excess renewable power accumulates, hydrogen (H_2) is generated directly through water electrolysis (splitting). A rough calculation shows that this is absolutely realistic: assuming electrolysis plants with an individual output of 1 MW, 2,000 to 4,000 such plants throughout Switzerland would be enough. These hydrogen plants would be conceivable at gas stations, bus depots or municipal facilities.

From today's perspective, hydrogen is the cheapest form of energy storage – with efficiency levels comparable to those of batteries. But since they are expensive, hydrogen vehicles are not suitable for all user groups. They primarily make sense where vehicles are driven a lot and hardly stand around, and where as large a reduction in CO_2 as possible is desired, such as public buses and larger passenger vehicles, which serve as shuttles or taxis, regional delivery vans and municipal vehicles. Within the scope of Future Mobility, a hydrogen-powered road sweeper co-developed with PSI and Bucher Schörling is being used to clean the roads in Dübendorf for two years.



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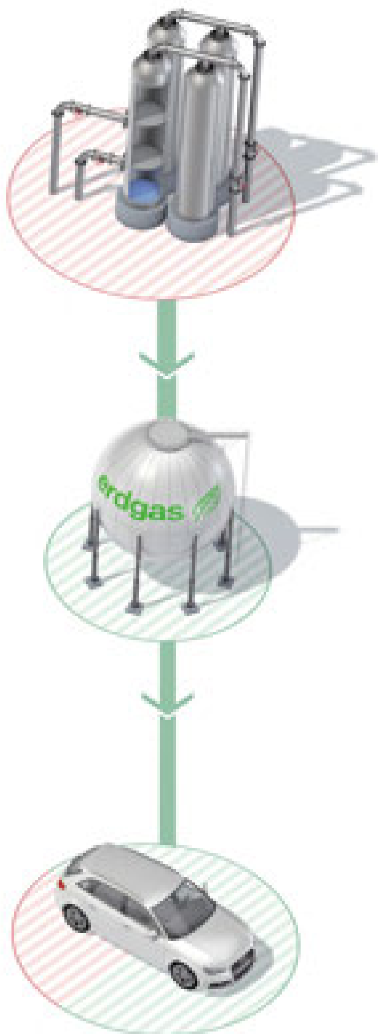
Summer energy for the winter: synthetic natural gas

It would be a nice idea, if we could "put aside" solar energy from summer months for the dark, cold wintertime. A concept called "power-to-gas" provides one possible solution: first, the excess electricity is converted into hydrogen via electrolysis and then into synthetic methane (CH_4) in another chemical process with CO_2. This synthetic methane produced in the summer can then be stored – together with biogas – in the natural gas grid for months on end and converted back into electricity in gas-fired combined-cycle or combined heat and power plants (CHP) during wintertime. However, the power-to-gas idea does have a drawback: as every step "costs" something in terms of energy, the overall efficiency of this form of storage is a mere 25 to 35 %. In other words, the electricity converted back would be very expensive and unable to compete with fossil energy sources.

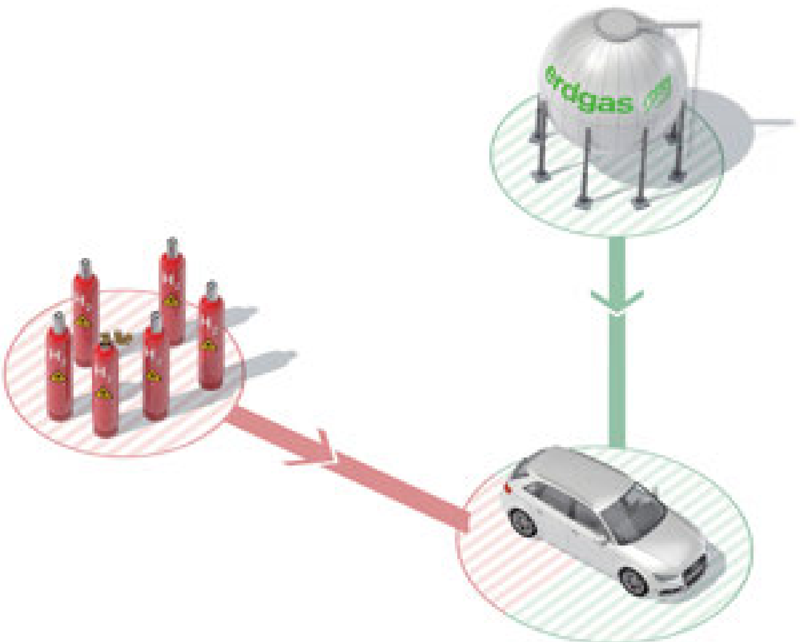
A way better alternative would be, the production of synthetic methane as fuel for gas vehicles – which is definitely economical. On the one hand, it avoids the losses incurred during the reconversion into electricity; on the other hand, fuels are generally more expensive than electricity. Of course, you also "pay" for the conversion of solar power into methane with higher energy losses, and the efficiency levels of power-to-gas plants are considerably lower than those for batteries and hydrogen plants. On the flipside, however, all industrial countries already have gas grids that are nowhere near stretched to capacity in the summer (when electricity excesses occur) and could easily accommodate and distribute the energy surpluses.

