Annual Report 2012

EMPA

Materials Science & Technology

Our Vision.

Materials and Technologies for a Sustainable Future.

IMPRINT
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Empa – the place where innovation starts

Over the past years Empa has achieved a great deal, and could celebrate some remarkable successes. It is recognized worldwide as an institute at the forefront of materials science and technology development, specializing in transferring research results into marketable innovations. This role was expressly confirmed by the most recent international peer review. Likewise, the Leiden Ranking, conducted last November, evaluated our scientific performance as excellent, demonstrating clearly that in terms of quality of research we can hold our own against the Top 20 universities and research institutes in the world. In 2012 we have once again increased our scientific output and reached a new "all-time high" with respect to the number of scientific publications, in addition to continuously extending our industrial partnerships. Last year over 500 cooperation agreements were signed – yet another record reflecting the high level of our knowledge and technology transfer activities to industrial and institutional partners. We can truly be proud of these achievements.

The 50-year anniversary of the Duebendorf Campus in August this year offers the opportunity not just to look back at what has been achieved but even more importantly to look forward and ask where our journey is leading us. An institution such as Empa, which transfers innovations derived from cutting-edge research on to the market, must, every now and so often, take stock of which direction it is heading and readjust its compass as is necessary in such a competitive environment. To achieve its goals, Empa must regularly optimize its strategy in times of limited resources.

Our main strength lies in the excellence of our staff at all levels, who make it possible for us to rise to ever-changing challenges with a never-ceasing stream of new ideas. The ability to develop innovative concepts in a "bottom-up" fashion, inspired by new research results and "top-down" requirements, is a specialty of our institution. Our work is aided by the enormous range of technical and scientific know-how of our staff in many disciplines, which we will need to exploit even further to generate trans- and interdisciplinary solutions. We have therefore resolved to pay special consideration this year to shaping our future and the culture of cooperation.

In the current Annual Report you will be able to discover for yourself the many ways, in which Empa makes an impact. I urge you to think about what to expect from the Empa of the future – an Empa we tend to think of as "the place where innovation starts". I very much look forward to hearing your thoughts.

Prof. Dr. Gian-Luca Bona
Director

01

Wheelchair comfort
Empa engineers collaborating with the company "r going" have developed an ergonomic seat shell, which helps wheelchair users to change position regularly, preventing the occurrence of pressure sores.

Winter heating with summer sun
Seasonal changes in temperature are no longer a problem with Empa's special concrete. The novel building material stores heat without loss and releases it in a controlled way whenever it is required.

02

Molecular "carpet"
Researchers at Empa and ETH Zurich have succeeded for the first time in creating regular two-dimensional polymers. The new material could find use as a molecular filter.

Electronic waste in Africa
As usage increases, the problem of disposal becomes acute: e-waste is a problem that must be taken seriously in West Africa. However, it also offers opportunities, as a UN study with Empa participation has shown.

03

Extending the Montreal Protocol
The Montreal Protocol bans CFCs because they destroy the Earth's ozone layer. The substitutes being used are, however, long-lived greenhouse gases; researchers are thus proposing a stepwise ban on them, too.

"Nano" in the building industry
The EU-funded project "Nanohouse," which was launched in 2010, is intended to find out if nanoparticles in construction materials represent a danger to man and the environment. The first phase has now been completed.

04

Brain competition at Empa
Schoolchildren with an enthusiasm for physics participated in a debating competition at Empa, arguing over tricky questions. The winning team represented Switzerland at the Physics World Cup held in Bad Saulgau in summer in southern Germany.

Helper at the bedside
Whether monitoring sleep patterns and behaviour or ensuring that bedridden patients move enough: the Empa / ETH spin-off "compliant concept" has developed an instrument that can sense the smallest movements.
Page 26

05

Filling up with hydrogen
In Brugg, the first hydrogen fuelling station for buses in Switzerland has been commissioned. As part of a cooperative project between Empa and the Postauto Schweiz AG, five CO_2-free buses are now on the road.

