

Annual Report 2013



Empa Annual Report 2013



Materials Science & Technology

Our Vision.

**Materials and Technologies
for a Sustainable Future.**

PAGES 4-5

Foreword

PAGES 6-7

Year at a glance

PAGES 8-49

In the spotlight: selected projects

PAGES 50-69

Research Focus Areas

PAGES 70-93

Driving innovation – the Empa approach

PAGES 94-99

Facts and figures

PAGES 100-103

Bodies of Empa and Organizational chart

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The long road from research to application

There was plenty to celebrate for Empa in 2013 – especially, of course, the 50th anniversary of the Dübendorf campus in the presence of senior representatives from science, industry, and politics. However, Empa also pursued its mission of transforming innovations from top-notch research into practical applications at other events, such as the recently launched Empa Technology & Innovation Forum. This heightened visibility among representatives from politics and industry and Empa’s “sharper” profile as Switzerland’s cradle for innovation is bound to have helped us obtain financial backing from our partners, such as from the Canton of Zurich, the Swiss Federal Office of Energy (SFOE), and many others. These external sources of funding are especially important for our pioneering demonstrators like NEST (for the building sector) and Future Mobility.

We have also set ourselves ambitious goals for 2014, focusing on research related to Switzerland’s pending energy turnaround. The new Swiss Competence Centers for Energy Research (SCCER) have yielded numerous exciting projects for Empa. The first four years of the SCCERs will fly by faster than we’ll like and the public will impatiently (but understandably) demand “tangible” results. I am convinced that Empa will make major contributions in this respect. Moreover, we are currently in the process of establishing the Coating Competence Center at Empa together with partners

from the coating industry. The first major facility is already being installed; more are set to follow in the course of the year.

All these projects have one thing in common: it often takes many years and numerous attempts to find a path from understanding the basic principles to new applications that can flourish on the market. Bridging this risky gap is one of Empa’s core tasks. Not only do we conduct first-class research; we also develop fundamentally new processes and synthesize novel materials, even if their successful transformation into practical applications is still a long way off and there is thus not yet a business plan for their marketing at hand. This is exactly what we understand by our motto “Empa – The Place where Innovation Starts.” Hence, Empa also campaigned for a special funding of precompetitive research from the Swiss National Science Foundation and the Commission for Technology and Innovation, which is being implemented for the first time as a pilot project in 2014. Coincidentally, Switzerland’s downgrading in the EU research program Horizon 2020 has given this initiative fresh impetus as the majority of Empa’s roughly 60 EU projects focus precisely on precompetitive research. In the current annual report, we want to present some examples from Empa’s wide range of activities and kick-started innovations. We wish you a lot of enjoyment and inspiration while browsing through it.



Prof. Dr Gian-Luca Bona
CEO

01

Things turn sour for A/C units

A new coolant for air-conditioning units in cars breaks down into the long-lived plant toxin trifluoroacetic acid in the atmosphere. Empa researchers calculated where how much of the coolant is emitted and where the pollution is highest.

The pros and cons of e-mobility

Although electric vehicles powered by renewable energy are environmentally friendly, producing them harms the environment. A study headed by Empa highlights the pros and cons and provides specific recommendations for sustainable mobility.



Kick-start for young entrepreneurs

The CTI Entrepreneurship program was launched at Empa in St. Gallen in late April. During the five-day courses, budding company founders learn about topics such as business creation and business development.

02

Recycling in developing countries

In February, Empa and the State Secretariat for Economic Affairs (SECO) launched the "Sustainable Recycling Industries" program with the aim of sustainably recovering and recycling secondary raw materials.



Nano-study on Swiss Accidents Ordinance

On behalf of the Federal Office for the Environment (FOEN), Empa investigated whether the Swiss Major Accidents Ordinance needs to be amended with regard to nanosafety. The current conclusion: the safety measures for chemicals are also sufficient for synthetic nanomaterials.

03

Mercury in energy-saving light bulbs

On behalf of the Federal Office for the Environment (FOEN), Empa studied the mercury content in 72 energy-saving light bulbs. The readings form the basis for estimating the overall amount of mercury in Switzerland.



New member of Empa's Board of Directors

On 1 July, Alex Dommann took over from Xaver Edelmann as new Department Head and member of Empa's Board of Directors. Previously, Dommann was CTO and Head of the Microsystems Technology Division at CSEM.



04

Cooperation for life-cycle assessments

Empa has relocated its service team for life-cycle analyses to Quantis, one of the world's leading consultancy firms in the field. Quantis is opening a new branch at Empa's technology center glaTec in Dübendorf.

Prize-winning bed sheet

Together with the Swiss Paraplegic Center and Schoeller Medical AG, Empa won the Techtextil innovation prize for a sheet that prevents bedsores for bedridden people.



05

Networking for managers

Successful premiere for the Empa Technology & Innovation Forum: over 120 managers from Swiss industry discussed topics such as "open innovation" and "innovation and sustainability" with Empa's Senior Management.

Empa as a meeting point

In mid-May, the "who's who" of materials research convened at Empa for the World Materials Research Institutes Forum. The main theme was "Materials meet life," i. e. the issue of how new materials interact with our bodies.

Page 85

06

"Wristwatch" gauges blood pressure

A novel sensor worn on the wrist will make permanent blood-pressure readings easier for hypertension sufferers in future. The company STBL Medical Research AG teamed up with Empa to develop the sensor.

Page 19

07

Empa/Eawag crèche turns 20

On 6 July, Empa's and Eawag's crèche celebrated its 20th anniversary. Today, a pavilion built in 2006 has room for 34 children.

Page 93



Number five for Douglas

In late July textile designer Annette Douglas received yet another award – the fifth within a short period of time, this time from the EU – for the sound-absorbing, transparent curtains developed with Empa.



08

50 years of Empa's Dübendorf campus

Senior representatives from industry and politics, including Federal Councilor Johann Schneider-Ammann, celebrated the 50th anniversary of the Dübendorf campus on 19 August.



End of the road for flame retardant

The flame retardant HBCD, which is used in polymers, electronics, textiles, and insulating boards, will no longer be permitted in future. The ban decided at a UN conference was partly based on Empa research.

09

Field test – passed with flying colors

After several months of field tests in several Swiss cities, the results of Empa's hydrogen-powered street sweeper are extremely positive: compared to conventional street sweepers, it consumes up to 70 percent less energy.



Dioxin from diesel particle filters

Diesel particle filters are a blessing for the environment – and, at the same time, chemical reactors that are difficult to control. Empa researchers discovered that, under certain circumstances, some filters produce the Seveso toxin dioxin.



10

Happy birthday, glaTec!

And yet another anniversary – the business incubator glaTec on the Empa campus in Dübendorf celebrated its fifth birthday in 2013. All 13 companies supported so far are active on the market and growing all the time. A resounding success!

Page 78

Nano database funding to continue

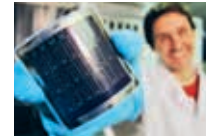
DaNa, a knowledge database that is easy to understand and contains information on synthetic nanomaterials, is to be funded by Switzerland and Germany for another four years – with a significant involvement of Empa (www.nanopartikel.info).

11

New world record for solar cells

With an efficiency of 20.4 percent, Empa researchers have set a new efficiency record for flexible solar cells based on CIGS semiconductors.

Page 30



Climate protection on the menu

Empa is partner in the program ONE TWO WE launched by the gastro company SV Group and WWF. Fewer goods carried by air, fewer products from greenhouses heated with fossil fuels, and lower energy consumption should render staff restaurants sustainable.

Zurich government at Empa

At the end of November, Zurich's cantonal government invited representatives from industry to the first Regional Dialog on the Empa campus in Dübendorf – a fitting location given central topic: the technology transfer from research to industry.

12

Moisture-storing plaster on the market

Empa teamed up with Sto AG to develop a plaster system with a high moisture-storage capacity. This helps prevent condensation on cool wall sections and heat bridges – and thus mold and microbe infestations. The plaster has been available since February 2014.

Ruzicka Prize for Empa researcher

On 4 December, Maksym Kovalenko was awarded the Ruzicka Prize 2013. The Empa researcher and assistant professor at ETH Zurich studies new nanomaterials for use in electronics, optics, and high-performance batteries.

Page 33

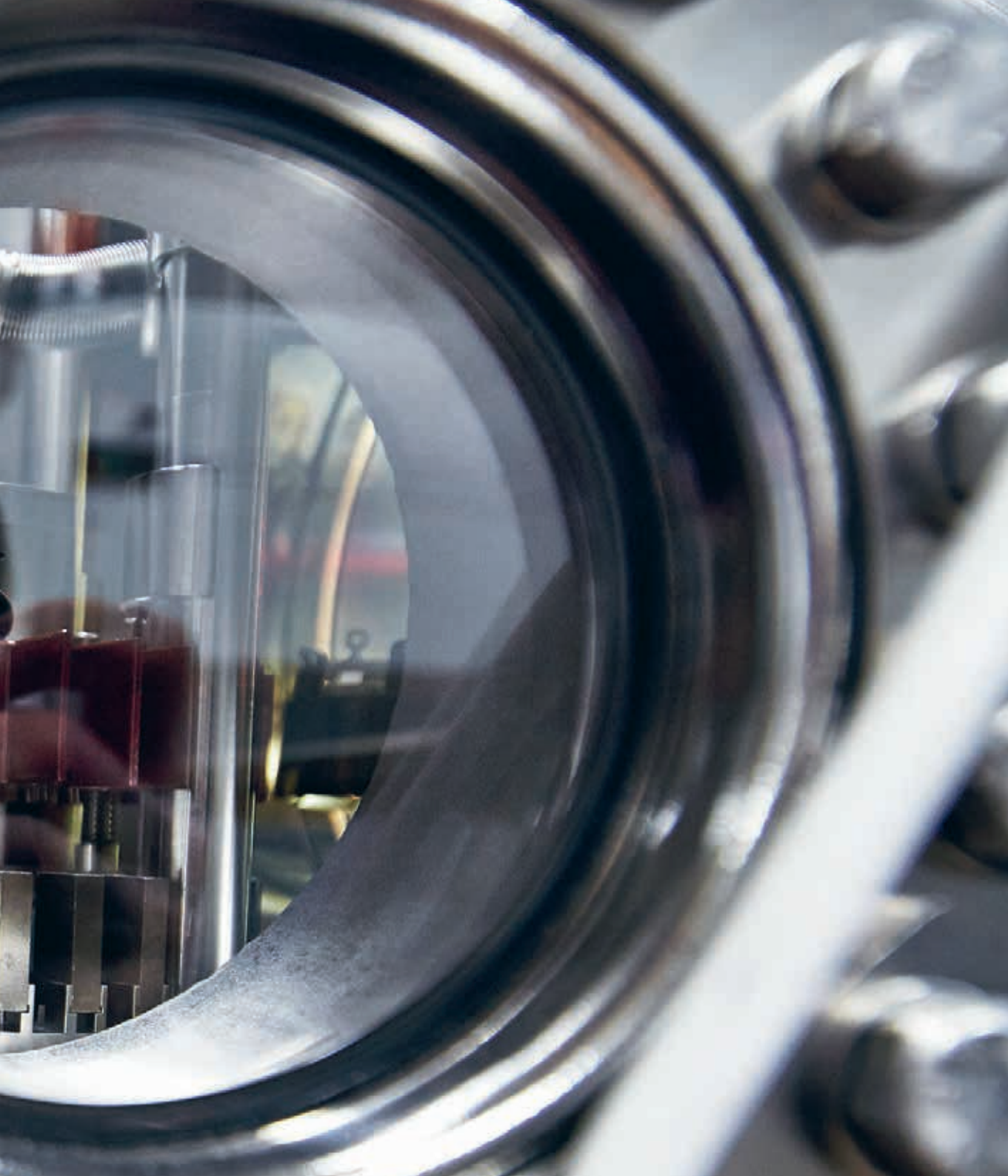


In the spotlight: selected projects

Investigating new materials and accelerating the development of innovative technologies; supplying the stimulus for the sustainable development of our society; providing the scientific basis for political and societal decisions – these are Empa's core objectives, which it pursues through research and development, cooperation, networks and partnerships, as well as services, expertise and consulting activities. In over 500 scientific publications and close on 1,100 contributions to scientific conferences, Empa scientists and engineers shared their latest results. The following snapshots from the institute's laboratories give an insight into Empa's multifaceted research activities.







How rigid do multi-story timber structures need to be?

In the spring of 2013, a special type of equipment was deployed at a building site in the village of Oberglatt near Zurich: a two-ton “shaker.” Placed on the third floor, it really got the new multi-story timber building to vibrate considerably, much like in severe winds or minor earthquakes.

127

kilometers per hour is the wind speed which we can expect statistically in Zurich every two years, according to Meteo Schweiz. By comparison, the infamous winter storm Lothar tore through the Swiss lowlands in December 1999 at speeds of up to 140 km/h; the top speed recorded on Jungfrauoch peaked at 249 km/h.

At twelve spots in the house, Empa researchers registered the horizontal and vertical movements on the building using acceleration sensors to obtain real values concerning the rigidity, fundamental frequency, and damping of the support structure – and thus study for the first time how structural and non-structural building components influence the horizontal rigidity and stability of multi-story timber structures

What do bookcases and multi-story timber buildings have in common?

When planning and constructing multi-story buildings, civil engineers are confronted with pretty much the same problems as ordinary mortals trying to assemble a bookcase: if they forget to attach the metal cross to the back the bookcase will remain wobbly and sway back and forth ominously at the slightest nudge.

Nowadays, of course, engineers do not use metal crosses. In order to guarantee the horizontal rigidity of the support structure and prevent damages caused by heavy winds or earth-



The scientists studied this three-story, semi-detached, timber-framed house in Oberglatt in the canton of Zurich.

quakes, for instance, they incorporate additional structural walls into the building or increase the rigidity of individual walls by applying thicker components, stronger material or more connectors. Ultimately, this all means: more material and work – and thus higher costs.

The fact that stiffening the building is not always the best solution does not exactly make things any easier, either. In order to

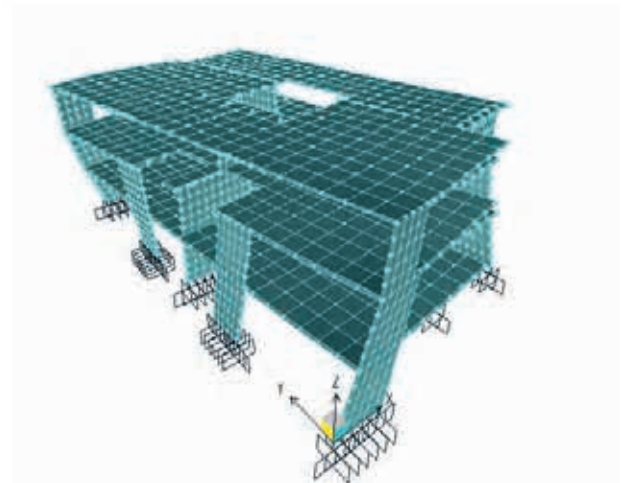
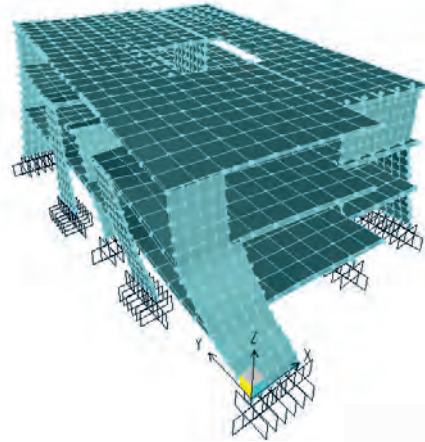
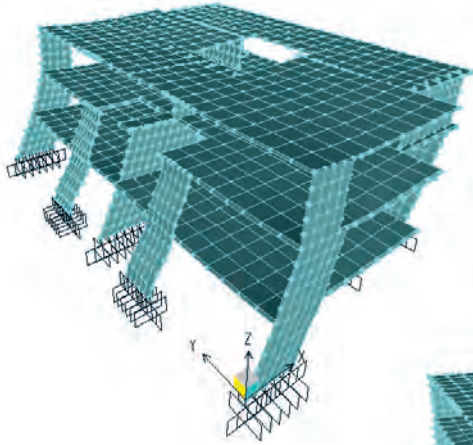
absorb the energy during an earthquake, sometimes it is more beneficial if the building is not all that rigid and, to a certain extent, can respond flexibly. Hence, the entire timber construction industry, but also architects, engineers, and building owners, are eager to get material values regarding rigidity, fundamental periods, and damping that are as close to practice as possible. Because only then can they use precisely the amount of materials that are actually needed – and in the right places, too.

Timber – a sustainable construction material

Until recently, however, there were only theoretical approximations at hand; no one had hard data on the dynamic properties of a multi-story timber structure that had been compiled on a “real” building erected using tried and tested construction methods. With the research project funded by the Forestry and Wood Research Fund (Fonds zur Förderung der Wald- und Holzforschung), which Empa conducted in collaboration with the engineering company Pirmin Jung AG (Rain), the architects of ZBF Architekten AG (Zurich) and the timber construction company Artho Holz- und Elementbau AG (St. Gallenkappel), the scientists have now laid the basis for predicting the horizontal rigidity of timber structures much more accurately. This means that in future timber will be able to fully flaunt its strengths as a sustainable material for multi-story buildings.



Empa's hydraulic horizontal oscillator makes entire houses vibrate with its moving mass of 1,000 kilograms.



Images of the modal analysis indicate the fundamental mod shapes and periods.

The 2,000-watt society is still far-off

In 1998 researchers from ETH Zurich developed the concept of the “2,000-watt society,” an energy-policy model based on the idea of supplying the growing global population with energy while saving the environment. Efficient technologies and processes would slash the energy

3,369

Swiss households were surveyed on their living, mobility, dietary, and consumer behavior. Not a single one of them fulfils the conditions of the 2,000-watt society.

consumption in the industrialized countries to 2,000-watts per inhabitant – the global mean. The energy freed up as a result could then be used to help combat poverty and hunger all over the world, without affecting the standard of living in the Western nations. The city of Basel served as a pilot region and the citizens of Zurich also flocked to the polling station to vote in favor of the 2,000-watt society. Along with energy consumption, the emission of greenhouse gases was also to be reduced to the equivalent of one ton of CO₂ per person, per year.

The Swiss population’s current energy consumption, however, still by far exceeds the sustainability target, as the annual energy statistics issued by the Federal Office for the Environment (FOEN) reveal. Nevertheless, such statistics use a “top-down” approach, dividing the total consumption by the number of inhabitants. Consequently, researchers from Empa and ETH Zurich set about analyzing Switzerland’s ecological footprint in detail from the “bottom up,” i.e. starting with the individual. The researchers hoped to find households that already met the criteria of the 2,000-watt or one-ton-CO₂ society today. Based on these examples, they would be able to work out groundbreaking sustainability strategies. 3,369 households completed a questionnaire on housing, mobility,

diet, and consumer goods. With the aid of the “ecoinvent” database maintained at Empa, the researchers determined the individual energy consumption and resulting greenhouse gas emissions and the overall influence of individual households on the environment.

Western lifestyle and the 2,000-watt society – a contradiction in terms?