Another (presumably more surprising) advantage of gas mobility: although a combustion engine still powers the vehicle, gas vehicles that run on biogas or synthetic methane boast the lowest CO_2 emissions of all vehicle concepts. The reason: vehicles exclusively powered by renewable energy sources cause by far the most CO_2 pollution while being produced (not while being operated). Gas vehicles have the upper hand here compared to alternative vehicle concepts as the bodywork and engine can be produced economically and with a relatively efficient use of resources. Empa is working with ETH Zurich and the automobile industry to develop new combustion processes for gas engines. Methane's high knock resistance of up to 130 octane will facilitate completely new engine concepts in the future with considerably higher efficiency levels than today.



The right car for frequent drivers

Electric cars and fuel-cell vehicles only partly make a suitable replacement for today's cars. Due to their short range, for instance, electric cars are a no-go for the "frequent driver" group – around 20 % of all car-owners, who are actually responsible for half the kilometers travelled. And fuel-cell cars aren't much better, either, as there is no network of hydrogen filling stations (yet). Only gas vehicles are able to hold a candle to diesel and gasoline cars: they can be refueled in a matter of minutes and boast a range of up to 700 km to the tank. Plus, the network of filling stations within Switzerland and in neighboring countries is extensive.



Ecofuel ignitions: hydrogen in natural gas engines

Hydrogen can be used not just in (expensive) fuel-cell vehicles hydrogen but also in (cheaper) natural gas cars. Due to its high knock resistance, synthetic methane, treated biogas or natural gas are nigh-on perfect fuels for combustion engines. Modern turbo- or compressor-charged gas engines increasingly exploit these advantages. These days, natural gas engines are considerably more powerful than even ten years ago. As nice as this high knock resistance is, however, it is equally challenging for the fuel ignition and "flame nucleation" before the actual combustion. Consequently, intensive research is being conducted all over the world – including at Empa in collaboration with ETH Zurich and the automobile industry – to optimize the ignition process for gas engines and gain a better understanding of the processes that go on during the inflammation phase.

A considerably more effective ignition can be achieved in gas engines if hydrogen is mixed with bio- or natural gas. After all, hydrogen can be ignited very easily. In test series with a hydrogen admixture of up to 25 % by volume, Empa researchers managed to increase the engine's efficiency level significantly while reducing its exhaust-gas emissions – and all without technically altering the engine.