06

Continuously monitored
A study by TA-SWISS and Empa has warned against omnipresent tracking technologies, to which we are exposed every day, since data security is not always guaranteed.

Battery testing station in operation
A project starting soon at Empa will investigate the reliability and operating lifetime of batteries of all sizes, to help make them more powerful and more secure in the future.

07

Empa technology goes Mercury
An ionizing system developed at Empa for a mass spectrometer will travel to Mercury on board an ESA satellite. The instrument is very light and reliable and can tolerate extreme temperatures.

A band-aid with many talents
The band-aid of the future will release medication into a wound in a controlled manner – and as healing progresses it will dissolve of its own accord: Empa develops a biodegradable, multifunctional bandage.

08

Deciphering diesel soot
The World Health Organization WHO has categorized the soot in diesel exhaust gas as carcinogenic. Empa researchers contributed to this conclusion by analyzing the structure and chemical composition of soot particles.

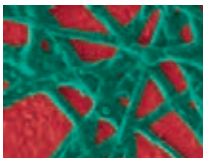
09

"ERC Grant" for Empa scientist
Empa researcher Maksym Kovalenko has been awarded about 1.8 million Swiss francs in funding for his work on nanocrystals in solid state matter. Aged 30, he is the youngest ever ERC prizewinner.

Are biofuels really "green"?
A study led by Empa scientists has conducted a life cycle analysis (LCA) on biofuels and come to the conclusion that only a small number of them actually are environmentally friendly.

10

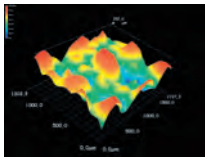
Artificial photosynthesis
Using a genetically optimized protein obtained from blue algae, Empa scientists have succeeded in increasing the efficiency of the electrodes employed in solar water splitting.
Page 19



11

Economic solar cells for the future
The EU-funded "TREASORES" project will, in the coming three years, develop economic production processes for organic electronics. The project is led by Empa researcher Frank Nüesch.

Innovative sheets for the bedridden
Pressure sores represent an ever present hazard to bedridden patients who do not move enough. Special sheets woven with Empa know-how minimize the danger thanks to microscopic structuring of the material.



Protection against "nano" sufficient
Empa has prepared a study for the Federal Office of the Environment, which analyses the risks posed by nanomaterials. The conclusion: at the moment no additional measures are necessary.