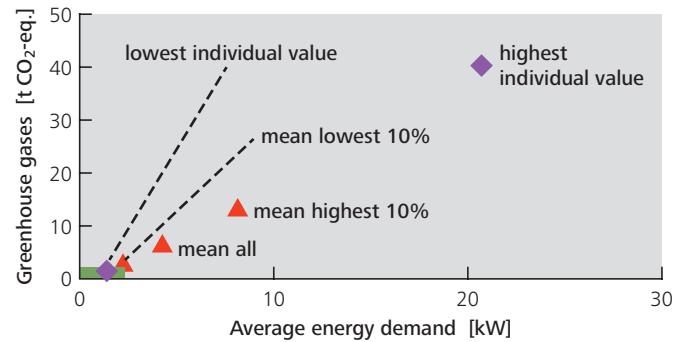
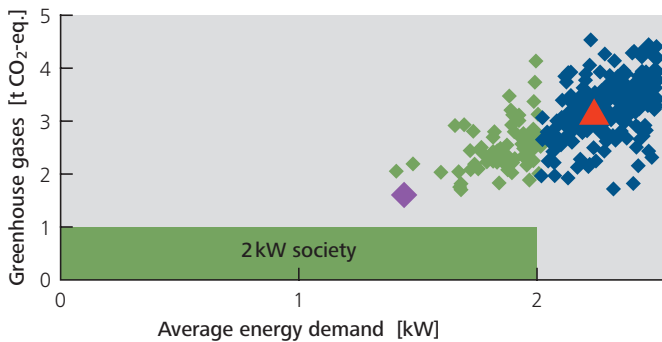
The results were sobering: of the 3,369 households, not a single one met the conditions of the 2,000-watt society. Only two percent of the respondents consume less energy than “allowed” – and even they emit way more than one ton of CO₂. And that’s not all: Only around a quarter of the energy is consumed as electricity, which means that a massive reduction in the overall energy consumption cannot be achieved with more economical electrical appliances alone. After all, the majority of the energy goes into heating and mobility. The most economical households actually performed particularly well here. For instance, the heated area per person was small and the heating requirements low. Such households also showed restraint with regard to mobility, limiting the amount they drive and fly. As a result, the researchers also see the most potential in living and mobility behavior. Precisely in so-called low-energy households, however, the heated area per person is too large.



Sufficiency is inevitable

Nonetheless, the researchers feel that reducing the energy consumption in the industrialized nations to the targets of the 2,000-watt society is still within the realms of possibility – albeit with “the maximum amount of effort.” In the case of greenhouse gas emissions, however, it is a different story: Switzerland would have

to produce around 80 percent of its energy needs from low-carbon sources, which, with the scheduled decommissioning of the nuclear power stations, means renewable energies – and not only for electricity, but also heating and mobility. This demands significant technical progress – and a change of lifestyle, as the study concludes.



Not one of the households surveyed meets the conditions of the 2,000-watt society fully: even for Swiss people who are economical with their energy, the CO₂ emissions are too high. The figure depicts the lowest individual value (purple) and the average of the most sustainable 10 percent (red) among the respondents.

Although the average environmental burden of all the respondents is relatively low, it exceeds the guideline values of the 2,000-watt society several times over: The highest level of energy consumption recorded is ten times higher than the targets of the 2,000-watt society and the resulting CO₂ emissions even 40 times higher.

Wristband revolutionizes blood-pressure monitoring

Blood-pressure measurements and monitoring are an arduous process for patients. A cuff that kicks in every 15 minutes for several hours and squeezes the upper arm, an annoying measuring device on the body and, if need be, even invasive monitoring, where a catheter is inserted

into the artery, are par for the course. No wonder those affected avoid the procedure if they can help it. A new sensor that is barely bigger than a wristwatch, however, should soon provide a more pleasant method to take blood pressure. The company STBL Medical Research AG is about to release a device on the market that can be worn comfortably on the wrist and records the blood pressure permanently – without so much as a tight cuff or invasive intervention in sight. It

takes the measurement by simultaneously gauging the contact pressure, pulse and blood flow on the surface of the skin near the wrist using various sensors.

Empa sensor heightens measurement accuracy

The contact pressure of the new device on the skin changes constantly, which is why highly sensitive corrective measurements are necessary. With this in mind, a team of researchers from Empa set about finding a suitable solution to the problem within the scope of a CTI-funded project. A sensor made of piezo-resistive fibers in the armband gauges the contact pressure on the skin. If the signal strength changes due to slipping or muscle contractions, it can cause measurement errors. The Empa sensor measures these changes precisely, enabling the readings to be corrected accordingly.

0.3

millimeters is the diameter of the Empa fiber made of carbon black and a thermoplastic elastomer that makes the blood-pressure gauge so accurate.

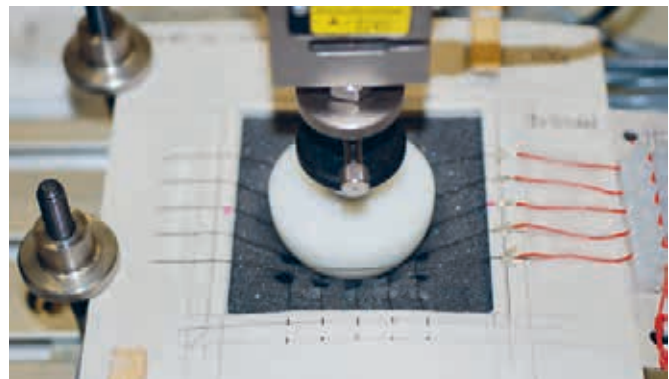
The electro-conductive fiber detects changes in position or pressure and converts them into an electrical signal, which it then transmits to the measuring device, thereby increasing the accuracy of the “blood-pressure watch” by over 70 percent. Meanwhile, tests have confirmed the performance of the sensors. Empa is now working hard to integrate the piezo sensor in the device in such a way that is not just visually attractive; it should also be easy to install.

Optimum results with optimum material

Empa’s sensor material, which makes the blood-pressure gauge work so precisely, consists of carbon black (CB) and a thermoplastic elastomer (TPE), extruded as fibers with a diameter of 0.3 millimeters. If the fibers are stretched, such as during a muscle contraction, for instance, the electrical resistance of the material changes, enabling reliable blood-pressure readings. Based on additional analyses, the Empa researchers were able to confirm that, compared to commercial piezo-resistive monofilaments, the CB/TPE fibers are considerably more accurate. However, the blood-pressure watch will not be the only use for flexible hybrid fibers in the future; the Empa researchers also envisage numerous interesting applications in the clothing industry, in architecture, and robotics.



Prototype of the “blood-pressure watch” with the Empa strap made of piezo-resistive fibers.



The fibers for measuring the contact pressure are produced at Empa. A constant current flows through the individual fibers. If they expand, their electrical resistance changes.

Wind energy? The sky's the limit!

A kite, a drum and a control panel – these are the core components of a new method to generate energy. The aim: to “harvest” electricity from wind using kites, which is precisely where TwingTec, a brand-new Empa spin-off, comes in. One key element is the kite’s Tensairity support structure, developed at Empa’s Center for Synergetic Structures.

50

kilowatts is the amount a TwingTec plant is expected to produce – and at a weight of just two tons. By contrast, a wind turbine with a comparable output is around 15 times heavier.

The operating principle is simple: the high-tech kite is attached to lines wound around drums at the ground station and soars way up into the air, which creates a pull on the lines and the drum starts turning. From this movement, electricity is generated through electro-magnetic induction. Once the kite reaches its maximum altitude, the drum reels it back in so that it can embark on a fresh climb and provide more power. The support structure is based on ultra-light Tensairity bars made of rods, cables, and a membrane, sta-

bilized with air at slight excess pressure. The kite is supposed to climb to 300 meters, withstand the tremendous wind power “up there” and soon supply our households with clean electricity from dizzying heights.

Follow-up project already underway

By the spring of 2013, the Empa researchers were already in a position to demonstrate the technical feasibility of the concept – and founded the company TwingTec AG shortly thereafter. The team is now launching the next phase. Joining forces with Empa, ETH Zurich, and the

University of Applied Sciences and Arts Northwestern Switzerland, the young company submitted a CTI project, which got underway in January 2014. Over the next year and a half, the aim is to create a demonstrator, followed by the first pilot plants in late 2015. This means a new ground station, optimized wings for the kite and a mechanism that controls the kite automatically.

Already under discussion at home and abroad

The spin-off is already in talks with its first prospective customers, who recognized the advantages of the method. An environmen-

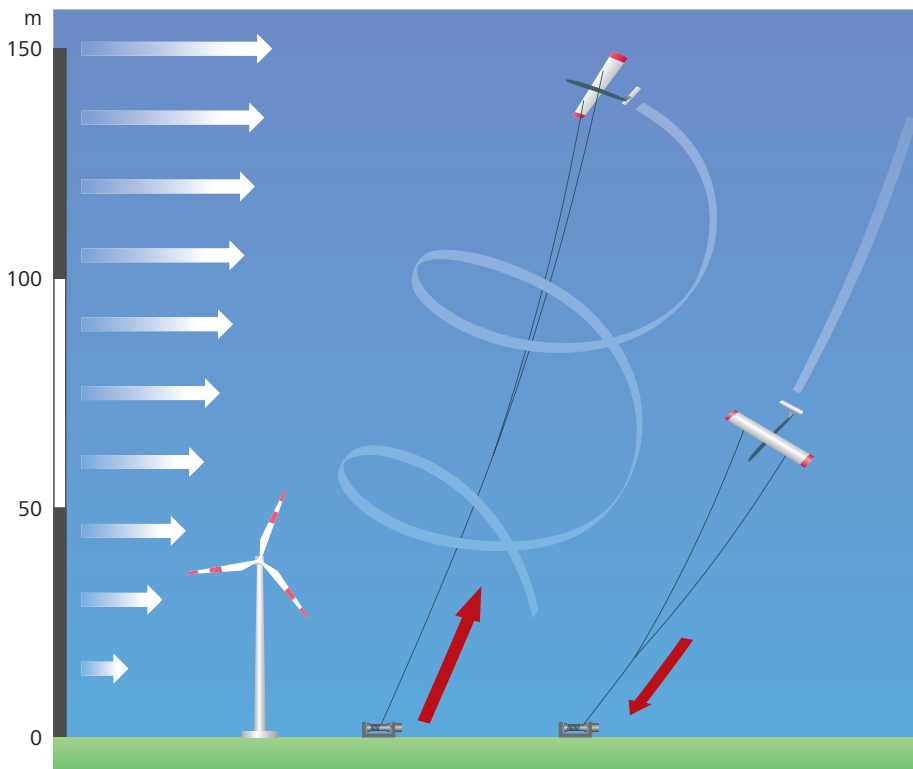
tally conscious farmer from Central Switzerland who already operates solar panels and a small wind turbine has offered his land for the kite tests. Meanwhile, many farmers have become interested in using their land for sustainable energy production, too. However, it is not only in Switzerland that the novel power generation method has sparked high hopes: a Nepalese monk is also on board. He runs a school in a village way up in the Himalayan mountains, but the lack of energy sources is restricting its development enormously. In wintertime, for instance, he is forced to close the school as there is no heating for want of sufficient ener-



The TwingTec kite based on Empa's Tensairity technology.

gy resources. Research is currently being carried out into whether the kite can also help solve the problem in Nepal: TwingTec has installed a wind gauge on site, which will record the local wind conditions for a year to aid future planning. The advantage of the TwingTec technology: compared to wind turbines, the plants are

very easy to set up and operate and do not require any major installation or complex building work. And they are much cheaper to buy, which means they can easily be used in areas with limited infrastructure, such as in remote regions or emerging and developing countries.



The kite can tap into wind power at altitudes of up to 150 meters, a conventional wind turbine only around 50 meters. The kite climbs in a circular motion while the pull generates electricity. As soon as the kite reaches its maximum altitude, it is reeled back in and starts climbing all over again.

New skin for chronic wounds

The number of people suffering from chronic wounds all over the world will continue to rise. One segment of the population that is particularly affected and is growing everywhere are the

elderly who often already suffer from diseases such as diabetes.

In the CTI-funded project Revcel®, Empa and the Lucerne-based company Nolax made a significant step towards a solution for the problem by developing a cell carrier or “scaffold” from synthetic material that supports the body to heal wounds. What is so innovative about the concept is that this scaffold – a small, spongy cushion made of polyurethane – is applied to the wound and gradually populated by connective tissue cells while the body breaks down the synthetic material, leaving nothing but a newly formed layer of skin and a clearly lesser scarring.

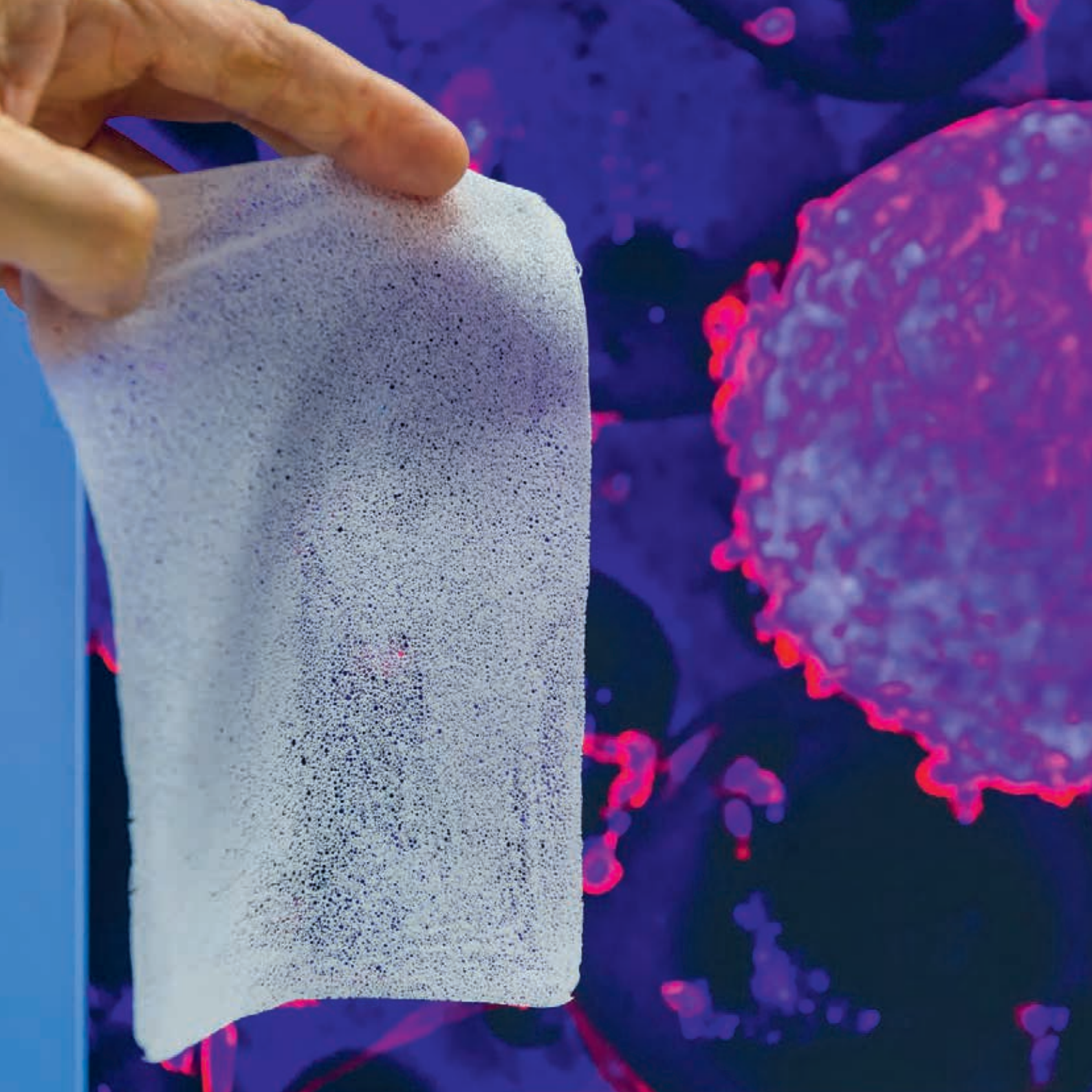
50,000,000

people are estimated to suffer from chronic wounds all over the world, e. g. due to malnutrition, diabetes, or vascular disease. Usually, a wound should heal within four to six weeks. Beyond that, any wound can become chronic.

When the job is done, the material simply dissolves

Although similar scaffolds already exist, they are often produced from animal products, which make them expensive and carry the risk of transmitting diseases. By choosing synthetic materials, however, both drawbacks can be eliminated. Empa’s industrial partner Nolax has decades of experience in the synthetics industry and has had products for medical applications on the market for quite some time. In 2009 the SME had its polyurethane-based scaffold patented. With Empa they found a perfect partner to develop its idea to the “proof-of-concept” stage:

New development: the original foamy scaffold (left) and in close-up.
(Photo: CTI, Alessandro Della Bella)



Contact

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Empa cell biologists and toxicologists provided the necessary expertise and experience in compatibility testing. Tests using different cell culture systems were conducted to optimize the material composition and the structure of the scaffold so that it is non-toxic, supports cell growth and dissolves completely without any side effects.

Cell culture tests inspired by real life

The tests devised by the Empa team represented the real-world situation very closely. In a highly complex process, the researchers created three-dimensional cell clusters composed of human connective tissue cells and verified whether cells from these clusters actually do colonize the scaffold, thereby mimicking the natural conditions in a wound much more effectively than today's usual tests with single cell cultures. Based on the results, Nolax continued to adapt the formula for the scaffold and improve its structure. Both teams worked very fast, carrying out, in total, over 100 series of experiments.

Last but not least, the results were verified in animal models at the University of Zurich's Veterinary Hospital – with convincing results. Using the scaffold, the wounds healed even faster and more effectively than the researchers had hoped for at the outset of this project. The results also impressed the judges at the CTI MedTech Awards 2013; out of around two dozen projects Revcel® was nominated for the prize in August along with two other contenders.

Nolax is currently working on a concept to produce scaffolds for clinical trials. Empa is also continuing its research in this field. As a next step, the Empa team is expanding the 3D cell culture concept and in future plans to employ it to gain insights into the immune-compatibility of the novel scaffolds.



Arie Bruinink and his team brought the necessary know-how to the table for the development of the new wound-healing scaffold.

(Photo: CTI, Alessandro Della Bella)

Turning excess electricity into synthetic natural gas

“Power-to-gas” is a key concept when it comes to storing alternative energies. It involves converting short-term excess electricity from photovoltaic and wind plants into hydrogen. Add to this the greenhouse gas CO₂, say from biogas production, then methane can be produced, which can be distributed easily and cost-effectively through the natural gas network and stored for longer periods of time. A “quasi-fossil” fuel is thus produced from renewable energies – the fundamental principle of “power-to-gas.”

20

nanometers is the diameter of the catalyst’s nickel particles. The pores, in which water accumulates, are only 0.5 nanometers wide.

Optimization with zeolite

Although the so-called Sabatier reaction, which produces combustible methane from hydrogen and CO₂, is nothing new; Empa researchers have now succeeded in optimizing the process significantly. In order to trigger the reaction between CO₂ and hydrogen using as little energy as possible,

a catalyst is required, which can be made of nickel, for instance. The gas molecules react more easily with each other on the surface of such a catalyst and the amount of energy required decreases, which is referred to as “sorption catalysis.” The Empa researchers have now combined a nanoscale nickel catalyst with a zeolite. Zeolites are crystalline aluminosilicates that are capable of absorbing water molecules and releasing them again when heated.