The Future Mobility Demonstrator has a natural gas/biogas filling station complete with a hydrogen admixture facility. It is currently being used to refuel three gas-powered Schweizerische Post delivery vans with a hydrogen-methane mixture and study them in routine operation. As hydrogen burns to steam in the engine, while increasing the efficiency level, substantial amounts of CO_2 can be saved with even a relatively low hydrogen admixture. Gas vehicles are thus the most cost-effective option for the sensible use of hydrogen from excess electricity.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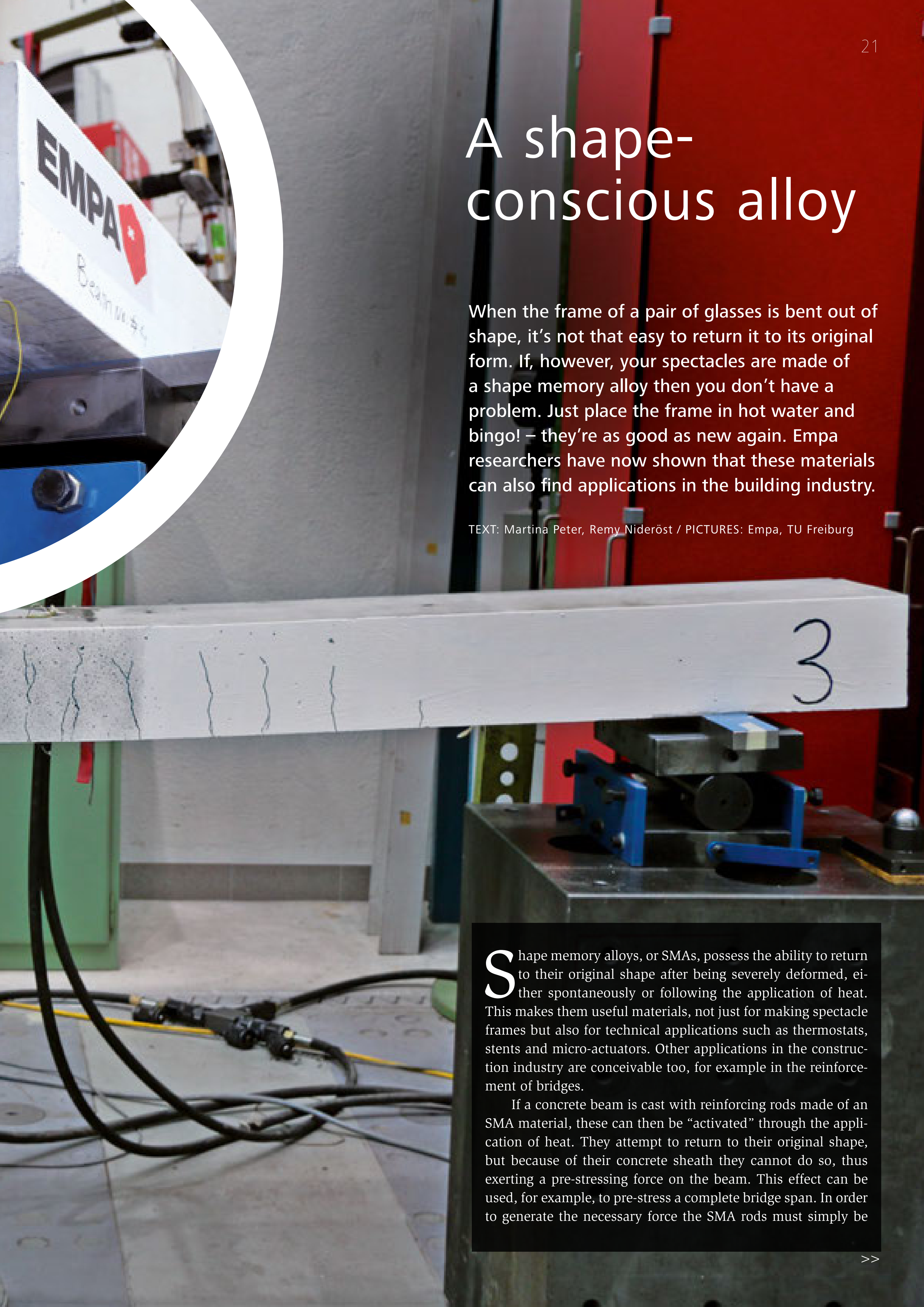

A shape-conscious alloy

When the frame of a pair of glasses is bent out of shape, it's not that easy to return it to its original form. If, however, your spectacles are made of a shape memory alloy then you don't have a problem. Just place the frame in hot water and bingo! – they're as good as new again. Empa researchers have now shown that these materials can also find applications in the building industry.

TEXT: Martina Peter, Remy Nideröst / PICTURES: Empa, TU Freiburg

Shape memory alloys, or SMAs, possess the ability to return to their original shape after being severely deformed, either spontaneously or following the application of heat. This makes them useful materials, not just for making spectacle frames but also for technical applications such as thermostats, stents and micro-actuators. Other applications in the construction industry are conceivable too, for example in the reinforcement of bridges.

If a concrete beam is cast with reinforcing rods made of an SMA material, these can then be "activated" through the application of heat. They attempt to return to their original shape, but because of their concrete sheath they cannot do so, thus exerting a pre-stressing force on the beam. This effect can be used, for example, to pre-stress a complete bridge span. In order to generate the necessary force the SMA rods must simply be

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How shape memory steel is formed (top to bottom): the ingot is heated in TU Freiberg's special furnace before the steel is milled while still hot. Once cool, a machine strikes ribs into the steel. Empa technicians set two shape memory steel lamellae into a reinforced concrete beam. Thermal image: the electrically heated steel reaches a temperature of 160° C within the concrete beam andcontracts. Load test for the pre-stressed concrete beam once it has cooled down goes to show: the experiment was a success.

heated by passing an electric current through them. This obviates the need for using elaborate tensioning systems and jacket tubes, as used in conventional pre-stressing techniques.