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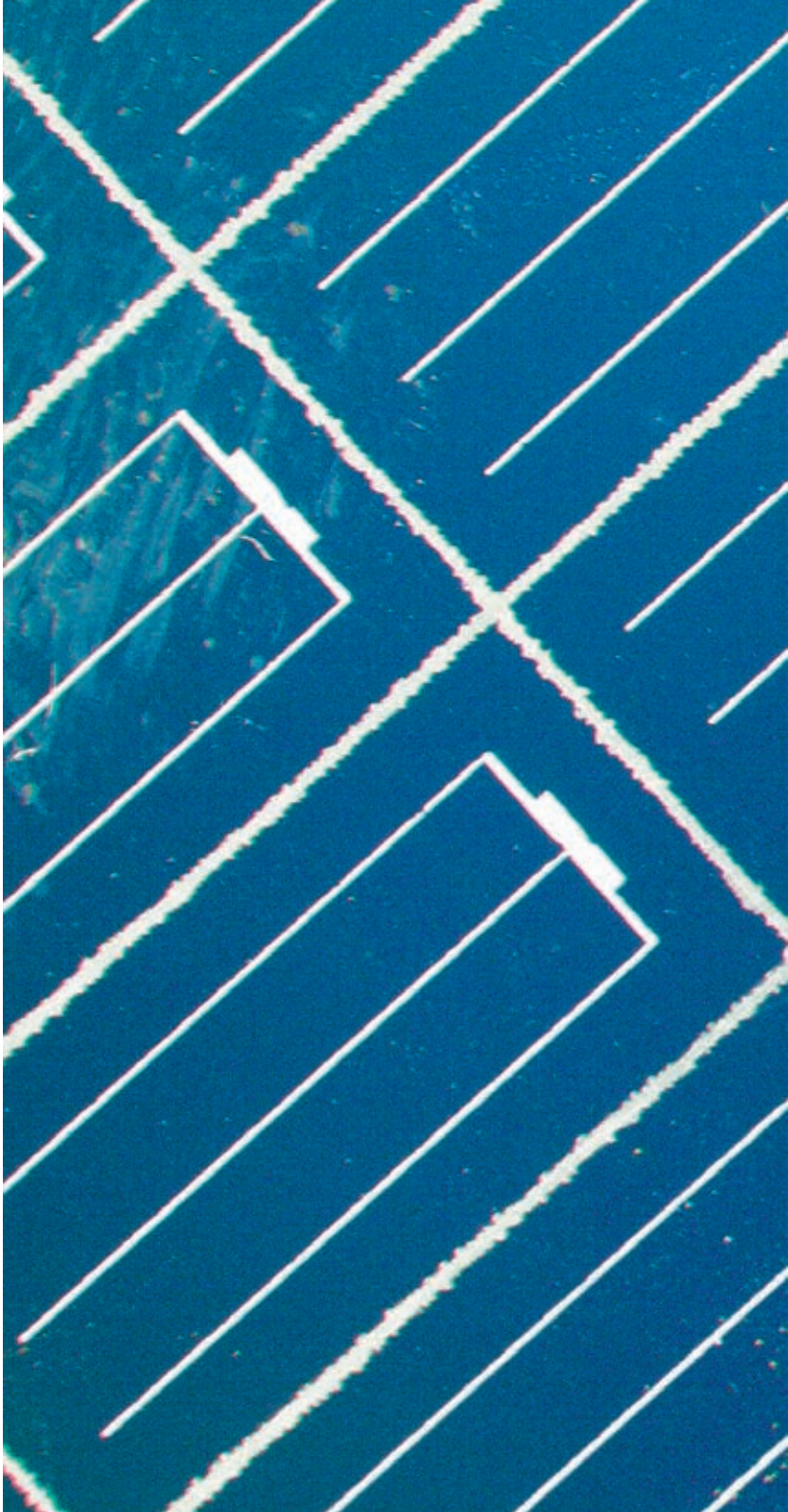
6th Empa Innovation Award
"And the winner is …" the highly insulating wall plaster based on Aerogel. The plaster is particularly suitable for renovating historical buildings and is a practical alternative to bulky insulating panels.