The principle is straightforward: during the chemical reaction between hydrogen and CO₂, both methane (CH₄) and water (H₂O) are produced. The researchers use the zeolite’s hygroscopic (i. e. water-binding) property to remove the water from the reaction mixture. This shifts

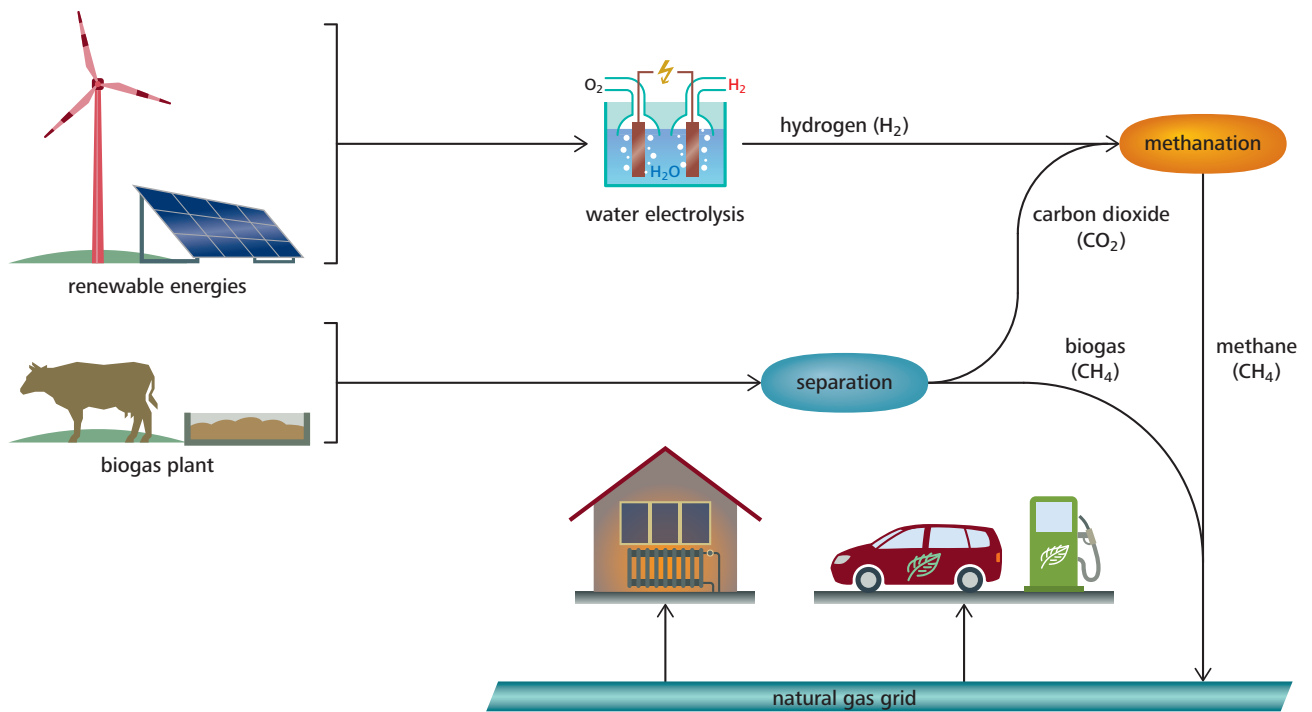
the chemical equilibrium towards methane, resulting in a higher yield of pure methane and thus greater efficiency of the catalytic process. As soon as the zeolite becomes saturated with water, it can be “unloaded” by heating, evaporating the water, and reused.

Further research in the pipeline

The process works – albeit at present only in the lab. The Empa researchers are currently on the lookout for industrial partners to build a methanation plant on a larger scale and use it as a pilot project. At the same time, the team would like to optimize the process even further. The next step is to use four or more sorption catalysts simultaneously. When one becomes water-saturated, the system automatically switches to the next “dry” catalyst while the previous one is already being “unloaded.” In future, however, new catalyst materials that are more efficient than nickel are conceivable in combination with novel zeolites and could improve the Sabatier process even further. This would mean that excess eco-electricity is no longer a disposable commodity but rather used as the basis for sustainable natural gas.



Zeolites bind the water produced during hydrogen methanation, thereby increasing the new process's methane yield.



Hydrogen can be extracted from excess green electricity at certain times of the day. It is combined with CO_2 from crude biogas to form methane in a special reactor. A valuable climate-neutral fuel has been made from waste materials and "waste energy."

Highly efficient flexible solar cells on their way towards industrial production

In order to provide solar power at an affordable price, scientists and engineers have long been striving to develop low-cost solar cells that are highly efficient and can be produced in large quantities. Empa researchers have now come another major step closer to this goal: they developed a new method for producing highly efficient thin-film solar cells out of CIGS (copper indium gallium diselenide) semiconductors, which involves incorporating tiny amounts of sodium and potassium into the CIGS layer. This special treatment alters the chemical composition of the complicated sandwich structure – and thus its electronic properties, as detailed electron microscope studies revealed. The details of the new method were published in the renowned journal “Nature Materials” in November 2013.

20.4

percent of solar energy can be converted into electricity by the latest record-breaking solar cell made of CIGS semiconductors. The thin-film cells are therefore just as efficient as their conventional silicon counterparts.

Catching up with silicon solar cells

This enabled the Empa researchers to greatly increase the efficiency for the energy conversion of sunlight into electricity with CIGS on flexible plastic foils – to an all-time high of 20.4 percent, a significant improvement on the previous record of 18.7 percent, which the same team notched up in May 2011. This means that CIGS cells are – at long last – able to keep up with the best polycrystalline silicon solar cells but with the additional advantage of flexibility and lightweight.

Until recently, the Empa CIGS cells were even the most efficient worldwide. Then following the achievements and processes of Empa, at the end of October, a German team at the Cen-

ter for Solar Energy and Hydrogen Research (ZSW) in Stuttgart showcased CIGS cells with an efficiency level of 20.8 percent, albeit with considerably higher production temperatures and on (rigid) glass as substrate. This marginally new record just goes to show that CIGS thin-film technology is a “hot” topic – and Empa is right at the cutting edge. The CIGS projects were funded by the Swiss National Science Foundation (SNSF), the Commission for Technology and Innovation (CTI), the Swiss Federal Office of Energy (SFOE) and the EU framework programs.

Highly efficient, light and flexible thin-film solar modules are ideal for numerous applications, including large-scale solar farms, on roofs, façades or portable electronic devices. They can be produced using “roll-to-roll” manufacturing, which facilitate additional cost savings compared to silicon technology and thus have the potential to actually make solar power affordable in the near future.



Thin-film flexible CIGS solar modules developed by Flisom in collaboration with partners of the “Flexible PV Systems” project (©2013 Flisom AG).

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From the lab to a 15-megawatt plant

The Empa researchers are currently working intensively to improve the “formula” even further – and to support upscaling from the lab to be able to produce larger modules for various industrial applications, too. Empa’s partner in the project is Flisom, a young company with the aim of industrializing flexible CIGS solar cells.



Empa researcher Stephan Bücheler removing a CIGS cell from the evaporator: a mixture of copper, indium, gallium, and selenium was deposited on the plastic carrier foil in high vacuum – hence the acronym CIGS.

At the end of February, Flisom managed to attract a Swiss investor and the previous strategic partner, the Indian industrial giant Tata, for a third round of funding and thus finance the construction of a production facility with an annual capacity of 15 megawatts. The plant is intended to serve as a prototype for facilities to produce flexible solar modules inexpensively on a major industrial scale.

Kesterite, a mineral with potential

Kesterite, a mineral compound composed of copper, zinc, tin, sulfur, and selenium, is another very promising material for highly efficient, affordable thin-film solar cells. One major advantage is the practically inexhaustible supply of the raw material. So far, the highest efficiency with this material achieved by IBM is merely 12.6 percent, however – still some way behind that of CIGS cells. Empa researchers are currently working on cost-efficient chemical printing methods that can be used to manufacture highly efficient kesterite solar cells.

High-performance battery of the next generation

The chemical foundations for today's extremely popular lithium-ion batteries were discovered at the TU Munich in the 1970s by J.O. Besenhard. A few years later, researchers from Oxford University found just the right material for the cathode: lithium-cobalt(III)oxide. However, it

wasn't until 1991 – 15 years after the initial results – that Sony launched a lithium-ion battery on the market to power a video camera. Nowadays, these power cells fuel billions of cell-phones, cordless screwdrivers, cameras, and electric toothbrushes – and a few thousand electric cars all over the world, too. However, we are gradually running low on lithium as a raw material. New ideas are thus needed.

One of the visionaries working on the next generation of batteries is Maksym Kovalenko. The Ukrainian national has been teaching at ETH Zu-

rich for the last two years and conducts research with his group at Empa. His specialty: finding alternative materials for batteries of the future and building electrodes out of nanoparticles that accelerate the chemical processes in the battery. The battery charges more quickly, can provide power more effectively and suffers less wear and tear. The solution might well be to combine these two strategies: new materials that only work well on a nanoscale.

There are already early indications of a future battery technology. One promising candidate is the sodium-ion battery. As the global sodium reserves are far greater than those for lithium – and not scattered as irregularly around the globe, either – a sodium-ion battery would solve many problems. However, the resource advantage comes at a (chemical) cost: sodium ions are

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nanometers is the size of the nanocrystals made of the semi-metal antimony. They could serve as an anode material in future sodium-ion batteries.



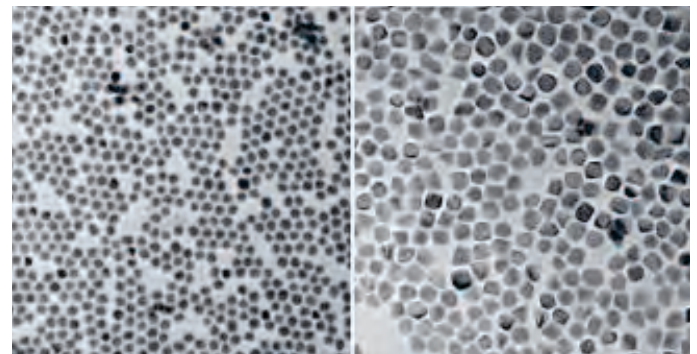
In 2013 Maksym Kovalenko received the Ruzicka Prize for his work. The award, named after Nobel Prize-winner Leopold Ruzicka, has been presented to budding researchers for outstanding achievements in the field of chemistry since 1957. The Selection Committee has already discovered countless talented young scientists over the years: prize winners include Richard Ernst (magnetic resonance, Nobel Prize 1991) and Charles Weissmann (prion research). The prize money is endowed by the Swiss chemical industry.

40 percent larger than lithium ions, which means they cannot be stored in graphite. This renders the previous anode technology based on lithium storage in graphite pretty much useless.

The search pays off

The Empa team recently struck gold in the search for a suitable material: nanocrystals made of antimony with a uniform diameter of 20 nanometers turned out to be the “best anode material for sodium-ion batteries discovered so far,” as the team wrote in a publication in the journal “Nano Letters.” What’s more, the researchers found that there is also an ideal size for the nanoparticles to function most effectively.

The Empa researcher stresses that he does not research technical solutions, but suitable concepts for the future. And while many variants have already been calculated and tested for lithium-ion batteries, a lot remains a mystery for other battery types. Currently, we only know about one tenth of a percent of the chemistry that could be used in future, Kovalenko estimates. With his nanostructured materials, however, the Empa researcher has ventured the first step into this “new” chemistry.



Antimony nanocrystals in the electron microscope: The crystals are all the same size. They are regarded as the best anode material for future sodium-ion batteries to have been found so far.

In minute detail

Researchers from Empa have spent the last two years evaluating and constructing a special class of scanning transmission electron microscope (STEM) at the Binnig and Rohrer Nanotechnology Center in Rüschlikon in conjunction with IBM. It is located in a special lab for extremely sensitive measurements: the “noise-free lab” does not just offer protection against seismic and acoustic interference; it also prevents temperature fluctuations and shields electromagnetic fields. The combination of the special lab and top-class electron microscopy stands to make measurements with unprecedented precision in Switzerland possible in future.

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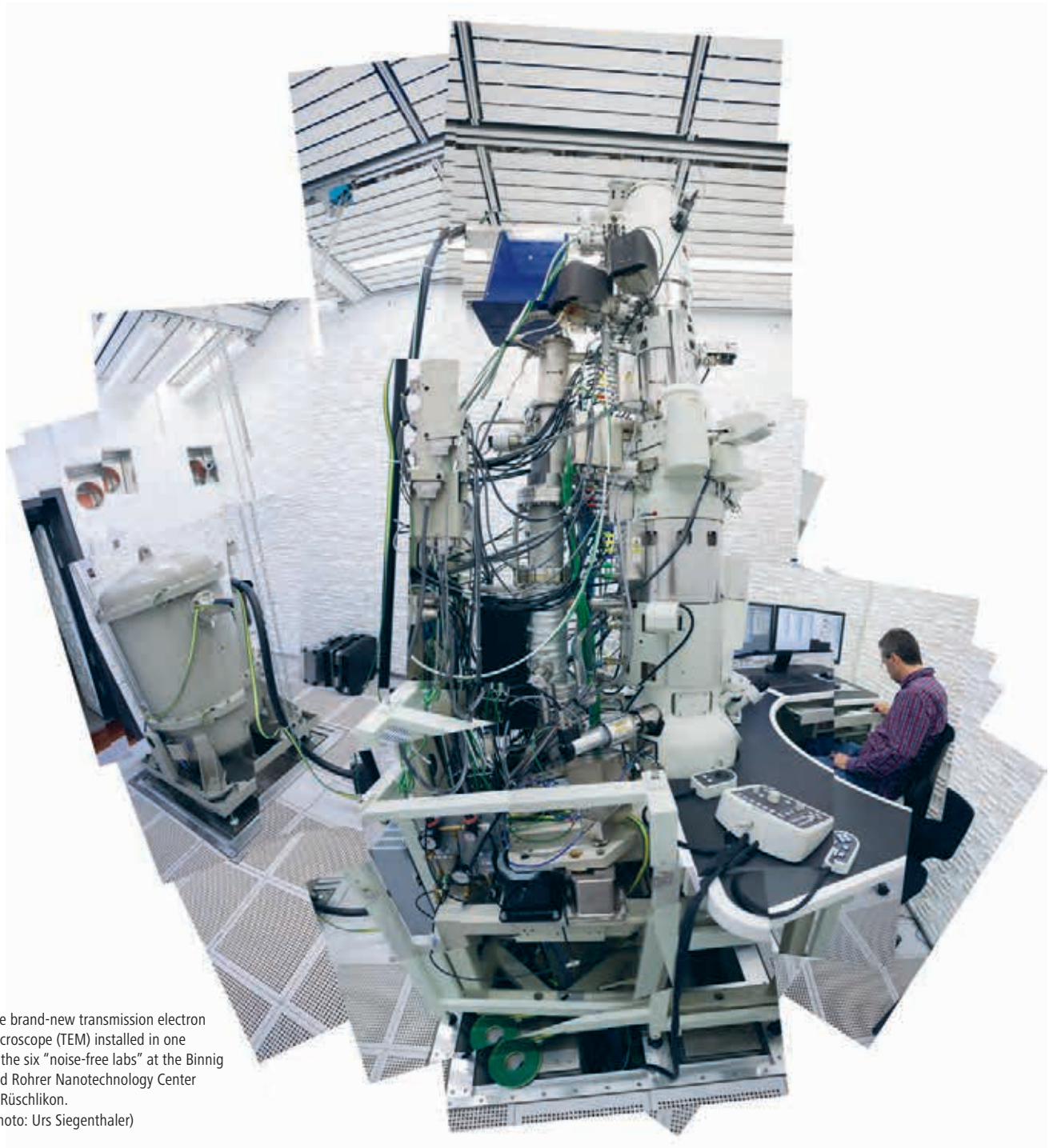
**meters is the resolution of the scanning transmission electron microscope in IBM’s “noise-free lab.”
It is able to display details that are smaller than the diameter of a single atom.**

extremely sensitive measurements: the “noise-free lab” does not just offer protection against seismic and acoustic interference; it also prevents temperature fluctuations and shields electromagnetic fields. The combination of the special lab and top-class electron microscopy stands to make measurements with unprecedented precision in Switzerland possible in future.

Expertise and intuition

During the collaboration, the competences the researchers from Empa’s Electron Microscopy Center brought to the table were just what the

doctor ordered. They have considerable experience in preparing samples that are merely 10 to 100 nanometers thin and know precisely how to handle highly sensitive electron microscopes. They had already succeeded in taking unparalleled pictures using the STEM at Empa: in order to depict lithium iron phosphate particles in 3D, the researchers scanned samples with an electron beam and detectors beneath the samples registered how many electrons were scattered in the process. This data gave rise to so-called dark-field images, where areas with higher densities appear lighter – much like an X-ray image. For a three-dimensional representation, the samples were gradually tilted by one to two degrees over an angle range of around



The brand-new transmission electron microscope (TEM) installed in one of the six "noise-free labs" at the Binnig and Rohrer Nanotechnology Center in Rüschlikon.
(Photo: Urs Siegenthaler)

150 degrees. This yielded over 100 images, from which the 3D structure of the nanoparticle could be reconstructed with the aid of complex computer algorithms. What might sound straightforward enough actually requires a healthy dose of expertise and experience to interpret the tomogram correctly. The results afford the scientists a glimpse inside materials. For instance, they can see whether nanoparticles have a different chemical composition in the core compared to their surface.

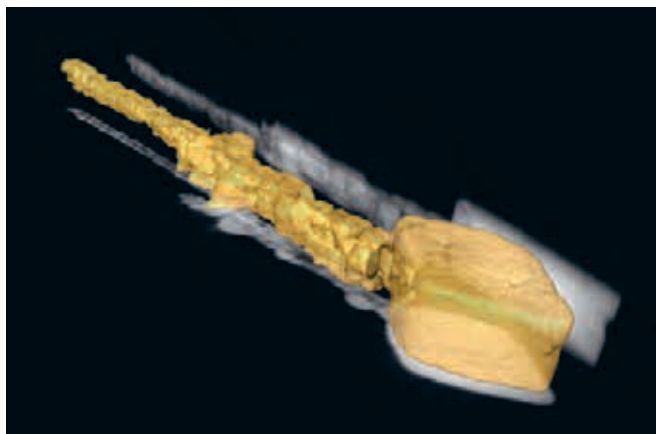
However, the STEM also helps to analyze ultrathin and boundary layers. This is how we know that barium titanate (BaTiO_3) reacts so quickly and strongly to electro-optical signals, for example. It would thus be just the ticket as a material for high-speed switches in photonics – the optical transfer of information. In a study published in the journal “Nature Communications” in April 2013, the researchers demonstrated that BaTiO_3 also retains the desired properties as an ultrathin layer grown on silicon – and therefore could actually be used in silicon photonics. Their goal is to run circuits with light instead of electrons in future. This could enable network components to be separated from each other geographically and thus more efficient server structures to be created.

A STEM for the “Champions League” of materials analysis

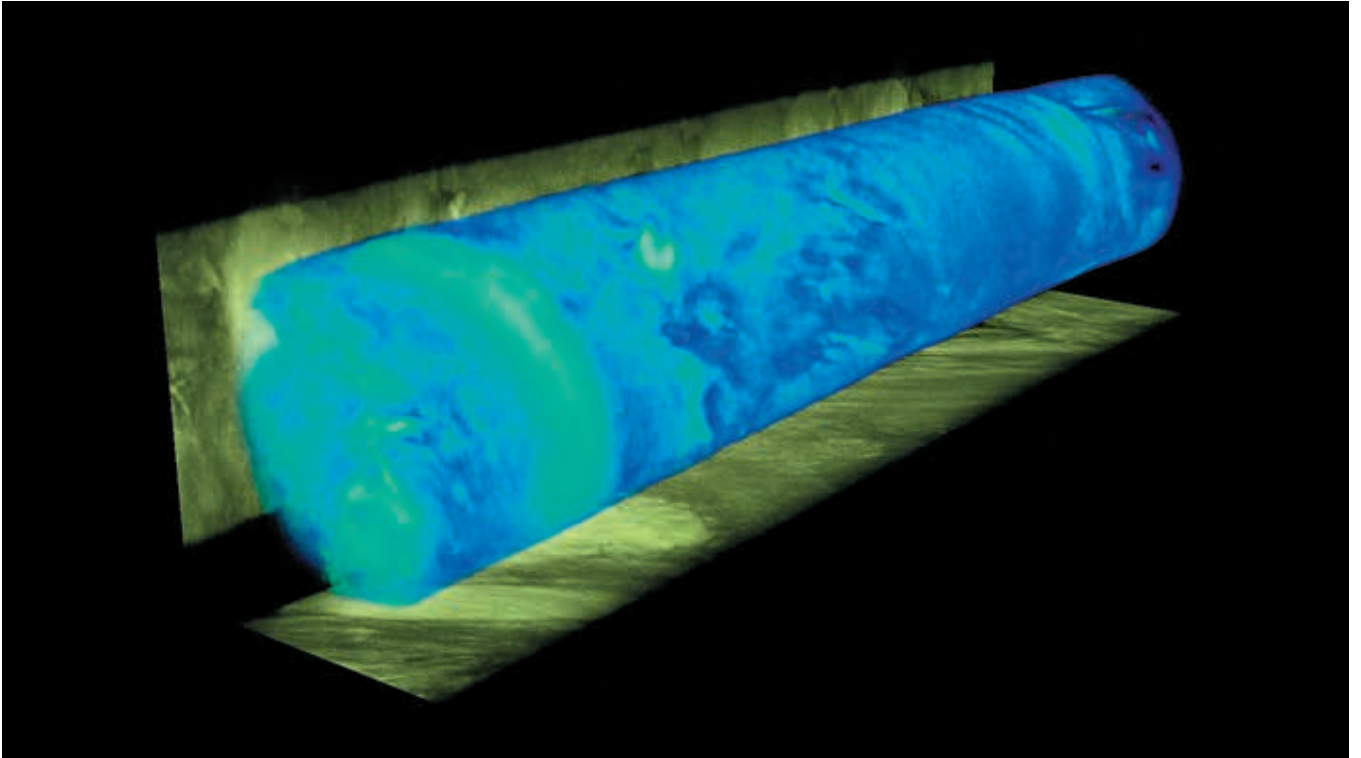
As initial tests revealed, the new STEM at the IBM Nanotech Center makes resolutions in the sub-Angstrom range (i. e. under

10^{-10} m) possible. Consequently, it is able to display details of the matter’s structure that are smaller than the diameter of a single atom.