The nickel titanium alloys used to make spectacle frames or stents are not very suitable for use in the construction industry. Iron-based SMA products are much more attractive, since both the raw materials and the processing costs are far cheaper. However, to date one problem has remained a stumbling block: to activate the memory effect the materials currently used must be heated up to 400° C, which for applications involving concrete or mortar, or other heat sensitive materials, is too high. Empa researchers led by Christian Leinenbach of the Joining Technology and Corrosion Laboratory have now succeeded in developing a novel iron-manganese-silicon SMA alloy which is activated at just 160° C, a temperature much more suitable for use with concrete. The material science researchers “designed” a range of virtual alloys using thermodynamic simulations, and then selected the most promising combinations. These were then manufactured in the laboratory and their shape memory characteristics tested, with great success. Several of the new materials met the construction engineers' requirements, an important milestone on the path to providing economic shape memory steel alloys for industrial applications – in other words, manufacturing them by the ton.

The long road from laboratory to finished product

Christoph Czaderski, of Empa's Engineering Structures Laboratory, believes that iron-based SMA materials have a promising future in the building industry since the process of pre-stressing is simpler and therefore cheaper than in conventional techniques. In addition they may allow engineers to create pre-stressed structures which are impossible or very difficult to achieve using conventional techniques. These include the use of short fibre concrete, near surface mounted laminates, column wrapping and ribbed armouring steel. A feasibility study financed by the Commission for Technology and Innovation (CTI) recently showed that it is possible to produce the new alloys on an industrial scale, not just a few kilos for laboratory use. The manufacturing process has been developed in collaboration with Leoben University (Austria), the Technical University Bergakademie Freiberg (Germany), and the German company G. Rau GmbH.

The working of cast ingots, each about 100 kg in weight, into thin strips around 2 mm thick or ribbed armouring steel rods at temperatures over 1000° C calls for high degree of technical knowledge, and the appropriate infrastructure. The working process also needs to be adapted for use with the novel alloys.

To carry forward the developments made at Empa, a start-up company, re-Fer AG, has been set up. This will in future produce and distribute iron-based SMA for the construction industry. The cost of the new products is expected to be about the same order of magnitude as that for stainless steel based materials. //

Video

Shape memory alloys – demonstrated in the lab.

http://youtu.be/eWgOa0Y4R_I

The art of healing bridges

Germany is currently embroiled in a hot debate on the badly needed refurbishment of ailing roads and motorways – especially bridges. In many places, road bridges should be reduced to a single lane to avoid stressing them unduly. At Empa, Masoud Motavalli is developing solutions to get old bridges back in shape.

INTERVIEW: Martina Peter / PICTURE: Empa

Mr. Motavalli, are Switzerland's bridges as poor as Germany's?

Fortunately not. In Switzerland, we have a continuous monitoring system in place. If something needs repairing, it gets repaired. But it isn't just Germany that has a problem with its bridges. In the US, around a quarter of the country's 600,000 bridges or so are thought to have shortcomings and be in urgent need of repair. 50, 60 years after the structures were built, the concrete is often damaged and the metal corroded.

Is it due to bad material that was used back then?

No, you couldn't say that. Material tires. Besides, the material was stressed far more than initially expected. Just think of how much the traffic has ballooned in the last 50 years.