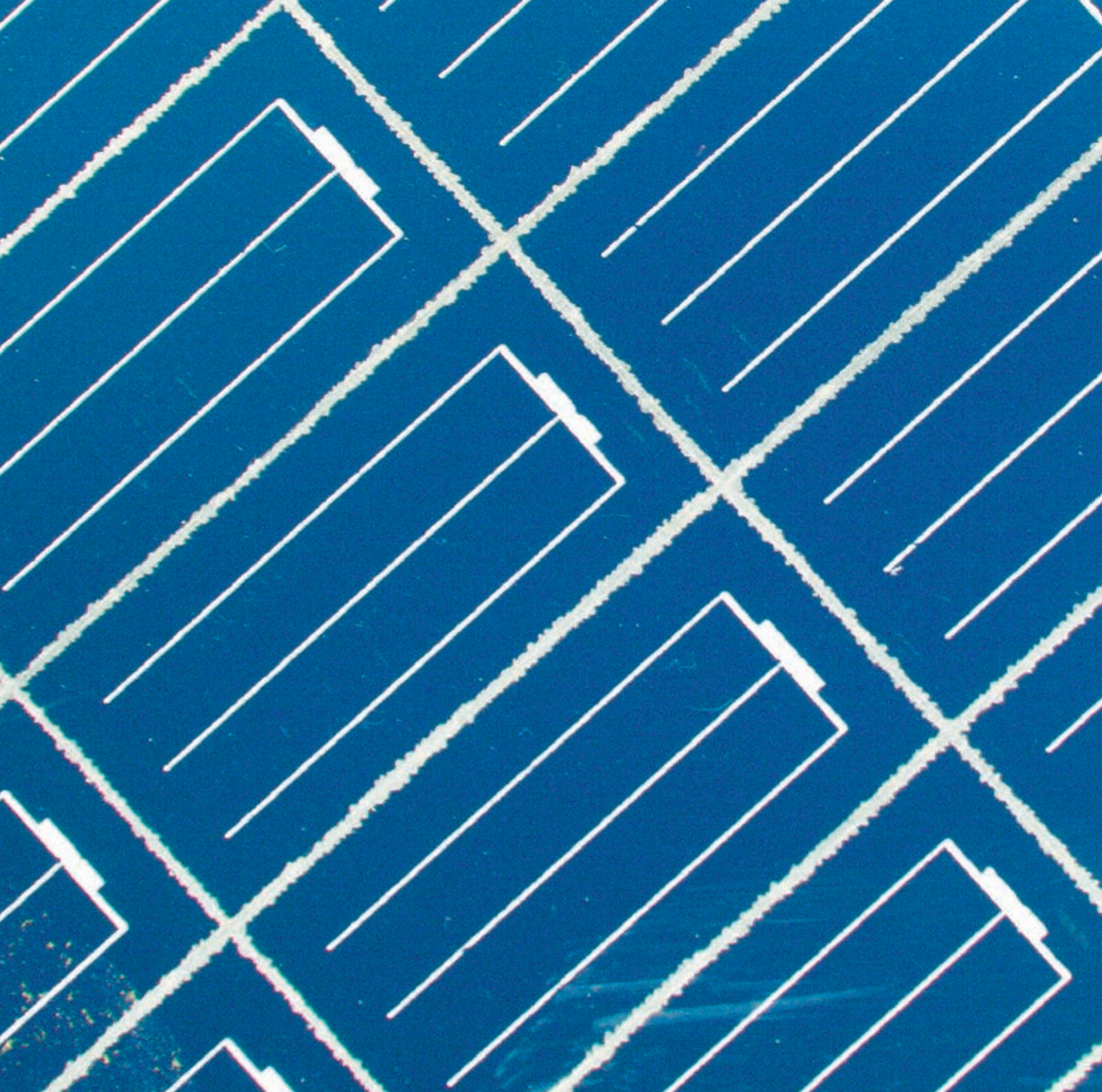
Really quite CLEVER
The first natural-gas fuelled hybrid vehicle with a manual gear shift has been developed at Empa with the participation of ETH Zürich and industrial partners. The test car "CLEVER" emits about 45 per cent less CO_2 than an equivalent petrol-fueled vehicle.
Page 50