However, the new STEM not only offers a higher resolution but also innovations: as with all optical elements, image defects or blurring also occur with electromagnetic lenses. Not all electrons come back together in one point after they have passed through a lens, for instance. Consequently, the new device has two cor-



3D view of a lithium iron phosphate particle, as found in Li ion batteries.



Opalinus clay, a possible barrier material for nuclear waste.

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rectors to rectify the spherical image defects and a cold field emission canon, which can direct the electron beam onto the sample at different voltages – 200 kV or 80 kV. Low voltage is advantageous if sensitive materials such as graphene or crystal-line interfaces are to be studied. High voltage is used if maximum resolution is required: at 80 kV, the resolution is around 0.14 nm; at 200 kV below 0.08 nm.

Sensitive materials are also the focus of the three-year project Atomic EELS funded by the Swiss National Science Foundation (SNSF), which was launched in 2013 with Empa at the helm. The objective is to determine the electronic structure, binding behav-

ior and oxidation state of different chemical elements with the aid of the new STEM and based on electron energy-loss spectroscopy (EELS for short). With a better resolution, more fine structure of the spectra can be seen. In order to interpret what these now mean, however, theoretical calculations have to be used. Otherwise, the assertions will remain somewhat vague and leave how spectra reflect the physical properties of a material open.

Empa as junior partner

In December Empa's Board of Directors signed a contract with ETH Zurich, making Empa an official junior partner of the Binnig and Rohrer Nanotechnology Center in Rueschlikon. This grants its staff access to the unparalleled cleanrooms and equipment for micro- and nanofabrication.



The "noise-free labs" are special labs for extremely sensitive measurements.

Monitoring health electronically in everyday life

In a constantly ageing society, diseases of civilization lead to increasingly high costs. After all, most metabolic malfunctions are only diagnosed and monitored in hospitals through expensive lab tests. It would be better to permanently monitor patients electronically – wherever they are and with warnings in real time as soon as physiological parameters such as blood sugar or cholesterol get out of hand.

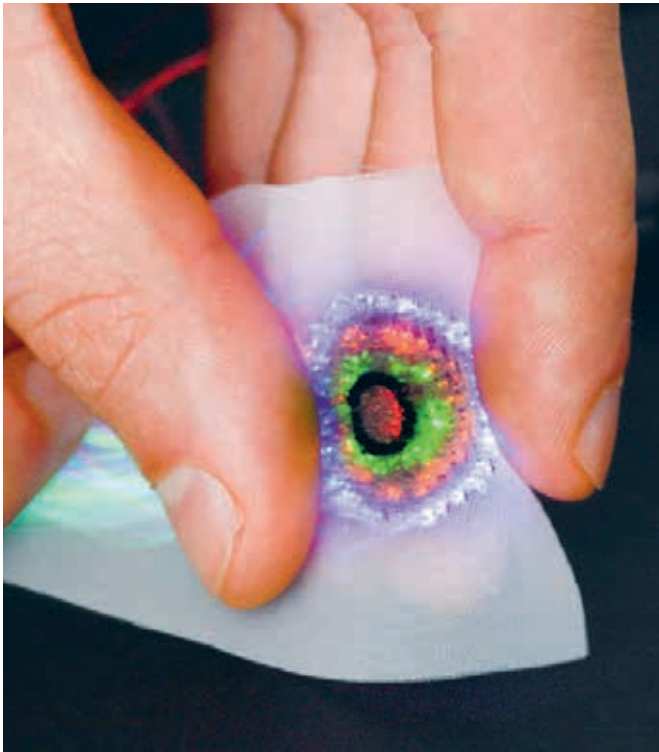
2,400

The number of kilocalories a 50-year-old male office worker weighing 75 kilos and 1.75 meters tall burns per day. A female clerk with the same measurements only burns 2,200 kilocalories. If the man were not in the office, he would burn 3,600 kilocalories daily.

Counting calories – through your T-shirt

One risk factor with various health effects is being overweight or obesity. Consequently, Empa researchers set about informing overweight people about their current calorie intake and consumption around the clock in the project Obesense. If this information were available in real time, it could motivate the person to change their eating behavior and reduce their weight for good. The crucial measurement data for calculating

calorie consumption is the respiratory rate and volume as it takes oxygen to burn carbohydrates. The more you breathe, the more you can burn, such as during physical exercise. The measurement involves stretching a light-conducting, elastic co-polymer across the patient's stomach and illuminating it with a light-emitting diode (LED). When the patient respire, the elastic fiber stretches and changes its optical conductivity. Less light reaches the integrated light sensor. The movement measured on the stomach can be used to determine the respiratory volume, which enables 24-hour monitoring of the calorie consumption.



How much oxygen is in your blood?

Another project that is also backed under the Nano Tera Initiative focuses on an alternative method for measuring oxygen consumption. A reading based on the so-called Fick's Principle requires three parameters: the blood volume pumped from the heart and the oxygen saturation in both the arteries and the veins. Two of these parameters, heart frequency and arterial oxygen saturation, can be determined easily using a pulse oximeter – a clip on the finger, toe or earlobe is sufficient.

It is harder to gauge the oxygen saturation in the veins as it varies greatly at different points around the body. However, this is made possible by a novel sensor shirt with several measurement points shining in the infrared range. Textiles researchers from Empa developed a light sensor for it from embroidered threads. Electronics currently being developed at the Centre Suisse d'Electronique et Microtechnique (CSEM) in Neuchâtel will be responsible for evaluating the signals.

Blood sensor analyzes metabolic products

In order to get a grip on metabolic diseases, we need to monitor certain signaling substances in the blood for a lengthy period of time. Although such online systems already exist, they are only for blood sugar levels and often used for diabetics. The aim of the project i-IronIC is to extend online monitoring to include sub-

Textile light sensor that is able to measure the oxygen content in the blood.
The sensor is flexible and washable and can be sewn into a monitoring T-shirt.

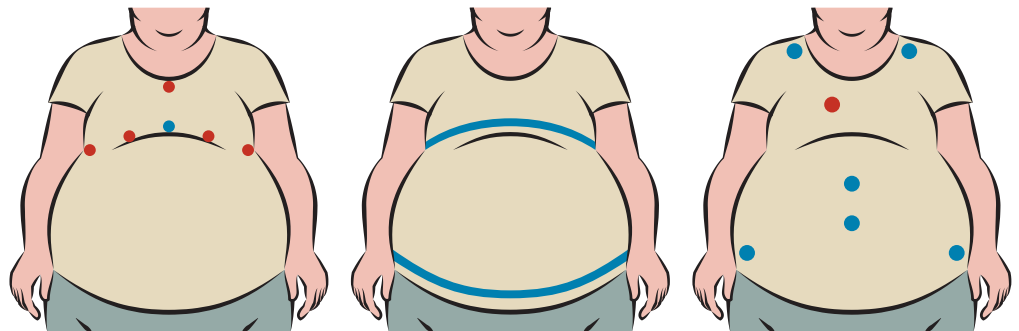
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stances that could only be recorded in expensive blood tests in the lab until now: lactate, cholesterol, ATP, and many more. This would enable cardiovascular diseases, chronic inflammation, and malnutrition to be detected more easily (and earlier). The biocatalysis experts from Empa involved in the project have been

isolating new redox enzymes that generate the necessary measurement currents and transfer them to the microelectronics, and integrating them in carbon nanotubes. The project's objective is an implantable blood sensor that is supplied with electricity from outside the body and provides data to the outside.



How the monitoring T-shirt works: six ECG sensors, one of which is on the back, monitor the circulation (left); flexible optic fibers measure the respiratory volume (center); light sensors gauge the oxygen concentration in the arteries and veins (right).

Nanoscale electronics

Graphene is a very special material: it consists of a carbon layer only one atom thick, in which the atoms are arranged in hexagons, much like a (flattened) honeycomb. Graphene is harder

than a diamond, extremely crack-proof, impermeable for gases and conducts heat extremely well. Moreover, due to its extraordinary electronic properties it is regarded as a possible substitute for silicon in semiconductor technology. Before graphene and related materials can be used in this field, however, there are a few hurdles to overcome. Firstly, graphene is not a semiconductor. It lacks a so-called band gap, which facilitates the insulating state in semiconductors. This means graphene cannot be “switched off,” it is always conductive. Consequently, Empa researchers set about developing methods to produce narrow graphene ribbons, which exhibit well-defined band gaps.

1
nanometer is the width of the graphene ribbons that can be produced using Empa’s “bottom-up” method.

searchers set about developing methods to produce narrow graphene ribbons, which exhibit well-defined band gaps.

Built, not cut to size

Until now, graphene ribbons have been “cut out” of graphene layers using lithographic or chemical methods. Due to the imprecise edges, though, the ribbons did not conduct adequately. Moreover, ultra-narrow graphene ribbons (so-called nanoribbons) with a band gap that would be suitable for electronic applications are not accessible via the traditional cut-out method due to its limited resolution. In order to get around this problem, the researchers developed a “bottom-up” method. This involved synthesizing graphene nanoribbons from

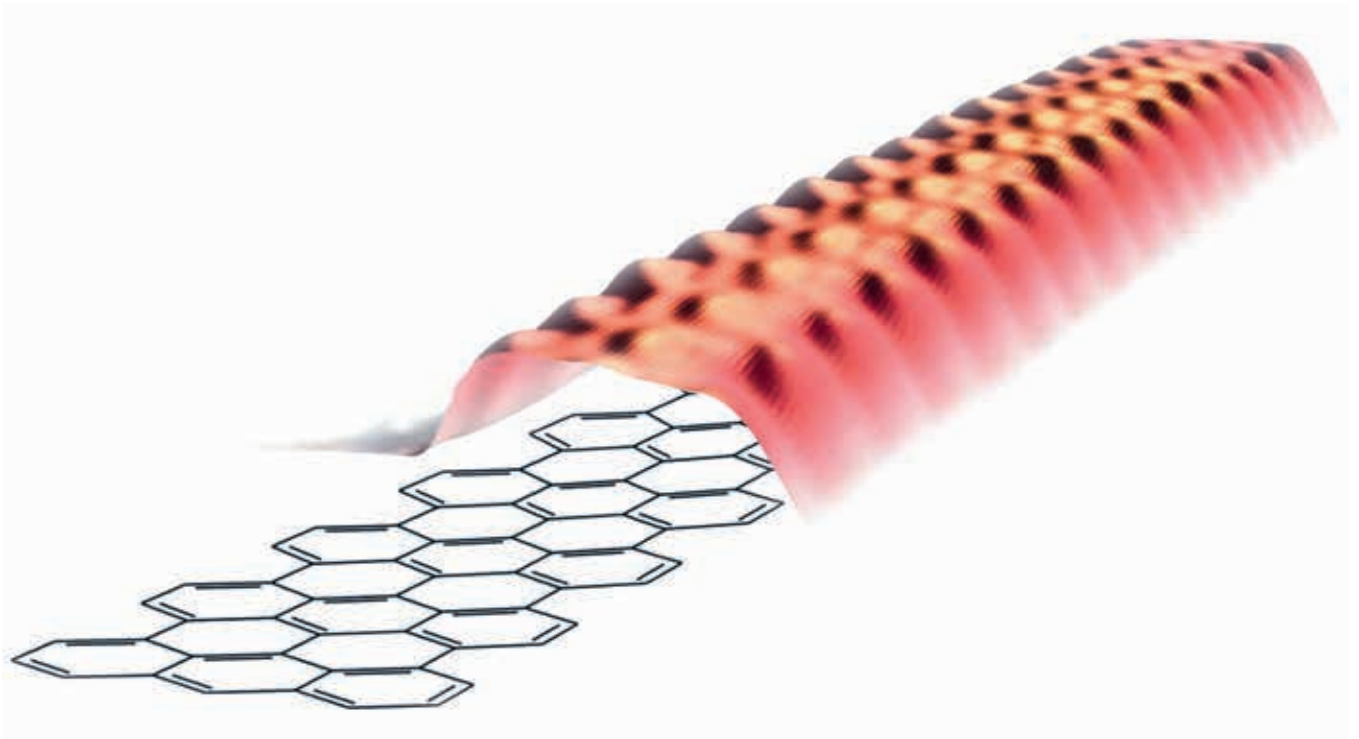


Image of a graphene nanoribbon taken with a scanning tunneling microscope.

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tailor-made precursor molecules via molecular self-organization, which enables these molecules – so-called functionalized polyphenylenes – to chemically link up with each other. In other words, the graphene ribbons are not cut to size; they build as it were “by themselves.”

For the time being, however, these graphene nanoribbons can only be synthesized up to a length of around 30 nanometers, the reason for which was also discovered at Empa: when the precursor molecules assemble into ribbons, hydrogen atoms attach themselves to the “coupling points” with a certain probability, preventing other precursor molecules from latching on, so the ribbon stops growing. The Empa researchers now aim to solve this problem and investigate the electronic and optical properties of the graphene ribbons more closely. With this in mind, a facility was recently constructed in a joint project with the company BASF that produces these graphene ribbons automatically following the “bottom-up” method. Four patent applications have already been submitted.

Moving closer to graphene semiconductors

One particularly exciting aspect of the “bottom-up” fabrication of graphene ribbons is the possibility of nitrogen doping by a simple modification of the precursor molecules, where some of the carbon atoms are replaced with nitrogen. The incorporation of nitrogen into the graphene ribbons alters their electronic properties. By assembling “normal” segments next to ones that have been doped with nitrogen, so-called heterojunctions and heterostructures can be produced. The researchers have already demonstrated that such heterojunctions exhibit similar properties to a classic p-n junction, i. e. a junction between positive and negative doping regions in classical semiconductors. These induce electric current to only flow in one direction if an external voltage is applied, or electron-hole pairs to be separated efficiently. But that’s not all: in future graphene could also be used in optical applications, such as solar cells. After all, the Empa researchers noticed that ultra-narrow graphene ribbons exhibit an unusually high absorption of visible light and should thus be well-suited as absorption layers in organic solar cells.

New prestressing material for the building industry: an iron alloy that remembers

Shape memory alloys (SMAs) return to their original shape automatically or under the influence of heat, even after major deformation. SMA materials are already used for spectacle frames, thermostats, stents, micro-actuators and much more.

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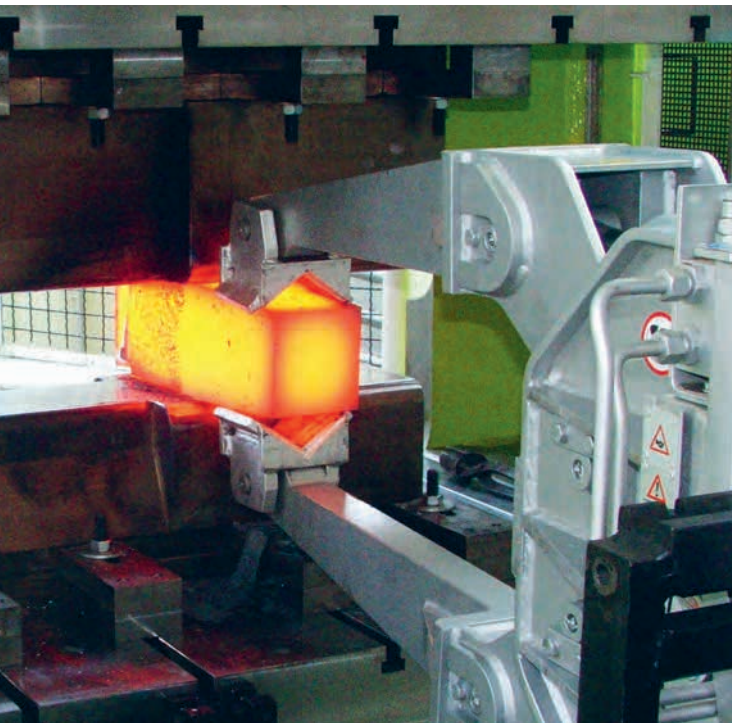
billion Swiss francs: according to the Federal Statistical Office, the amount spent on new buildings in Switzerland in 2012. One billion of this went on reinforced steel and around six million on prestressing steel. A market potential of around CHF 6 to 10 million a year is expected throughout Europe for the new alloy.

However, shape memory materials are not only interesting for medicine or expensive designer glasses; applications are also conceivable for the building industry. The first special applications using SMA were already demonstrated at Empa a number of years ago, still based on nickel and titanium at the time. If a concrete girder is reinforced with SMA bars, they can be “activated” with heat: they want to shrink back to their original shape. As they are cast in concrete, however, this is not possible, which creates prestress in the bars. The same effect can also be exploited in prestressing cables to prestress bridge decks, for instance. To prestress, the cable merely needs to be heated by passing electricity through it.

This replaces the complex devices with ducts, anchor heads, and stressing jacks with oil hydraulic, which makes the new technology an interesting alternative in the building industry.

Nickel-titanium not a must

Nickel-titanium SMAs, however, are far too expensive for this purpose. Besides the established nickel-titanium systems, there are also other shape memory alloys, those based on iron espe-



cially being of interest for construction. Nevertheless, until recently they had to be heated to 400 °C to activate the shape memory effect, which is far too high for use in concrete and cement or other temperature-sensitive materials. Empa researchers have now succeeded in developing a novel iron-manganese-silicon alloy that can already be prestressed at temperatures of around 160 °C, which concrete can withstand. The materials scientists designed virtual alloys based on thermodynamic simulations on the computer, which were then constructed in the lab and their shape memory properties studied – with positive results: several of the simulated newmaterials were appropriate to satisfy the demands of their civil-engineer colleagues – a milestone on the path towards affordable iron-based shape memory alloys for applications on an industrial (i. e. ton) scale.

The long road from the lab to finished product

Iron-based SMAs may have good prospects in the building industry. Prestressing is easier and thus cheaper than conventional systems with prestressing steel. Moreover, prestressed systems, including short-fiber concrete, column confining, near surface mounting reinforcement or ribbed reinforced steel bars, which are very difficult – if not impossible – to make using conventional methods, are even conceivable.

Forging an iron-based shape memory alloy (SMA) cast block:
to shape the block, it is heated to around 1,150 °C (Photo: TU Freiberg).