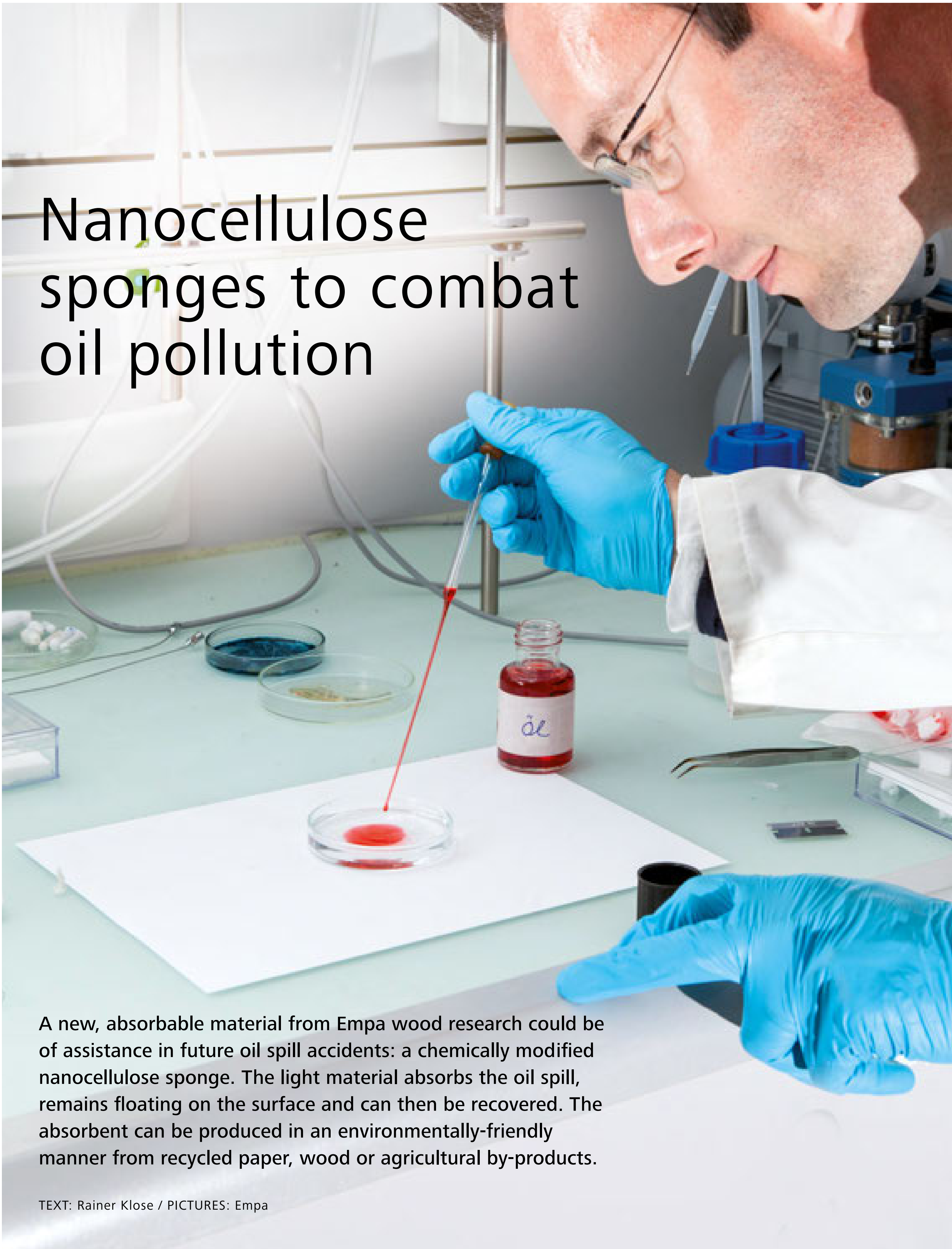
How can an old bridge be brought back up to scratch?

We've been investigating various repair methods and developing practicable solutions for years. Around 20 years ago, in a world first, Urs Meier and his Empa team stuck carbon-fiber-reinforced polymer cables (CFRP) to a damaged reinforced concrete bridge and thus saved the Ibachbrücke near Lucerne from collapse. Today, we even reinforce steel bridges with pre-stressed CFRP cables. But instead of sticking them on, we clamp them to steel sections, which enables us to attach them to places where sticking would be difficult, such as where bolts are poking out. And if need be, CFRP cables can be removed or replaced easily, discretely and without damaging the structure. Incidentally, this is precisely how we strengthened a railway bridge constructed by Gustave Eiffel in a recent project with the SBB. (Note from the editor: in 1891 there was a railway disaster in Münchenstein in the Canton of Basel-Land when a bridge built by Gustave Eiffel collapsed. In one of its first ever studies, Empa revealed that an unsuitable formula had been used for the calculation).

Are there other methods?