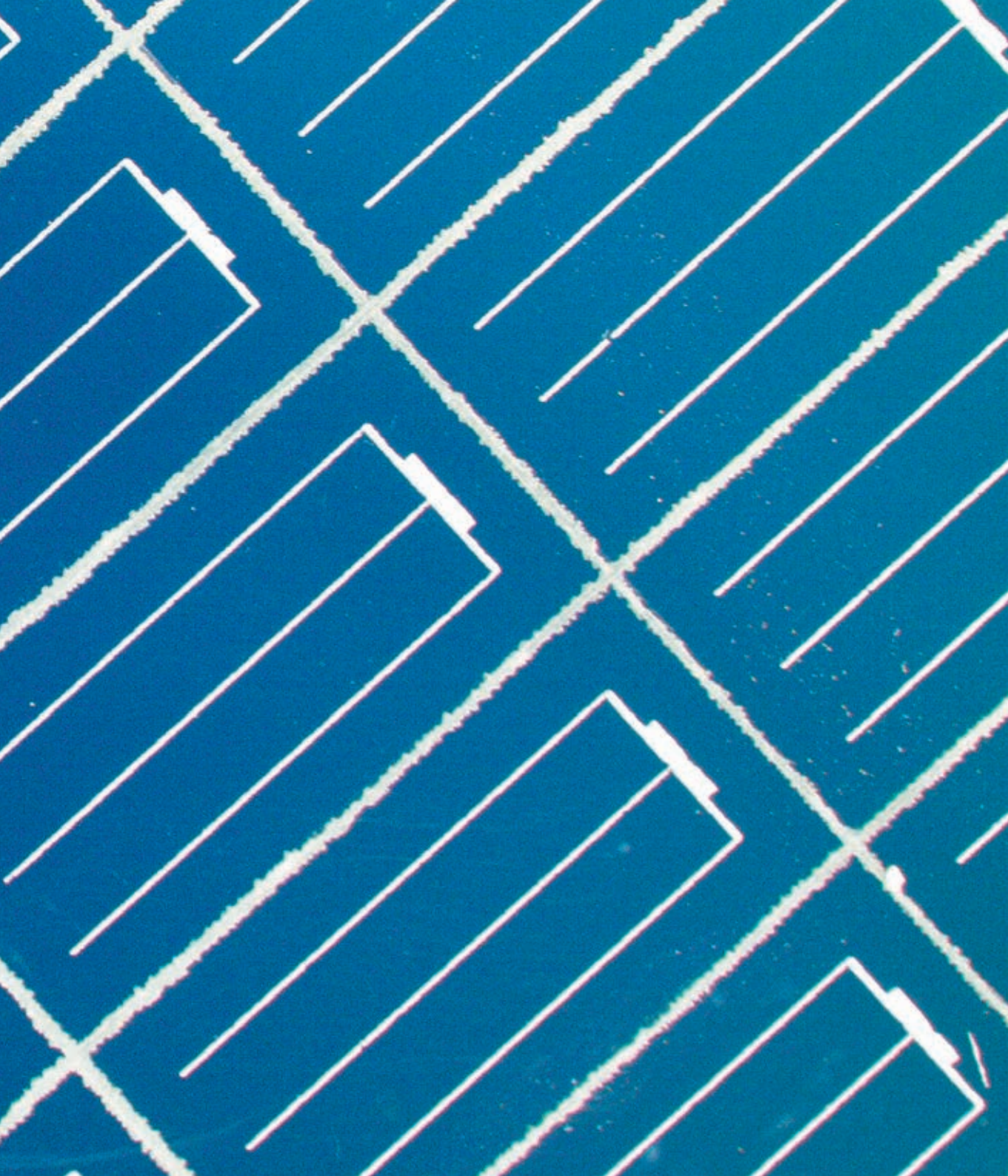
A turbocharger for fuel cells
Empa scientists have succeeded in manufacturing thermoelectric converters, which can convert waste heat into electric power even at very high temperatures, such as those found inside a fuel cell.
Page 16

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







Use-inspired Research

Innovative Developments

Knowledge and Technology Transfer

Services and Expertise

Advanced Training and Education

State-of-the art analysis methods at the atomic level

Until recently if one wished to analyse a sample for both its chemical and physical properties, one had to study it with two different instruments. Now, a unique new instrument called the 3D NanoChemiscope has been developed at Empa which can simultaneously analyse the chemical and physical properties of a surface in three dimensions. To date, samples first had to be scanned with a scanning force microscope (SFM), in which a very fine tip moves over the surface of the sample to measure its topography. Then the sample had to be analysed in another high-end instrument, the ToF-SIMS or time of flight secondary ion mass spectrometer. This device identifies the elements found in the surface molecular mono-layer of the sample. However, when transporting the sample from one instrument the other there is always a danger of contamination or surface re-organisation. In addition it is practically impossible to find the exact location scanned by the SFM again.