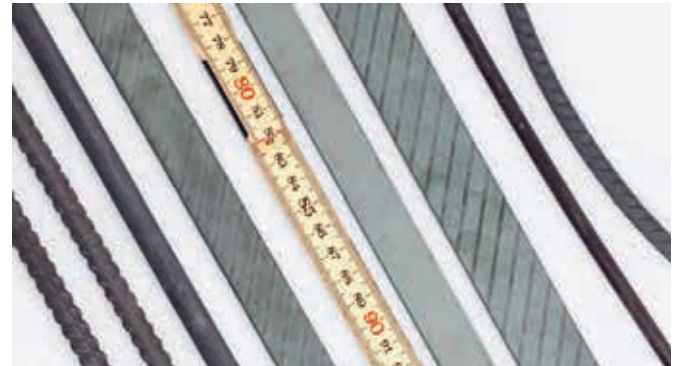
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A feasibility study funded by the Commission for Technology and Innovation (CTI) recently revealed that the new alloys do not merely work on a lab scale of a few kilograms; they could also be produced on an industrial scale. The practical production process was realized with partners including the University of Leoben in Austria, the TU Bergakademie Freiberg in Germany and the German company G. Rau GmbH. The reshaping of the cast block into two-millimeter-thick laminates or ribbed reinforced steel bars at temperatures of over 1,000 degrees requires tremendous expertise – and the right equipment. After all, the reshaping process had to be adapted to the novel alloys and optimized. The laminates produced in this manner stood up to the subsequent tests, which involved embedding them in grooves in the surface of the concrete.

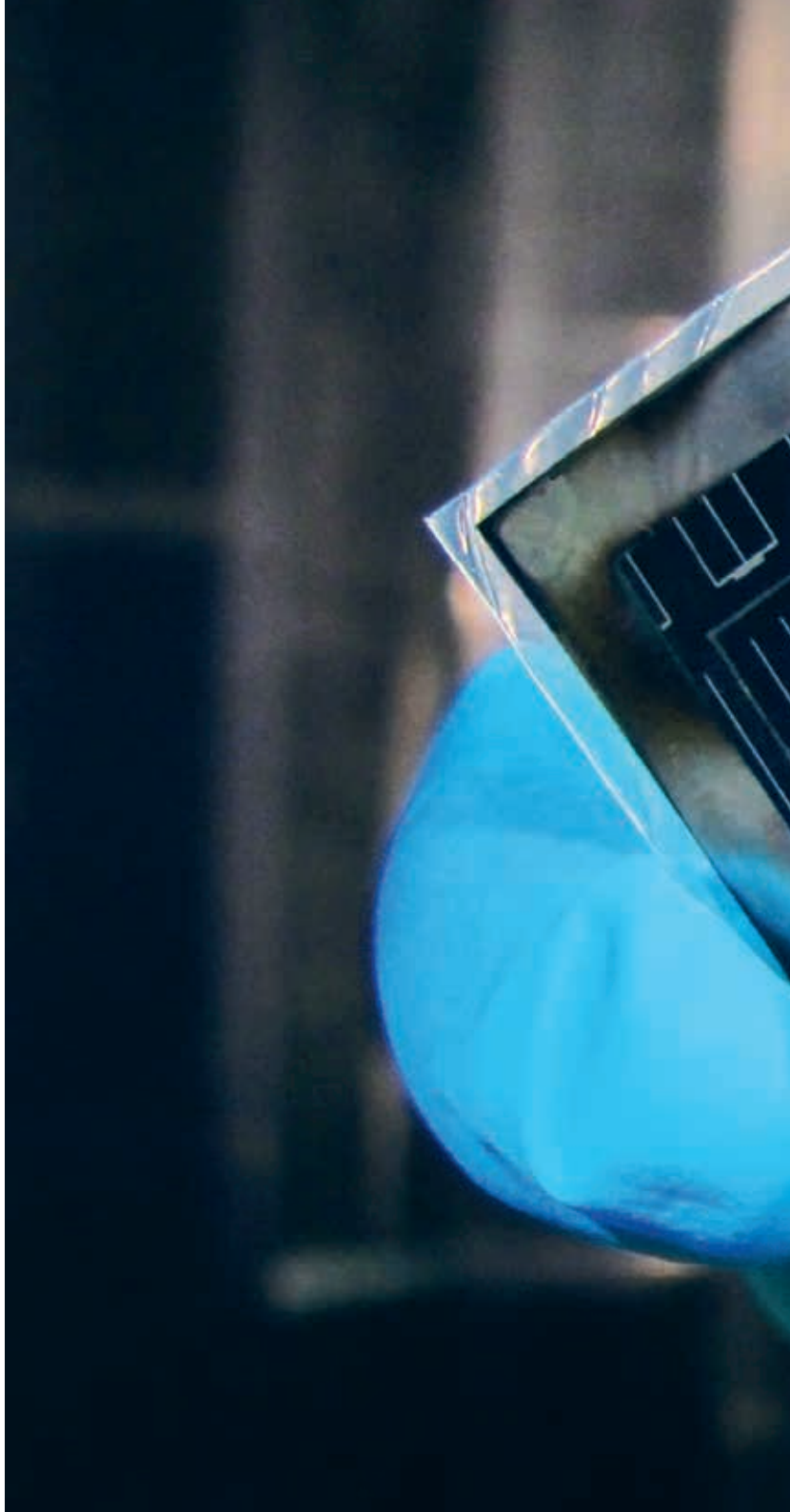
Building on the Empa developments, the start-up company re-Fer (www.re-fer.eu) was founded in 2012 with a view to producing and selling iron-based SMAs for industry in future. As the production grows, the costs are soon expected to drop to the same level as stainless steel – many times lower than the price of nickel-titanium alloys.

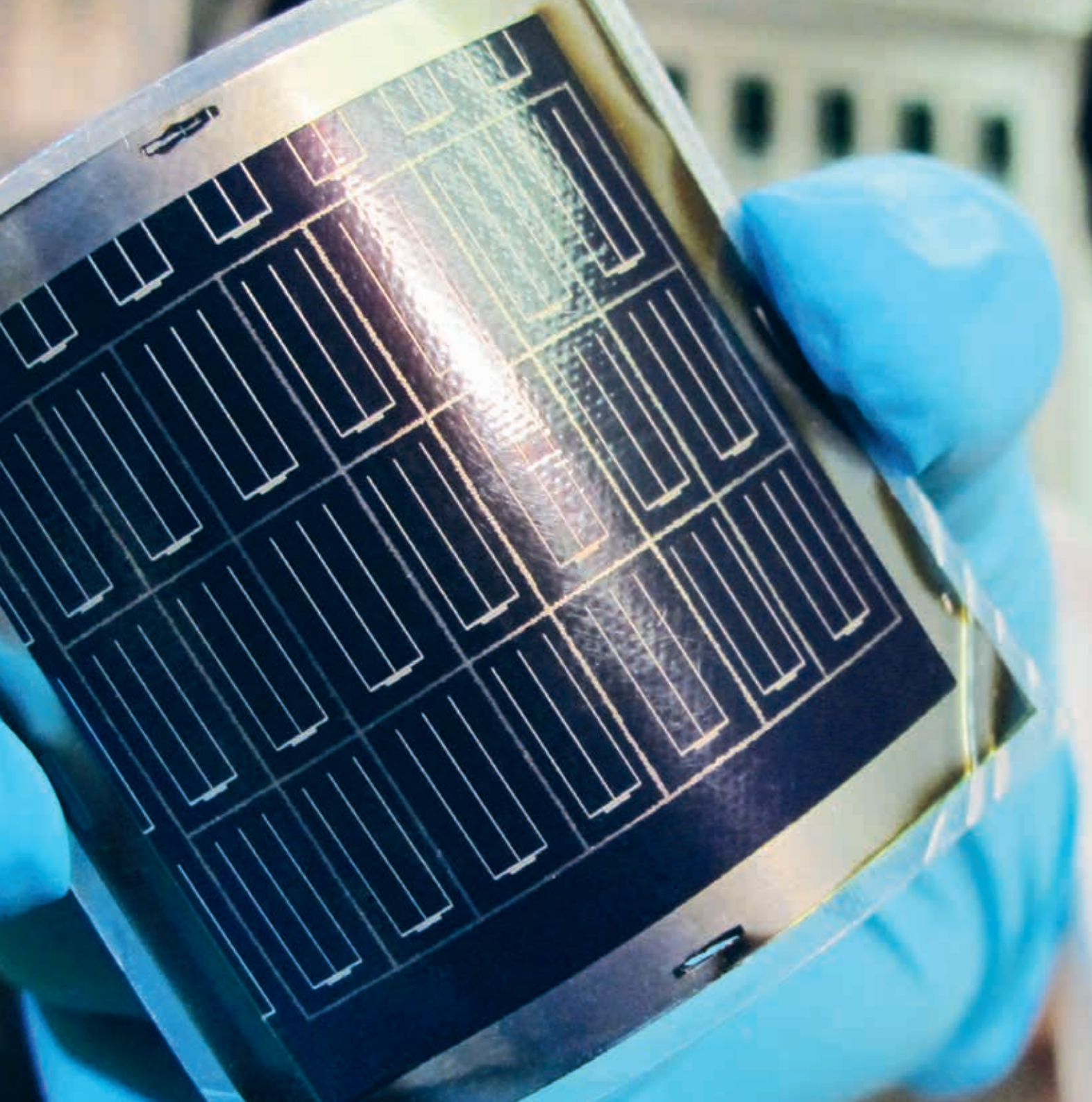


Concrete reinforcements for the building industry made of an Iron-based alloy (SMA): Fe-SMA laminates and Fe-SMA bars, each with and without ribs.

Research Focus Areas

Where are the greatest challenges of our time? Without a doubt in the areas of human health and well-being, the environment and global climate, dwindling raw materials, in a safe and sustainable energy supply and the renewal of our infrastructure. In its five Research Focus Areas – “Materials for Health and Performance,” “Natural Resources and Pollutants,” “Energy,” “Sustainable Built Environment,” “Nanostructured Materials” – Empa combines the interdisciplinary knowhow of its 28 research laboratories to create practical solutions for industry and society.

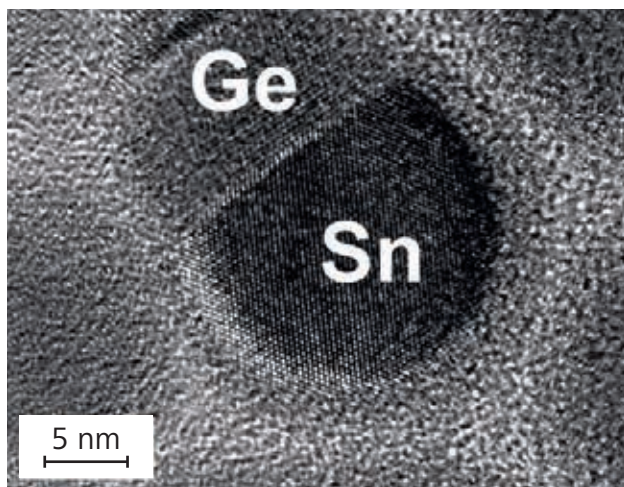






When structure is more important than chemistry

The vision of modern materials science is to develop customized materials with nanocomponents and a clever architecture that boast better or new properties. The notion that the properties of materials greatly depend on their microstructure is as old as materials science itself.



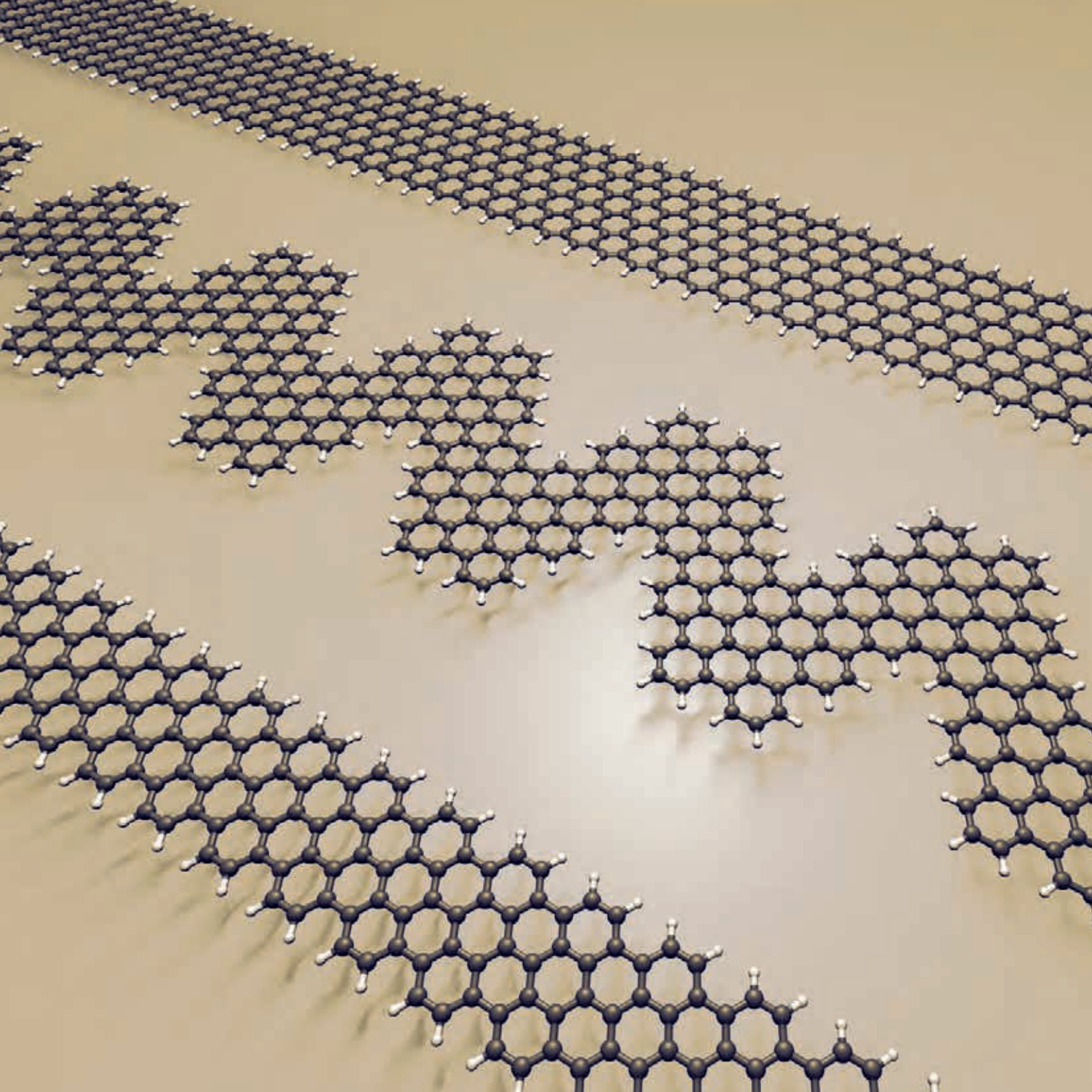
Designing materials brick by brick in a targeted and controlled manner, however, has only been made possible with the advent of nanotechnology. The components of this “material Lego” are nanoparticles or nanocrystals, which already exhibit a complex inner structure in and by themselves. These are then turned into robust materials using suitable coating methods or via self-organization and a subsequent consolidation process.

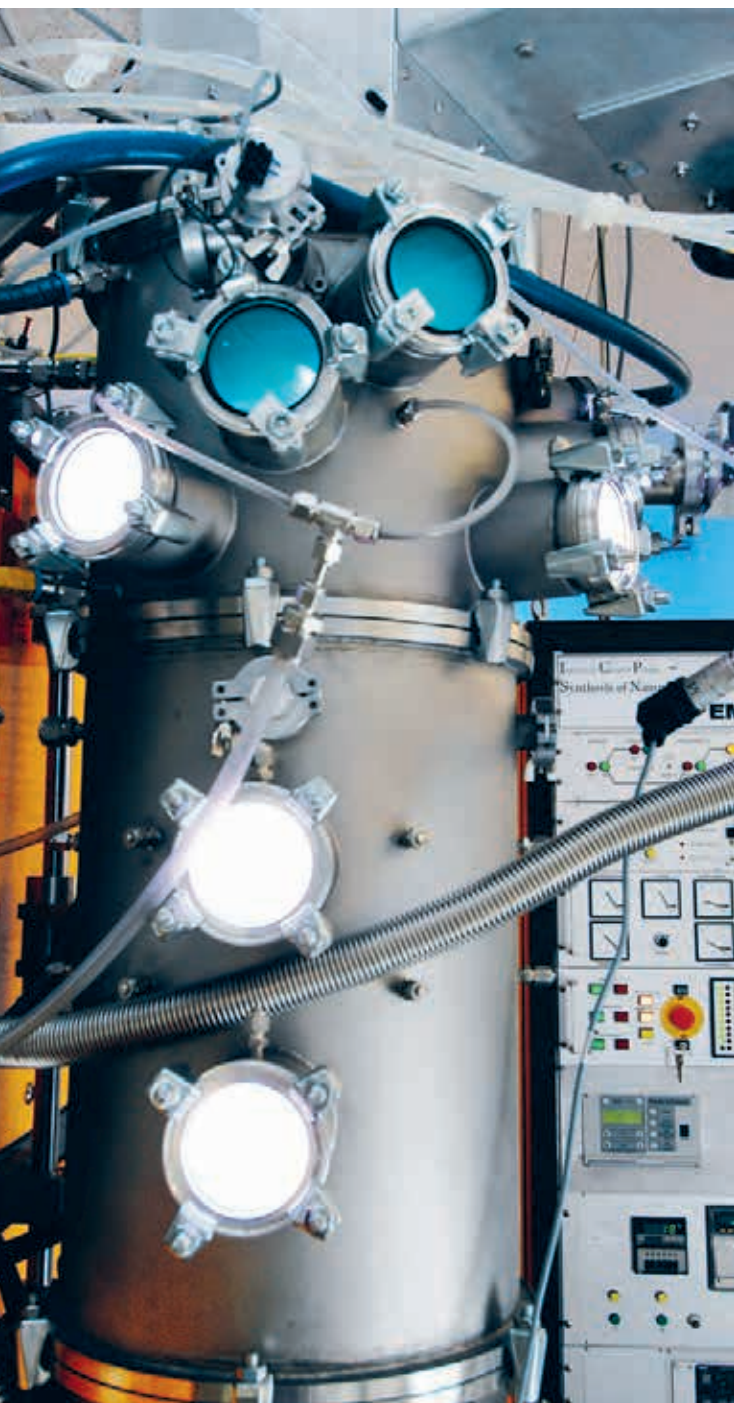
“Material Lego” on the computer

The realization of this vision could be described as “digital manufacturing,” a computer-based processing technique where the development of suitable materials and the production of the resulting part take place in a single process. Only the function of the components along with the relevant boundary conditions are specified and fed into the computer to calculate the ideal solution – a monolithic, three-dimensional structure

with anisotropic material properties that can be manufactured by 3D printing.

In the research focus area “Nanostructured Materials,” Empa investigates, develops, and synthesizes nanocomponents for energy-related applications such as solar cells and batteries or





for the electronics of (the day after) tomorrow. In the field of lithium-ion batteries, Empa is working intensively on the development of new anode materials (see p. 33). Today's lithium-ion batteries use graphite anodes, a material that is far from ideal in terms of its storage capacity for lithium. Tin or silicon would be at least ten times better (in theory, anyway). As these materials expand massively during the charging process, however, the associated mechanical tension makes the anodes go brittle or disintegrate and thus contaminate them. As a result, the capacity of the batteries decreases dramatically after a few charging and discharging cycles. This could be avoided by using the materials as surface-stabilized nanoparticles. A research team at Empa has succeeded in producing tin nanocrystals that are ten to 30 nanometers in size virtually monodispersely. The first anodes made of these crystals already display good cycle stability – and with an excellent capacity of 1,000 mAh/g, almost three times more than today's graphite anodes.

Microwave plasma facility for the production of non-oxidic nanoparticles.

Non-oxidic nanoparticles from the microwave plasma facility

With silicon, however, scientists are much closer to a market launch. Within the EU-funded project SIMBA, Empa researchers teamed up with industrial partner UMICORE to develop a pilot plant for the production of silicon nanoparticles, which involved upscaling a microwave plasma facility developed at Empa. Around 900 grams of silicon nanoparticles can now be produced per hour – 100 times more than with its predecessor. The results of the first silicon anode are extremely promising: at 1200 mAh/g, the capacity is already very high and no significant losses were observed for over 300 charging and discharging cycles.