We also want to use more alloys with a "memory" to repair bridges (see previous article). This already works very well on a smaller scale. In the near future, we'll be carrying out tests on roughly seven-meter long concrete beams reinforced with shotcrete that has been fortified with smart alloys. We're interested in how much energy is needed for the "smart metal" reinforcement to make the bridge sound again. Ultimately, we also want to know how we can best implement this in practice. With the right measures, the lifespan of a bridge can thus be extended for a good 50 years – regardless of what went on before. //

Nanocellulose sponges to combat oil pollution



A new, absorbable material from Empa wood research could be of assistance in future oil spill accidents: a chemically modified nanocellulose sponge. The light material absorbs the oil spill, remains floating on the surface and can then be recovered. The absorbent can be produced in an environmentally-friendly manner from recycled paper, wood or agricultural by-products.

TEXT: Rainer Klose / PICTURES: Empa

All industrial nations need large volumes of oil which is normally delivered by ocean-going tankers or via inland waterways to its destination. The most environmentally-friendly way of cleaning up nature after an oil spill accident is to absorb and recover the floating film of oil. The Empa researchers Tanja Zimmermann and Philippe Tingaut, in collaboration with Gilles Sèbe from the University of Bordeaux, have now succeeded in developing a highly absorbent material which separates the oil film from the water and can then be easily recovered, "silylated" nanocellulose sponge. In laboratory tests the sponges absorbed up to 50 times their own weight of mineral oil or engine oil. They kept their shape to such an extent that they could be removed with pincers from the water. The next step is to fine tune the sponges so that they can be used not only on a laboratory scale but also in real disasters. To this end, a partner from industry is currently seeked.

One step production – from cellulose plants

Nanofibrillated Cellulose (NFC), the basic material for the sponges, is extracted from cellulose-containing materials like wood pulp, agricultural by products (such as straw) or waste materials (such as recycled paper) by adding water to them and pressing the aqueous pulp through several narrow nozzles at high pressure. This produces a suspension with gel-like properties containing long and interconnected cellulose nanofibres.

When the water from the gel is replaced with air by freeze-drying, a nanocellulose sponge is formed which absorbs both water and oil. This pristine material sinks in water and is thus not useful for the envisaged purpose. The Empa researchers have succeeded in modifying the chemical properties of the nanocellulose in just one process step by admixing a reactive alkoxysilane molecule in the gel before freeze-drying. The nanocellulose sponge loses its hydrophilic properties, is no longer suffused with water and only binds with oily substances.

In the laboratory the "silylated" nanocellulose sponge absorbed test substances like engine oil, silicone oil, ethanol, acetone or chloroform within seconds. Nanofibrillated cellulose sponge, therefore, reconciles several desirable properties: it is absorbent, floats reliably on water even when fully saturated and is biodegradable. //

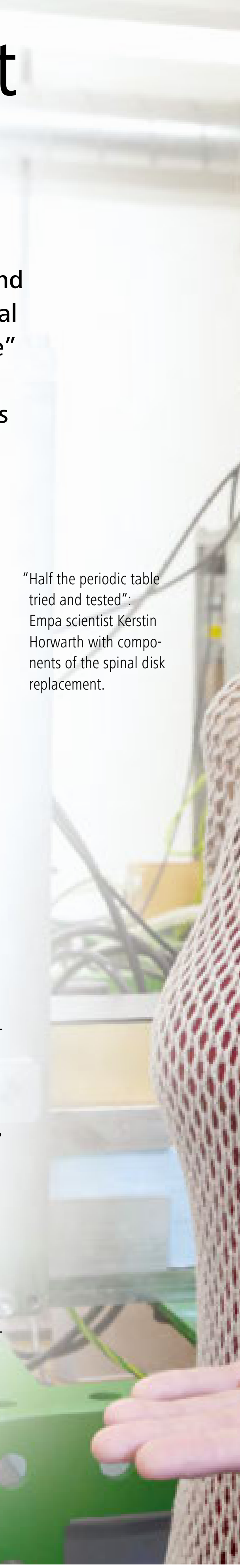
Nano-fibrillated cellulose normally soaks up water and oil at the same time. Now, however, Empa scientists have chemically modified the material in such a way that it only combines with oily substances. The effect can be observed in a lab experiment: the red oil droplet disappears into the nano-cellulose sponge, leaving clear water behind.

Large photograph (left): Philippe Tingaut developed the chemical modification of nano-cellulose.