Progress in the synthesis of graphene nanostructures

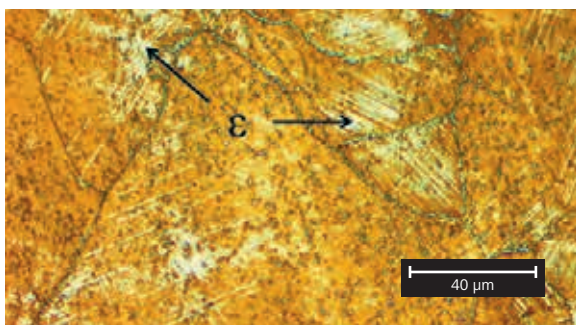
Scientists have long pinned their hopes on graphene, a single atomic layer of carbon, for countless applications, be it to reinforce synthetic materials or in micro- and nanoelectronics. Together with colleagues from the Max Planck Institute in Mainz, Empa researchers have developed a unique method for the synthesis of graphene nanostructures. This bottom-up procedure involves vacuum deposition of suitable precursor molecules on a substrate surface, where they combine to form the desired nanostructure via molecular self-organization. The fascinating thing is that the geometry of the graphene nanostructure is clear-

ly defined by the precursor molecules – and thus its physical properties such as thermal conductivity, the electronic bandgap, or the local distribution of the electrons according to their spin state. Three years after the initial publication of the method in “Nature” Empa has now signed a long-term collaboration with the BASF group to develop a robust industrial process for the synthesis technique.

Materials science and engineering for innovative solutions

The quality of the built environment in Switzerland is pivotal to our high standard of living. Secure and efficient supply and transport infrastructures and attractive, comfortable housing and workspace are a matter of course for us. If we want to maintain this level in the future,

however, various challenges need to be overcome. Many infrastructural elements are reaching a critical age and the growing population and increasing demand for mobility require a tremendous amount of effort in the fields of maintenance and expansion. The energy transition is inconceivable without the comprehensive renovation or replacement of existing buildings and infrastructure. Empa has been investigating these issues comprehensively by combining materials science and engineering and developing new, innovative solutions.



Cheap shape memory alloys within reach

Last year, Empa researchers made a breakthrough in the use of shape memory alloys as pre-stressing elements in the building sector (see p. 47). Empa had already demonstrated the potential of these materials in earlier projects – albeit with alloys that were far too expensive for the building sector. Thanks to the close collaboration between materials scientists and engineers, a cheaper iron-based alloy has now been developed and produced in larger amounts. Used in practice, the pre-stressing elements made from the alloy are cast in concrete and heated so intensely that a phase transition occurs in the material, creating mechanical tension. Together with a newly founded company, re-fer AG, the technology is now being optimized further and brought to marketability.

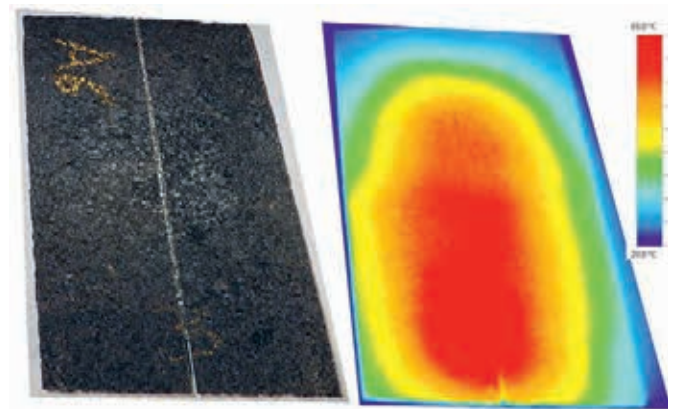
Metallographic microsection of the iron alloy: the ϵ -phase of martensite is responsible for the material's shape memory effect.

Asphalt with self-healing powers

Along with rutting, cracks are one of the main reasons for replacing road surfaces. Temperature and load changes combined with water exposure are the main causes of cracks. Especially at an early stage, fine cracks in the asphalt can be closed if the surface can be heated to around 80 °C or above. This is accomplished by adding electroconductive materials such as steel fibers or pellets to the tarmac and briefly heating it with the aid of an electromagnetic induction loop above the surfacing. In lab experiments, Empa researchers were able to demonstrate that the effect can already be achieved with relatively little additional material. However, the surfacing currently heats up too slowly to actually consider an upscaling today. The long-term goal is the regular “repair” of the surfacing using a mobile induction heater to prevent any significant cracks from forming in the first place, which would greatly increase the service life of Swiss road surfaces.

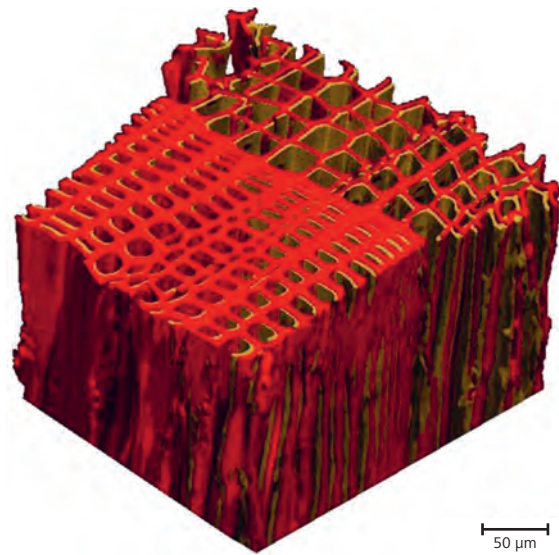
Understanding why wood shrinks and swells

Within the scope of a Sinergia project funded by the Swiss National Science Foundation and completed in 2013, researchers from Empa and ETH Zurich succeeded in better understanding the shrinking and swelling behavior of wood when exposed to moisture thanks to a skilful combination of computer modeling and experimental work. Not only were three dissertations suc-



Asphalt test specimen with a clearly visible artificial crack before (left) and after (right) being treated with the newly developed method: thermographic imaging demonstrates the “healing” effect of inductive heating.

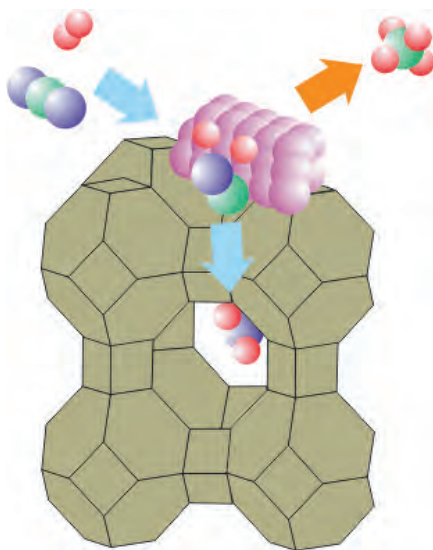
cessfully completed in the process; it also yielded the first models for the anisotropic shrinking behavior of wood at a cellular level. Moreover, the team devised reproducible experimental methods for 3D microscopy, including image processing algorithms, which may one day help to improve our understanding of the only renewable building material.



If two phase-contrast X-ray images are superimposed, the shrinking and swelling behavior of a spruce wood sample is clearly visible (red: 25 percent relative humidity; beige: 80 percent relative humidity).

Reducing emissions – or avoiding them in the first place

The increasing needs of a growing global population in terms of consumption, mobility, food, housing etc. require a responsible approach to our (limited) resources. A change in thinking in favor of closed material cycles and the avoidance or reduction of harmful emissions are pivotal. It is one of Empa’s central goals to achieve this with innovative processes and new materials.



A more efficient catalyst – thanks to ceramic foam and computer simulations

Modern engines and drive technologies are becoming increasingly efficient in terms of fuel consumption, which means they emit fewer and fewer pollutants. Effective exhaust gas treatment systems can reduce the emissions even further. Empa has been developing new catalytic converter materials and is studying the transport of material and heat flow through the catalyst using a novel catalytic substrate that the institute developed from ceramic foam. Flow simulations on the computer enable the researchers to analyze flow conditions in the catalyst in detail and further optimize the structure of the catalytic substrate. The goal is to significantly reduce the amount of catalytically active noble metal, such as platinum and palladium, in the catalyst without compromising its efficiency – i. e. the reduction of harmful exhaust gases.

Zeolites bind the water produced during hydrogen methanation, considerably increasing the methane yield from this new process.

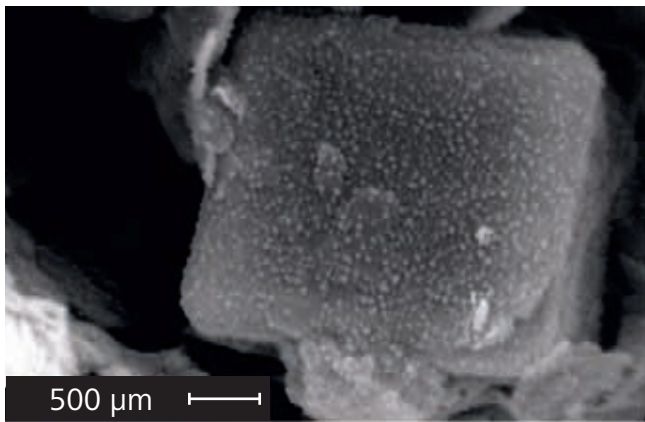
“Power-to-gas”: chemical storage of excess electricity

“Power-to-gas” is a key term when it comes to storing renewable energies. Temporary excess electricity from solar plants, for instance, is converted into hydrogen by water splitting and, in a second chemical reaction with the greenhouse gas carbon dioxide (CO₂), used to produce methane. Empa researchers have

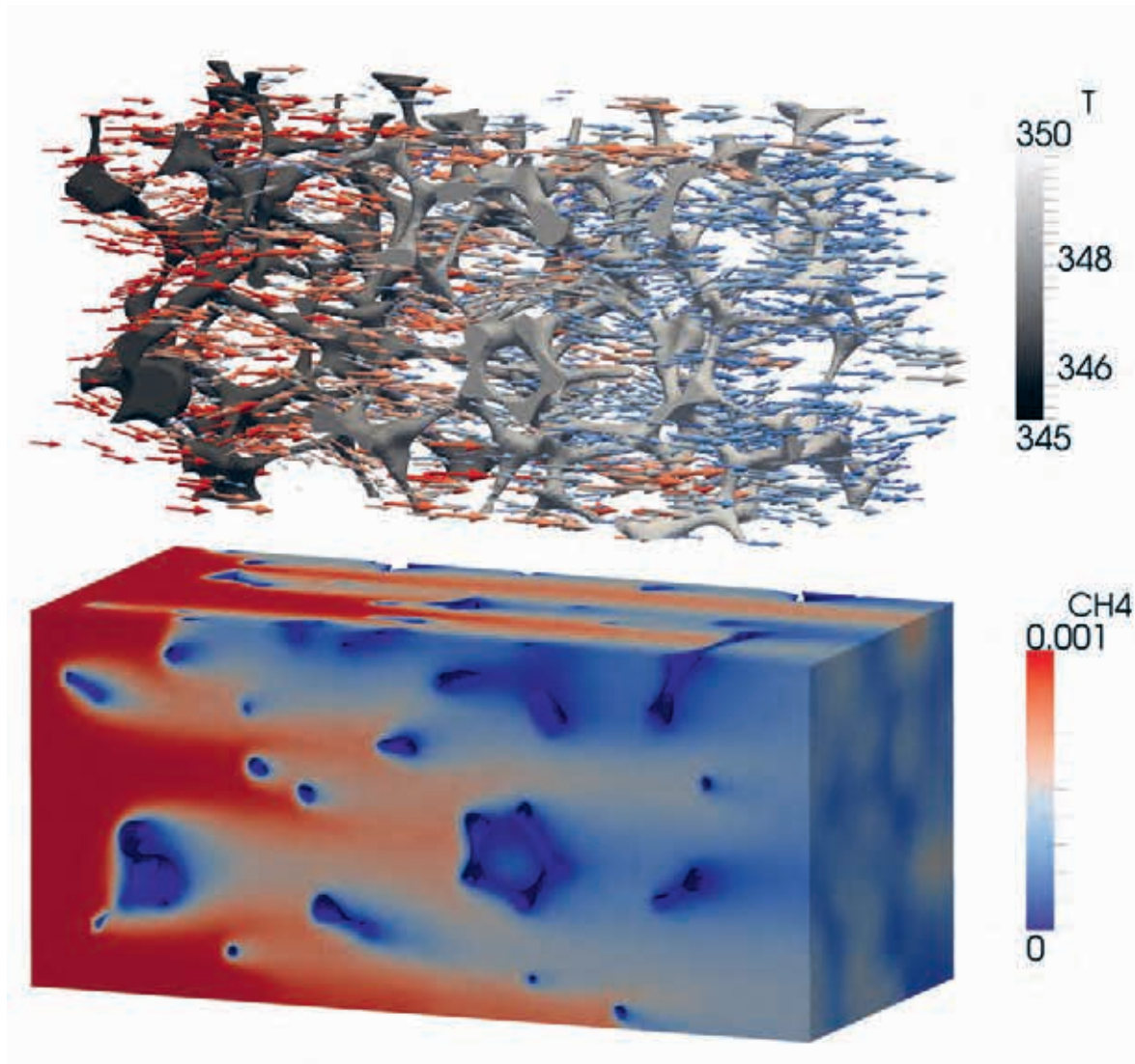
succeeded in optimizing this process further: a new nanoscale nickel catalyst on a zeolite surface offers considerable advantages. The gas molecules react more easily with each other on the catalyst surface, which reduces the activation energy to start the reaction. Moreover, the porous zeolite, a crystalline aluminosilicate capable of absorbing water molecules and releasing them again when heated, speeds up the reaction and thus significantly increases the methane yield (see p. 27).

E-waste as a secondary source of raw materials

The growing demand for electronic goods is also tremendously increasing the consumption of rare metals. In this process, metallic raw materials constantly shift from the geosphere to the biosphere. At the same time, the metal content in the available mineral ores is declining and the extraction of these metals is causing massive environmental pollution. The situation gets especially worse for technical metals, which are used in numerous information, communication, and energy technologies. Many of these, especially rare earth metals, are still barely recovered or recycled. Empa studies reveal that, with suitable technical and organizational measures in the existing recycling system, the recovery of said metals from e-waste has a huge potential. E-waste is expected to become a secondary source of raw materials – with a corresponding positive impact on the environment.



A nanocrystalline nickel catalyst on a zeolite substrate, seen as white dots in the scanning electron microscope.



Numerical analysis of methane combustion in a porous catalyst made of ceramic foam: the greater the amount of methane that is burned, the hotter the catalyst surface becomes. The simulation displays the reduction in methane concentration due to its oxidation (red: high methane level; blue: low methane level; flow direction from left to right).

Energy efficiency and renewables in the spotlight

The hallmarks of a sustainable energy supply are the affordable creation, operation, and maintenance of the infrastructure it requires, a minimal burden on the environment and a safe and reliable supply. How to balance these (partly contradictory) goals is the subject of

intensive debate in politics and society. In light of the looming climate change and the re-evaluation of the risks of nuclear technology, the new Swiss energy strategy is primarily based on energy efficiency and renewable energies. By developing new materials, concepts, and technologies for the energy sector, Empa is doing its bit for this social mission.

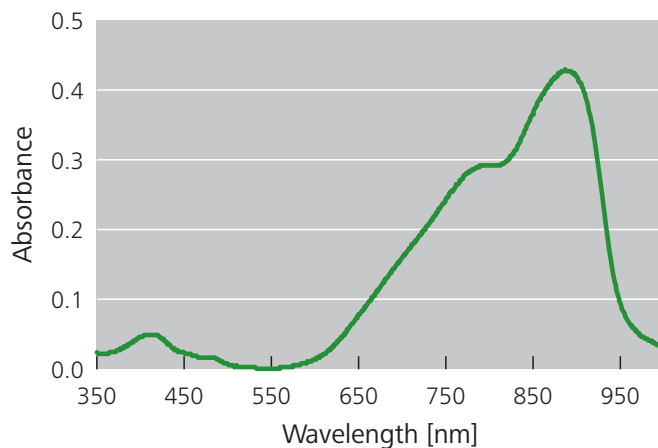
Conventional solar cells made of silicon are standard nowadays. They are produced in high-temperature processors and interconnected to form photovoltaic modules. Thanks to coating and printing processes in the cost-effective roll-to-roll method, however, the next generation of thin-film technology beckons. Organic semiconductors are just the ticket for these processes with a high throughput. These are synthetic conductive materials, which are excellent at absorbing light and thus can be used as ultrathin coats

that are only around 100 nanometers thick. Materials such as cyanine dyes have such a narrow absorption band that they only convert certain areas of the solar spectrum into



Empa researcher Frank Nüesch drizzles a solution of cyanine dye onto a special fabric containing fine conductor tracks. These components are destined for the production of low-cost solar cells in the future.

electricity. This enables cyanine dyes to be produced that only absorb light in the near-infrared range but are virtually transparent for visible light. Empa produces and researches such lab cells. In future, they could be used to manufacture solar windows, facade elements or transparent photovoltaic foils.



Absorption of a 40-nanometer (nm) thin coating made of a cyanine dye: the absorption spectrum displays the strong absorption in the near-infrared range (between 700 and 950 nm) and the weak absorption in the visible range (under 700 nm).

“Harvesting” wind energy at dizzying heights

The Empa spin-off TwingTec is pursuing a novel approach in the wind-energy sector (see p. 21): A high-performance kite based on Tensairity technology uses tow lines to transfer wind energy to the ground, where it is converted into electrical energy by a winch system. Together with the University of Applied Sciences Northwest Switzerland, ETH Zurich and Alstom, the young company demonstrated the technology’s feasibility in 2013. Now plants with an output of 50 kilowatts are expected to follow. Such wind power stations are cheap to install as hardly any construction work or heavy components are required. It can be used connected up to the network or off-grid in areas without a power grid. An autonomous demonstrator is to be completed in 2014 and the first pilot installation is scheduled for late 2015.



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Ten percent more efficiency with coal and gas power stations

Nowadays, around 70 percent of the world's electricity is produced in coal and gas power stations. If the steam temperature can be increased to 700°C and the pressure to 35 bars in these plants, their efficiency would increase by ten percent – that's more than the entire electricity production from wind, the sun, and biomass in 2012. In order to tap into this potential, Empa researchers are developing new methods to demonstrate the suitability of new alloys for these operating conditions by combining thermomechanical fatigue tests with metallographic studies. Renowned industrial partners are using Empa expertise in joint projects, which hopefully will soon make more efficient power stations possible.

Thermomechanic stress test on a new alloy for steam turbines.

Wellbeing: (not) an everyday commodity

We experience it on a daily basis: during exercise, you sweat and feel uncomfortable in your sports gear; your socks aren't fitting quite well and you get blisters on your feet. Or you injure yourself in a sporting accident and your blood pressure spirals out of control, mainly due to your way of life. Scenarios that almost each and every one of us has already experienced at one point or another. With its research activities in the field of health and protection of the human body, Empa helps to avoid and alleviate such situations – or at least control them better.



Overheated and dripping with sweat – a thing of the past?

Materials science in the interest of sports: this is not just about material battles, say, in Formula 1 or the skiing world cup. This kind of research helps anyone who wants to stay fit, for instance by providing lighter, more comfortable, and safer sportswear. It enables the wearer to feel comfortable, even during intensive physical exercise, as the novel textiles transport sweat away from the body quickly and

help prevent overheating. These functionalized textiles and clothing systems, however, are also made available to fields outside the world of sports. For instance, Empa developed self-cooling models for policemen who have to work in heavy protective vests and functional heat-resistant suits for firefighters.

Development of sportswear with the aid of body scanners:
the color picture displays how tightly the sports gear sits on the body.

A blood-pressure gauge worn on the wrist

One of the consequences of our modern lifestyle is high blood pressure, one of the most common causes of death worldwide. Nevertheless, according to the World Health Organization (WHO), not even one in two people measures their own blood pressure as such measurements are time-consuming, especially over a longer period of time. Until now, continuous blood-pressure readings have not been possible. Thanks to a novel sensor for the wrist, however, this is soon bound to change. Together with an industrial partner, Empa researchers have developed a blood-pressure measuring device the size of a wristwatch, which permanently gauges and displays the blood pressure. Spurious impulses on the wrist, which made such measurements impossible in the past, can now be recorded and corrected thanks to Empa technology. Several sensors measure the contact pressure, pulse frequency and blood flow around the wrist area, enabling a reliable calculation of the blood pressure (see p. 19).