Joint implants without an expiry date

Artificial joints have a limited lifespan. After a few years, many hip and knee joints have to be replaced. Much more complex are intervertebral disc implants, which cannot easily be replaced after their "expiry date" and which up to now have had to be reinforced in most cases. This restricts the patient's freedom of movement considerably. Researchers at Empa have now succeeded in coating mobile intervertebral disc implants so that they show no wear and will now last for a lifetime.

TEXT: Cornelia Zogg / PICTURES: Empa



"Half the periodic table tried and tested": Empa scientist Kerstin Horwarth with components of the spinal disk replacement.

Due to the daily stresses and movement in the body, even the best artificial joints wear out; the material undergoes wear, and wear particles can trigger unwanted immune reactions, making it necessary to replace the joint. This is normally a standard procedure that can be repeated up to three times with most implants. As bone material is lost each time an implant is explanted, the new joint has to replace more bone and is therefore larger. In the case of intervertebral discs, this is virtually impossible. They are too close to spinal nerves and tissue structures that could be damaged by another operation.

Up to now, intervertebral discs have not been replaced by mobile joints, but by so-called cages, a kind of place holder that both supports and allows the adjacent vertebrae to grow and fuse together. However, this causes stiffening at the point where previously the disc had provided adequate freedom of movement. Over the years, this stiffening can result in the adjacent discs also having to be reinforced due to the increased stress on them. Mobile intervertebral disc implants could reduce this problem. However, many products currently available carry the risk of triggering allergies or rejection reactions due to material abrasion.

What makes artificial joints durable?

Initial attempts to increase the lifespan of artificial joints were made by various manufacturers in the past using a super-hard coating made of DLC ("diamond-like carbon") - with disastrous consequences. Approximately 80% of DLC-coated hip joints failed within just eight years. Researchers at Empa's "Laboratory for Nanoscale Materials Science" investigated this problem and found that the implant failure did not originate from the coating itself, but was caused by the corrosion behaviour of the bonding agent between the DLC layer and the metal body. This layer was made of silicon which corroded over the years, causing it to flake, which led to increased abrasion and, as a result, bone loss. "Our aim was to find a bonding agent which does not corrode and which lasts a lifetime in the body," explains Kerstin Thorwarth.

The first step towards intervertebral discs

This was a laborious task, as the Empa researcher emphasises: "We tried half the periodic table." One was finally found and tantalum was used as the bonding agent. This coating was tested in a so-called total disc replacement - a mobile disc implant. We simulated 100 million cycles, i.e. about 100 years of movement in a specially designed joint simulator. The small intervertebral disc implant held out, remaining fully operational with no abrasion or corrosion. The new bonding agent is soon also to be used in combination with DLC coatings for other joints. "The intervertebral disc is the most awkward joint in terms of implants. Because tantalum has performed so well, the DLC project can now be applied to other joints," says Thorwarth. //

Silver in the washing machine

A team of Empa researchers headed by Bernd Nowack studied silver-coated textiles in the washing machine and made a surprising discovery: materials with a conventional coating release more nanoparticles into the wastewater than those with nano-coatings – a finding that could change the future analysis and regulatory approach towards silver textiles. Nano-textiles should not be regulated any more strictly than textiles with a conventional coating, which should be taken into consideration in current discussions on a possible special regulation of nano-silver. In the next step, the Empa team wants to study the behavior of silver coatings when washed with com-mercially available detergents.

New ways to prevent and treat chronic wounds

In our aging society, chronic wounds are becoming increasingly more common. Various companies specialize in the topic and often enlist Empa's help. A "Technology Briefing" in St. Gallen showcased some joint projects. For instance, the Empa spin-off Compliant Concept developed the Mobility Monitor, which provides information on when and how often a patient needs to be turned to avoid painful pressure ulcers, which can lead to chronic wounds. Empa also developed a bed sheet in collaboration with Schoeller that prevents bedsores due to its micro-structured surface. And Nolax teamed up with Empa to develop a "wound foam", a polymer that helps the body to heal chronic wounds.

Efficient filtration of diesel exhaust fumes

Thanks to particle filters, diesel vehicles nowadays hardly emit any harmful soot particles. Nonetheless, particle filters are still a hot topic, as the fifth VERT Forum at Empa with well over 20 speakers from research, industry and public authorities revealed. Some years ago, Empa teamed up with industry and the authorities to devise a filter assessment test. A VERT-certified particle filter guarantees that it will retain 98 percent of the soot particles. So far, 40 certified particle filter systems are available on the market and researchers are working flat out to optimize them even further.

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