Environmental protection and safety: mutually exclusive?

Until now, fire safety in buildings or even vehicles, planes, or trains could only be achieved at great expense or by using ecologically and potentially harmful chemicals. In 2013 one of the most common but critical flame retardants, hexabromocyclododecane (HBCD), was banned by the UN Chemicals Conference in Geneva, due in no small part to the environmental research conducted at Empa. The ban on one of the most important substances in fireproofing also means that there needs to be environmentally friendly and safe alternatives. Empa researchers have synthesized new substances, which have an excellent flame-retardant effect but dispense with halogens in the chemical structure altogether. These phosphoramidates are already found in polyurethane foams, where they can be used in buildings in a number of ways, e. g. as thermal insulation or foam in furniture and mattresses.

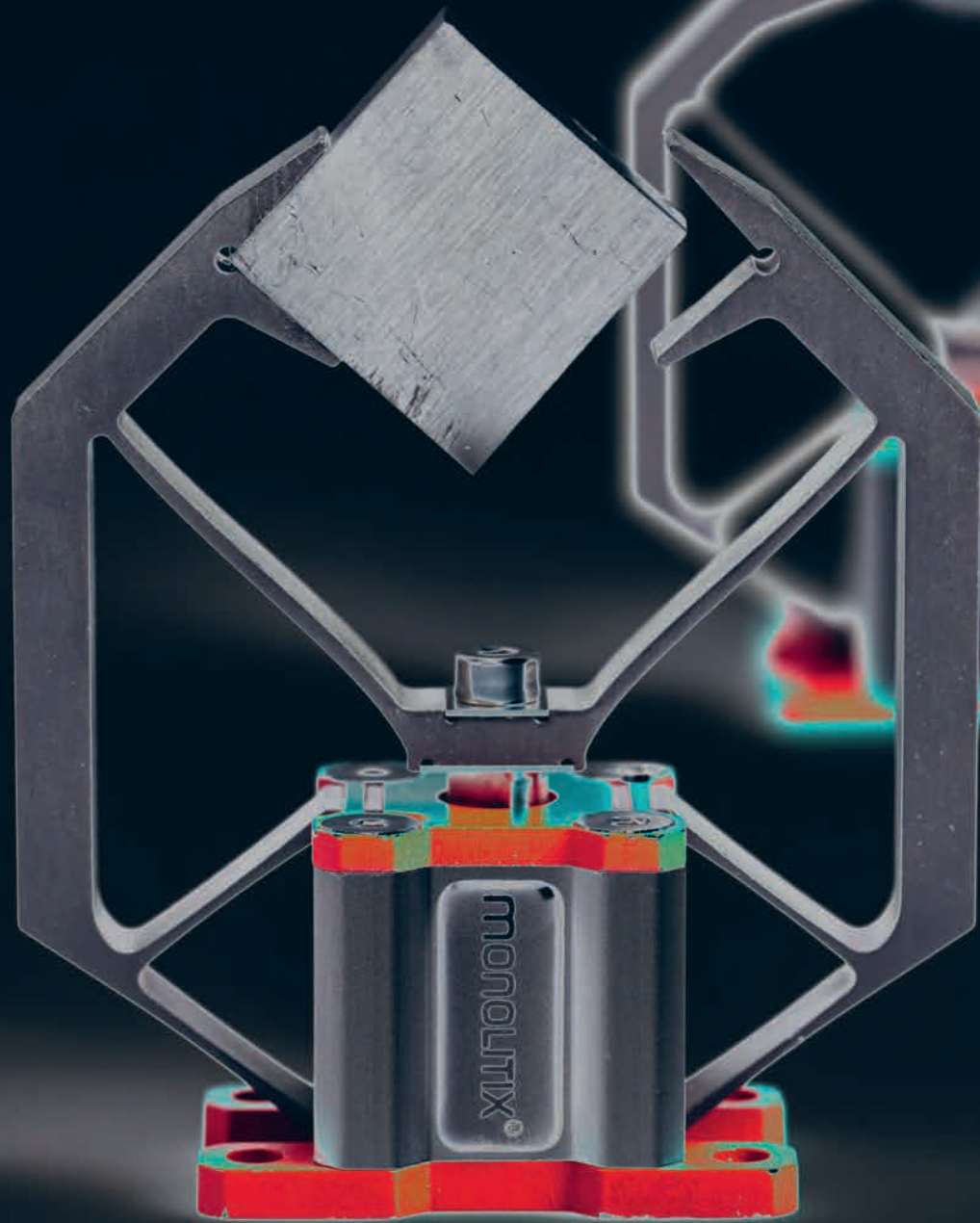
Flammability tests reveal that organic compounds containing phosphorous can even provide better protection than the substances commonly used thus far.



Driving innovation – the Empa approach

The institute's trademark is use-inspired research and development, in close proximity to industry and the economy. Through efficient and individual forms of cooperation and a broad spectrum of services, Empa is in a position to offer its partners tailor-made solutions to overcome the challenges they face. Be it in developing new products, optimizing existing technologies, finding solutions to specific problems or bringing specialist personnel up to date on the newest developments in their field, Empa, with its 500-odd highly qualified scientists and its first-class technical infrastructure, is the right address.

Empa – The Place where Innovation Starts!





Collaboration + knowledge transfer = innovation

The fact that Switzerland is right at the very top of the international innovation rankings stems, among other things, from the close collaboration and sound knowledge transfer between industry and the Swiss research institutions. Empa's office for technology transfer forms a key

link between the institute's laboratories and companies, answering legal questions on all aspects of working with industry, universities, and the public sector, drawing up and negotiating contracts, and making sure that intellectual property is protected and utilized. Last year, once again, the number of new research collaborations with private and public organizations was very high, adding up to more than 110 new research contracts. Moreover, 14 new patent applications were filed and 19 new license and technology transfer agreements were concluded with industrial partners



How to “filter” CO₂ out of ambient air – thanks to cellulose

Extracting the greenhouse gas CO₂ from the atmosphere – i. e. from ambient air – and thus mitigating climate change remains one of the most important

challenges of the 21st century. A newly developed CO₂ adsorber technology from the ETH-Zurich spin-off Climeworks AG (www.climeworks.com) is based upon a cyclical adsorption/desorption process with a new cellulose-based filter material, which was developed in collab-

The mobile CO₂ adsorber pilot plant by Climeworks can extract around one ton of CO₂ per year.



The new coil gauge (inset) was used to examine the 36 stay cables on the new cable-stayed bridge over the river Elbe near Schönebeck. (Photo: DMT-Prüflaboratorium für Zerstörungsfreie und Zerstörende Prüfung-Seilprüfstelle-, Bochum, Germany)

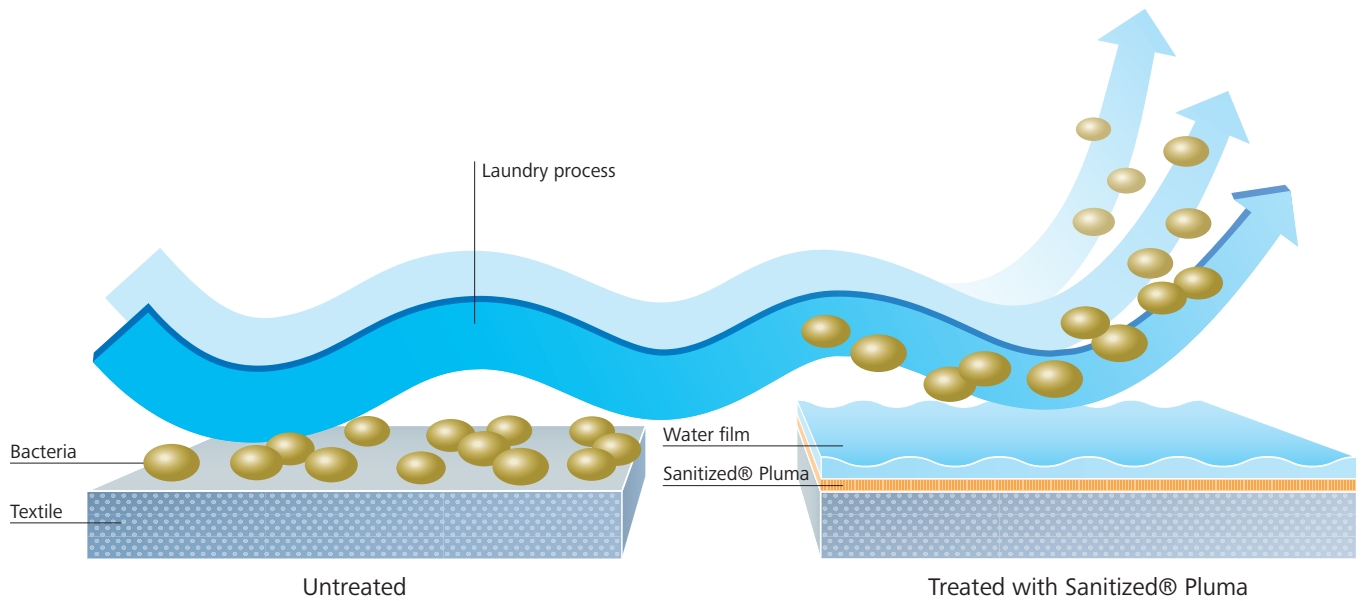
oration with Empa. The material can adsorb CO₂ from humid air, store it, and then desorb it again as highly pure gas by heating the material to approximately 90 °C, such as for technical use in the production of synthetic fuels. The adsorber can be used for a large number of adsorption/desorption cycles. Meanwhile, Clime-works is running a mobile CO₂-adsorber pilot plant that is capable of extracting one ton of the gas per year.

Non-destructive analysis of steel cables with large cross-sections

The condition of a wire cable cannot be evaluated at first sight. Only a professional analysis will establish whether a cable is still safe to use. Until recently, the testing apparatus could only analyze cables with a maximum diameter of up to 160 millimeters. In light of the market needs, the German cable-testing company DMT GmbH and Empa pooled their expertise in the field of non-destructive cable testing and teamed up to develop a coil analysis device for metallic cables with diameters of up to 200 millimeters. Already in use, it is based on a technology developed at Empa that discovers damages through an electromagnetic process with a current coil and a battery-fed power source.

Clothing that doesn't absorb any odor

In order to improve patient safety against bacterial infections, a bacteria-repellent surface coating is often used in medical engineering. As body odors can also be caused by bacteria, treating textiles in a similar way should prevent the unwanted development of odors, which was the goal of a project supported by the Commission for Technology and Innovation (CTI) conducted by the company SANITIZED AG in collaboration with Empa and Swis-satest Testmaterialien AG (formerly Empa Testmaterialien AG). The result is available now: the Sanitized® Pluma technology. The textile fibers are coated with a special polymer that holds a microscopically thin film of water on the fiber's surface. This prevents bacteria from docking onto the textile and any bacteria that are already present can simply be washed away, either by hand or by machine wash at low temperatures, which saves energy and water and prolongs the service life of the textiles. The innovation recently won the Swiss Technology Award 2013.



The innovative Sanitized® Pluma technology won the Swiss Technology Award 2013
(Illustration: © SANITIZEO AG).

Incubating innovation

The aim of Empa's business incubators glaTec, tebo and STARTFELD is to boost the transfer of technology by promoting spin-off and start-up companies. Various awards just go to show how successful the technology centers are. In 2013, for instance, around 100 experts ranked the glaTec company QualySense, which develops robots to quality inspect and sort

grains, seeds, and beans, in tenth place out of the top 100 start-ups in Switzerland. Another glaTec company, compliant concept (intelligent bed systems for the treatment and prevention of pressure ulcers), came in 34th. And the Empa spin-off Monolitix, which specializes in compliant mechanisms, was shortlisted for the prestigious De Vigier Award 2013, made it to the final of the Heuberger Jungunternehmerpreis 2013 and reached the final (top three) for the ZKB Pioneer Award 2014.



Five years of glaTec

In 2013, a total of twelve companies were glaTec tenants on the Empa campus in Dübendorf and had to face a wide variety of challenges: while for some the priority is facilities and contact to research groups, others need help with market assessments or coaching for talks with potential investors. glaTec supervises the fledgling companies until they are "mature" enough to venture the leap into independence – already for five years now. glaTec's five-year anniversary in late October offered customers, investors, and guests an opportunity to get to know the business incubator and its start-ups better.

Empa CEO Gian-Luca Bona (left) is delighted with the success of the two business incubators along with glaTec Managing Director Mario Jenni (center) and the Managing Director of tebo/STARTFELD, Peter Frischknecht.



glaTec

Technologiezentrum
an der Empa in Dübendorf



tebo

Technologiezentrum
an der Empa in St.Gallen



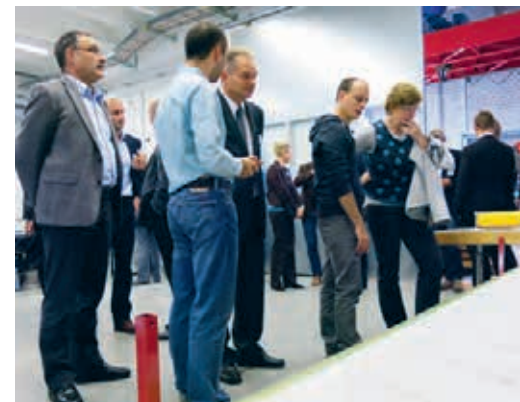
STARTFELD

However, it is not just anyone who can take up residence at the Empa technology center: the selection process is strict and the shortlisted projects are evaluated by the advisory committee. A dozen entrepreneurs, CTI start-up experts, and marketing, economic, legal, and financial experts really put the applicants through their paces, sounding out the applications with regard to their innovative potential, market relevance, and business model. The idea is to find out whether the entrepreneurs-to-be have the potential to implement their business plans. Only then does Empa's Board of Directors decide whether to accept it into its "incubator." As the old saying goes, quality not quantity: it is better to have fewer companies but with greater potential and prospects for success. glaTec as

a home base and the Empa spin-off label should denote that something outstanding can be expected here.

Fruitful collaboration between tebo and STARTFELD

With the very same goals in mind, tebo is collaborating with both the University and the University of Applied Sciences of St. Gallen within the framework of the STARTFELD initiative. The city and canton of St. Gallen and the two cantons of Appenzell all chip in parts of the funding. Several start-ups promoted by STARTFELD were also accepted in the CTI Startup funding process, including Weibel CDS, which produces innovative, user-friendly primary packaging and devices for drug delivery, and Boxtango, which is developing a nov-



A "market place" at the glaTec anniversary celebrations offered customers, investors, and guests an opportunity to get to know the business incubator and young resident companies better.

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el cargo-handling technique for containers and swapbodies in inter-modal transport in Europe. Boxtango was also a finalist for the STARTFELD Diamond 2013, a prize awarded by St. Galler Kantonalbank, and – like Monolitix – the Heuberger Young Entrepreneur Prize. Combivap, which produces light-emitting diodes (LEDs) out of organic materials, was also shortlisted for the STARTFELD Diamond 2013. In the end, the award went to Cosibon, which is developing a novel customer loyalty system that offers trading companies, product manufacturers, and consumers a completely new form of communication.

There were major changes at two tebo companies: the successful Empa-Testmaterialien AG was renamed Swissatest Testmaterialien AG. However, its collaboration with Empa remains unchanged. And Bluesign Technologies AG, developer of the bluesign® system, which analyzes all the relevant input streams and environmental influences in the textile value chain, has ballooned from five people to over 30 in just six years – and recently left tebo.

Committed to (continuing) education

Following the Technopark® Academy's lead, glaTec, tebo and STARTFELD have also joined forces with other partners to form a consortium that designs and conducts entrepreneurship courses for neo-entrepreneurs on behalf of the Commission for Technology and Innovation (CTI). Last year, 17 five-day courses were offered and received a very positive response. Three of these were held at Empa in St. Gallen, organized by STARTFELD.

Innovations thanks to strong partnerships

Collaboration with industry has always taken a front seat at Empa. Besides the intensive exchange with industrial partners in over 110 new research projects, the development of joint platforms was also a key focus in 2013.

NEST – an innovation catalyst in the building sector

NEST is a modular building with a permanent core (the so-called backbone) and exchangeable living and office modules known as “units.” It enables faster research and development of building and insulating materials, residential facilities, building technology, and energy

management systems than with conventional buildings. In NEST, international research teams from universities, renowned architecture firms and innovative companies in the building industry join forces, design housing concepts of the future, incorporate their research modules into NEST and jointly evaluate the results they obtain. The basic funding for NEST, which amounts to a total of 38 million Swiss francs, was secured in 2013. A consortium comprising the State Secretariat for Education, Research and Innovation (SERI), the Swiss Federal Office of Energy (SFOE), the Canton of Zurich, the City of Dübendorf, the Ernst Göhner Foundation, the ETH Board, Eawag,

and Empa is responsible for securing funding for the backbone and its operation as well as for the majority of the units. The remaining funding is provided by the project partners in



the course of realizing the various units. Canvassing potential partners is one of the main priorities for 2014. As a new realization partner, the Swiss-Liechtenstein building services association *suissetec* agreed to co-fund an additional unit called “Solar Fitness/Wellness” at the end of 2013. This means that there are currently five units in the pipeline: besides “Solare

Fitness/Wellness,” these are “City Lifting,” which tackles the topic of condensed housing by adding floors; “HiLo,” the penthouse of the future; “Meet2Create” – new office and work concepts; and “Visionary Wood,” which aims to revisit the use of timber. The actual construction work is due to get underway in 2014 and the official inauguration of NEST is planned for 2015.



Diverse modular superstructures are built around NEST’s central core (the “backbone,” left). (Visualization: Gramazio&Kohler)

Plans for the Coatings Competence Center (CCC) in full swing

Switzerland is one of the world's leading countries in the coating technology sector, with 80 percent of hard coatings being produced by Swiss companies. Empa is looking to team up with partners from industry and academia to set up the Coatings Competence Center (CCC). On the one hand, the center should provide training in the field of coating technology. On the other hand, it should "hand over" the latest research results from the lab to interested industrial partners as quickly and directly as possible so that they can develop innovative products and technologies that are able to succeed on the market – and thus give the companies a competitive edge on the international stage. In 2013 the basic decisions for the planned center were taken and various agreements with interested partners could be reached. Now the implementation phase is about to get underway.

New technology park in St. Gallen

The sale of the Tagblatt newspaper building right on Empa's doorstep in St. Gallen has opened up new prospects. Spearheaded by Empa's technology center tebo located in St. Gallen a technology park is to be built on the premises, where companies that match Empa's competence profile can settle and explore new possibilities for collaborative projects.



What the technology park on the former Tagblatt premises, right on Empa's doorstep in St. Gallen, could look like one day. (Visualization: Standortförderung Stadt St. Gallen)

Top-notch research and innovation thanks to global “teamwork”

The longer the more, modern-day research relies on an extensive international network and cooperative partnerships, which Empa fosters through bilateral collaborations, participation in international research programs and the exchange of talented scientists.



“Brain transfer” – putting great minds together

Experiencing the “spirit” of the best research institutions abroad, for instance under the EU’s Erasmus program, is extremely important – especially for budding scientists. Empa signed numerous bilateral agreements on student exchange with renowned partner institutes. Last year Empa CEO Gian-Luca Bona signed an agreement with the Los Alamos National Laboratory in the US and a memorandum of understanding (MoU) with the Korea Institute of Metals and Materials (KIM) as well as – during a state visit to Switzerland by the President of South Korea, Park Geun-hye – the Korea Institute of Science and Technology (KIST).

The agreements with Empa’s Korean “sister institutes” all began with Federal Councilor Johann Schneider-Ammann’s official visit in June 2013, whose delegation also included Empa CEO Bona. The primary goal was to identify fields with innovative potential that would be of interest to both countries – and intensify

Signing of a memorandum of understanding (MoU) between Empa and the Korea Institute of Science and Technology (KIST) in Berne, with the President of the Swiss Confederation, Federal Councilor Didier Burkhalter, and the President of the Republic of Korea, Park Geun-hye, in the background.

research collaboration in fields such as energy, natural resources, environmental technologies and sustainable building.

Empa also expanded its cooperation with the Royal Institute of Technology (KTH) in Stockholm with respect to graduate student education and research on the sustainable use of information and communication technology (ICT). Empa scientist Lorenz Hilty, who is also professor of computer science and sustainability at the University of Zurich, was appointed professor of information technology and sustainable development at KTH in early 2013. Following road engineering expert Manfred Partl, Hilty is already the second Empa researcher to hold a chair at KTH.

Empa and NIMS are co-editing open-access scientific journal

Empa and the Japanese National Institute for Materials Science (NIMS), with which Empa has been closely collaborating on nanoscience and -technology for a number of years, are co-editing the open-access journal “Science and Technology of Advanced Materials” since early 2014. Both institutes are looking to develop the journal into one of the world’s leading publications in the field of materials science. Gian-Luca Bona will be regional editor and Harald Krug the new co-editor-in-chief.

Empa hosts “who’s who” of materials science

In mid-May Empa welcomed NIMS representatives and colleagues from around 50 “sister institutes” from all over the world to the 5th symposium of the World Materials Research Institutes Forum (WMRIF). The core topic, “Materials meet Life” – i. e. the question as to how materials interact with our bodies and how this knowledge can be used to develop state-of-the-art medical technology and materials – attracted tremendous interest and inspired lively discussions among the participants.



Empa CEO Gian-Luca Bona (far left) accompanied a Swiss government delegation led by Federal Councilor Johann Schneider-Ammann (fourth from left) to South Korea in July. A researcher at the Korean Institute of Science and Technology (KIST) explains his work to the delegates. (Photo: ST Office Seoul)

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In this respect nanotechnology is often the subject of debate and still raises certain concerns, particularly with regard to synthetic nanotubes, the impact of which on the human organism has not yet been investigated in great detail. This is where research conducted at the National Institute of Standards and Technology (NIST/US) and Empa comes in. Both collaborate closely to identify opportunities, but also risks related to nanotechnology, at an early stage and assess them correctly. The studies are then validated in international round robin tests with prestigious partner institutes from all over the world.

Empa is now co-editor of the open-access journal
"Science and Technology of Advanced Materials".

Once again, the Empa Academy's program was brimming with highlights in 2013, with a total of almost 5,000 participants making their way to around 90 events. Roughly 2,000 scientists bounced ideas off each other on their specialist fields at 35 scientific conferences, courses, and talks. Within the scope of the by now well-established "Technology Briefings,"



representatives from industry and economy met with experts from various research fields at seven events to bridge the gap between science and practice. And the "Tage der Technik" proved to be particularly popular with this year's topic, "Electricity." 280 participants accepted the invitation from Swiss Engineering, the Swiss Academy of Engineering Sciences (SATW), and Empa to find out about designing a sustainable power system for Switzerland.

50 years of Empa's Dübendorf campus

In August, the Empa campus in Dübendorf celebrated its 50th birthday. Federal Councilor

Johann Schneider-Amman, President of the ETH Board Fritz Schiesser, former member of the National Council Brigitta Gadiant, current members of the National Council Lothar Ziörjen (who is also the Mayor of Dübendorf), Maria Bernasconi, Martin Bäumle and Barbara Schmid-Federer, Zurich's Government Councilor Regine Aepli and President of ETH Zurich Ralph Eichler were all present to offer their congratulations. Around 240 guests were

92 percent of all participants attending events at the Empa Academy rated them as "good" or even as "very good." (Photo: Andreas Bucher)

treated to a quick glance back over the last 50 years and a glimpse into the future of Empa on tours around various labs.

VIPs visit Dübendorf

In the fall, the Government of the Canton of Zurich chose Empa as the venue for its (inaugural) “Regional Dialog” – on the one

hand, because it is virtually predestined for the event’s topic, the technology transfer between research and industry; on the other hand, because, from the Government’s perspective, Empa is a nationally and internationally recognized institution and thus a key “brand” for Zurich as both a research and an economic hub. The participants – around 70 executives from innovative industries in the region and the entire Government Council – were given an in-depth insight into Empa’s diverse activities.

A new platform – the “Empa Technology & Innovation Forum”

In order to boost the exchange with industry, Empa last year launched a new series of events entitled the Empa Technology & Innovation Forum. Intended as a networking platform for top executives from national and international companies, the series got off to a flying start in April with the first event on the topic of “Open Innovation,” followed by a second one in November under the banner of “Sustainability and Innovation,” thereby securing a permanent spot on Empa’s calendar of events for the future.



The Government of the Canton of Zurich (with Empa CEO Gian-Luca Bona, third from left) met at Empa to put its heads together with representatives from industry. (Photo: Andreas Bucher)

Communication on many fronts

Communication is growing increasingly diverse – and science communication is no exception. New channels and possibilities pop up to reach your target audience(s) or stakeholders, to put it in more modern terms. The majority of these revolve around the “new” electronic media, the social networks. Over the last year, Empa has become “socialized” quite extensively on various channels.



Empa goes social

As we keep hearing, anyone who doesn't tweet, “post” or dish out “likes” is stuck in the dark ages of communication. Sure enough, social media are an ideal instrument for addressing primarily younger “followers” and communities. Therefore, Empa decided to become more socially active from a communicative perspective, finally venturing into the universe of Facebook, Twitter, Flickr and the like last fall. This move broadens Empa's already existing services on the business platforms Xing! and LinkedIn as well as on the video podcast portals YouTube and iTunes.

For about a year, the EmpaNews app has also been available in the iTunes Newsstand (and, of course, on the Google Play Store for Android devices). The digital research magazine offers numerous extra features, such as videos, audio-podcasts, photo galleries, interactive graphics, and links – and can be read anytime, anywhere.

Engaging in a direct dialog

Anyone who wanted to experience Empa and its staff “live,” though, also had plenty of opportunity to do so at a number of events held on the Empa premises, including the 50th anniversary of the Empa campus in Dübendorf with distinguished guest Federal Councilor Johann Schneider-Ammann – as Swiss Minister of Economic Affairs, Education and Research, Empa’s highest ranking principal. Or the first “Regional Dialog” organized by the

Government of the Canton of Zurich, to which the Government Council invited senior executives from industry and economy to discuss the topic of technology transfer between research and industry – a topic that has long been dear to Empa’s heart. The direct interaction with existing and potential industrial partners was also the focus of the recently launched series of events, the “Empa Technology & Innovation Forum,” with over 120 participants attending the first two events (see p. 88).



Federal Councilor Johann Schneider-Ammann congratulating Empa on the occasion of the 50th anniversary of its Dübendorf campus.



EmpaTV is interviewing Brigitte Buchmann, member of Empa’s Board of Directors.

Empa exponents, with the Board of Directors headed by CEO Gian-Luca Bona leading the way, also made numerous “guest appearances.” This included various panel discussions on topics like energy turnaround or innovation management, such as at the “Swiss Energy and Climate Summit” in Berne last summer, the “Infrastructure Days” organized by the Federal Department of Environment, Transport, Energy, and Communication led by Federal Councilor Doris Leuthard in Lausanne in November or events on the future “Swiss Innovation Park” and its Zurich hub, which is likely to be constructed on the old Dübendorf Airfield right on Empa’s doorstep. Moreover, Gian-Luca Bona accompanied a Swiss government delegation headed by Federal Councilor Johann Schneider-Ammann to South Korea in July to evaluate and launch potential bilateral cooperations in the high-tech sector (see p. 85).

Visitors from near and far

Guided tours remain extremely popular at Empa. In October, for instance, Empa took part in ETH Zurich’s “Treffpunkt Science City” on the topic of new materials as an external partner: the 80 slots for the soiree, which included a visit to four Empa labs, were booked out in no time. Altogether, in 2013, well over 2,700 visitors seized the opportunity to sneak a peek behind the scenes of modern materials science at Empa. Once again, these included numerous government delegations from Switzerland and abroad. Be-

sides the Cantonal Government of Zurich, the Government of Appenzell Innerrhoden also paid Empa a visit (at its St. Gallen site), as well as a delegation from Thailand led by Thai Research Minister Phiraphan Phalusuk and from the Luxembourgian government headed by Tom Eischen, Energy Commissioner at the Ministry of Economics. Various industrial and business delegations, including from France, Austria, Romania, Kazakhstan, and South Korea, also used their visits as a platform to exchange ideas with Empa representatives.

Corporate culture in transition

Empa was involved in the study “Women in Engineering Professions – Sought-After and Respected?” one topic of the National Research Program 60. The Rütter + Partner consultancy examined the impact of corporate culture on the careers of female engineers and scientists, especially revealing obstacles in the paths of women on their way to positions in senior management. Based on the results, Rütter + Partner designed a half-day workshop particularly aimed at raising awareness of the issue among senior managers. From now on, Empa will incorporate the subject of gender-specific management culture into the further training program for its management team.



eawag empa kinderpavillon

can accommodate 34 children in three groups. These figures alone are testament to the project's success.

Meanwhile, the Empa and Eawag crèche is a permanent feature of both institutes and instrumental in top researchers' enjoyment of working at Empa and Eawag as they can leave their

Combining career and family

20 years ago, the parents' association IG Kinderpavillon was founded with the aim of opening a staff crèche for Empa and Eawag. On 1 November, 1994 it moved into its first home in the former guesthouse with two rooms, a kitchen, a bathroom and a large garden. Today, the crèche is located in a pavilion completed in 2006 that

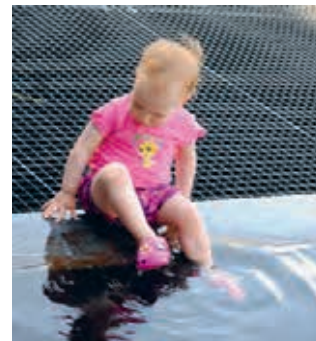
The crèche's logo has also changed:
from the early days (above) and today (below).

children in safe hands barely a stone's throw away until they are old enough to go to kindergarten. Members of staff who come from abroad especially appreciate the service. In August the association celebrated its 20th anniversary with a summer fair. The children were delighted with a new climbing frame and the former



Eawag research ship Forch, which were set up as new attractions in the pavilion garden.

Reconciling a successful career with family life is perfectly feasible at Empa. In the summer of 2013, the institute once again received the title of "family AND career" with the "best practice" rating. In recent years, tremendous progress has been made in the field of "work content, management understanding and human resources development." Empa also goes to great lengths to create ideal conditions for combining a career and a family. Paternity leave for instance, was doubled from five to ten days in 2013.



The 20th anniversary of the parents' association IG Kinderpavillon was celebrated in the summer with a garden party and games for the young and old.

Facts and figures

Excellent research and a proximity to industry – these are the two “poles” between which Empa operates. And the longer, the more successfully, as certain statistics reveal: in 2013 Empa scientists and engineers published around 530 scientific papers, more than ever before. In the course of the year, around 110 projects funded by the Swiss National Science Foundation (SNSF), 110 projects supported by the Commission for Technology and Innovation (CTI) and over 60 EU projects were on the go at Empa – another new record. What’s more, Empa attracted a total of over CHF 63 million in second and third-party funding – also an all-time high –, around half of which was allotted to industry-related projects. And the roughly 20 Empa spin-offs and other start-ups in Empa’s business incubators employ a total of around 250 people – and counting.

ft	right		Eva
bottom	top	bottom	6
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Kentax

2x evap

13c

up 192d

up | empty

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down PTCDA

down | 3-Ethynyl
phenanthrene

3b(SI)

54a

STM

Transfer
carrier

FEL

manipulator
cool

18a



25e

illed 4.11.2013

Argon

FEL



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heat

	15/07/13	23/07/13
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SCIENTIFIC OUTPUT

	2012	2013
ISI publications	509	527
Conference contributions	1043	1134
Doctoral studies completed	44	26
Doctoral studies in progress	160	188
Teaching activities (in hours)	3500	3885
Prizes and awards	37	45

EMPA ACADEMY

	2012	2013
Empa events	95	88
Participants	4000	4500
Scientific conferences	9	13
Events for industry	31	35

KNOWLEDGE DISSEMINATION & TECHNOLOGY TRANSFER

	2012	2013
New R&D Agreements	150	111
Active exploitation contracts	87	83
New exploitation contracts	33	19
New patent applications	18	14

CURRENT PROJECTS

	2012	2013
Swiss National Science Foundation (SNSF)	99	110
Commission for Technology and Innovation (CTI)	108	108
EU-Projects	64	62

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

	2012	2013
Companies total	29	32
thereof Spin-offs	15	18
Employees total	197	250
thereof Employees of Spin-offs	87	94

STAFF (AS OF 31. DECEMBER 2013)

	2012	2013
Scientific staff	519	516
of which professors	24	25
of which Ph.D. students	119	131
of which sci. staff excl. profs. & Ph.D. students	376	360
Technical & administrative staff	446	442
of which apprentices	42	38
Total	965	958

MEDIA EXPOSURE

	2012	2013
Radio & TV	88	100
Print	945	845
Online	1938	1795
Total	2971	2740
Languages	34	31

PROFIT AND LOSS ACCOUNT (IN MILLIONS OF SWISS FRANCS)

	2012	2013
Revenue		
Federal founding contribution	97.8	97.3
Measures "strong Swiss Franc"	0.0	0.0
Third-party funding	59.4	61.4
Of which income from services	13.3	14.6
Miscellaneous income	2.6	2.0
Financial income	0.0	0.4
Total revenues	159.8	161.1
Expenditure		
Personnel costs	105.8	106.5
Material costs	6.0	5.1
Operational expenses	35.9	36.3
Changes in performance bond	3.3	0.0
Reserve increase for projects	3.8	4.6
Total expenditure for current activities	154.8	152.5
Balance	5.0	8.6
Investment		
Fixed assets	3.8	4.3
Movable assets	8.4	8.3
Information technology	0.2	0.5
Total investment	12.4	13.1

Bodies of Empa

ETH Board

The ETH Board has overall responsibility for the management of the ETH Domain, which incorporates the two Federal Institutes of Technology (ETHZ, EPFL) and the four federal research institutes (PSI, WSL, Eawag and Empa).

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Barbara Haering [DrDrh.c., Econcept AG, Zurich](#)

Beth Krasna [Dipl. Ing. ETH, independent supervisory board member](#)

Joël Mesot [Prof. Dr, PSI, Villingen](#)

Jasmin Staiblin [Dipl. El.-Ing., Alpiq Holding AG, Lausanne](#)

Markus Stauffacher [Dr, ETH Zurich](#)

Olivier Steimer [lic. iur., Waadtländer Kantonbank, Lausanne](#)

Industrial Advisory Board

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

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MEMBRES

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Norman Blank [Dr, Sika, Zurich](#)

Peter Chen [Prof. Dr, ETH Zurich](#)

Andreas Hafner [Dr, BASF, Basel](#)

Robert Frigg [Prof. Dr mult. h.c., MEDTECinside, Bettlach](#)

Jan-Anders Manson [Prof. Dr, EPF Lausanne](#)

Markus Oldani [Dr, ALSTOM, Baden](#)

Andreas Schreiner [Dr, Novartis, Basel](#)

Eugen Voit [Dr, Leica Geosystems, Heerbrugg](#)

Research Commissions

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

RESEARCH COMMISSION

Thomas Egli [Prof. Dr, Eawag, Dübendorf](#)

Karl Knop [Dr, Zurich](#)

Dimos Poulidakos [Prof. Dr, ETH Zurich](#)

Heike Riel [Prof. Dr, IBM, Rüschlikon](#)

Marcus Textor [Prof. Dr, ETH Zurich](#)

Alexander Wokaun [Prof. Dr, PSI, Villigen](#)

INTERNATIONAL PEER REVIEW COMMITTEE

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Jacques Marchand [Prof. Dr, University Laval, Canada](#)

Claudia Stürmer [Prof. Dr, University of Konstanz, Germany](#)

Eberhard Umbach [Prof. Dr, KIT, Germany](#)

Sukekatsu Ushioda [Prof. Dr, NIMS, Japan](#)

Organizational chart 2014

Research Focus Areas

Nanostructured Materials

Dr Pierangelo Gröning

Sustainable Built Environment

Dr Peter Richner

Health and Performance

Dr Alex Dommann

Natural Resources and Pollutants

Dr Brigitte Buchmann

Energy

Dr Peter Richner

GENERAL MANAGEMENT

CEO	Deputy	Members
Prof. Dr Gian-Luca Bona	Dr Peter Richner	Dr Brigitte Buchmann Dr Alex Dommann Dr Pierangelo Gröning Dr Urs Leemann

DEPARTMENTS

Advanced Materials and Surfaces	Civil and Mechanical Engineering	Materials meet Life
Dr Pierangelo Gröning	Dr Peter Richner	Dr Alex Dommann
Electron Microscopy Center Dr Rolf Erni	Center of solid-state kinematics and actuation Dr Flavio Campanile	Center for X-ray Analytics Dr Alex Dommann
LABORATORIES		
High Performance Ceramics Prof. Dr Thomas Graue	Road Engineering/Sealing Components Prof. Dr Manfred Partl	Protection and Physiology Dr René Rossi
Joining Technologies and Corrosion Dr Lars Jeurgens	Applied Wood Materials Dr Tanja Zimmermann	Advanced Fibers Prof. Dr Manfred Heuberger
Nanoscale Materials Science Prof. Dr Hans Josef Hug	Structural Engineering Prof. Dr Masoud Motavalli	Materials-Biology Interactions Dr Katharina Maniura/Dr Peter Wick
Advanced Materials Processing Prof. Dr Patrik Hoffmann	Mechanical Systems Engineering Dr Giovanni Terrasi	Bioactive Materials Prof. Dr Dr h. c. Linda Thöny-Meyer
nanotech@surfaces Prof. Dr Roman Fasel	Building Science and Technology Prof. Dr. Jan Carmeliet	Electronics/Metrology/Reliability Dr Urs Sennhauser
Mechanics of Materials and Nanostructures Dr Johann Michler	Mechanics for Modelling and Simulation Prof. Dr Edoardo Mazza	
Thin Films and Photovoltaics Prof. Dr Ayodhya N. Tiwari	Center for Synergetic Structures Dr Rolf Luchsinger (PPP Empa – Festo)	
Functional Polymers Prof. Dr Frank Nüesch	Concrete/Construction Chemistry Prof. Dr. Pietro Lura	
	Acoustics/Noise Control Kurt Eggenschwiler	

Knowledge and Technology Transfer

NEST

Reto Largo

Empa Academy

Anja Pauling

glaTec – Technology Center in Dübendorf

Mario Jenni

tebo – Technology Center in St. Gallen

Peter Frischknecht

Reliability Network

Dr Urs Sennhauser

International Research Cooperations

Prof. Dr Harald Krug



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www.empa.ch/portal

Mobility, Energy, and Environment

Dr Brigitte Buchmann

Materials for Energy Conversion & Devices

Dr Corsin Battaglia (as off 1.9.2014)

Analytical Chemistry

Dr Heinz Vonmont

Air Pollution/Environmental Technology

Dr Lukas Emmenegger

Internal Combustion Engines

Christian Bach

Hydrogen and Energy

Prof. Dr Andreas Züttel

Technology and Society

Heinz Böni a.i.

Support

Dr Urs Leemann

Library (Lib4RI)

Dr Lothar Nunnenmacher

Informatics

Stephan Koch

Mechanical Engineering/Workshop

Stefan Hösli

Finances/Controlling/Purchasing

Heidi Leutwyler

Communication

Dr Michael Hagmann

Facility Management

Peter Wegmann

Human Resources

André Schmid

Marketing, Knowledge and Technology Transfer

Gabriele Dobenecker

Construction3 RI/Technical Services

Hannes Pichler

Empa. Materials Science and Technology.



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