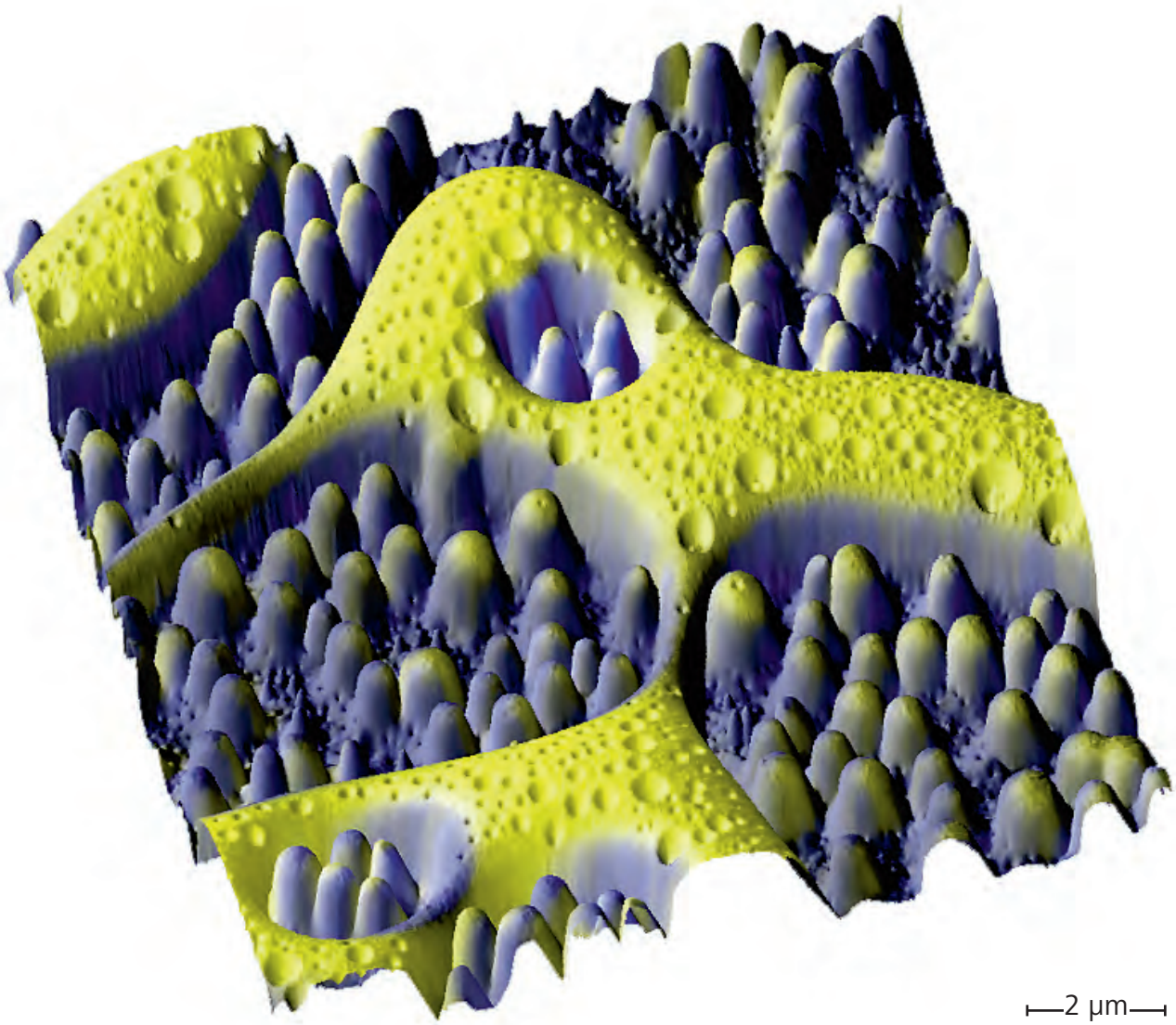
20

nanometers is the positional accuracy achieved by the 3D NanoChemiscope. Thanks to its piezomotors, a sample can be transported from the ToF-SIMS to the SFM and back again, returning with sub-micron precision to its original position.

Can the scanning force microscope and the mass spectrometer be „unified" into a single autonomous instrument?

In order to measure not only the mechanical properties of a sample such as hardness, elasticity or coefficient of friction, but also to determine the chemical composition of the surface, the SFM and ToF-SIMS need to be integrated into one self-standing instrument. The problem

The combined ToF-SIMS/SFM surface analysis of a PCBM/CyI-polymer blend, produced by Empa's "Functional Polymers" Laboratory for the development of organic solar cells.


2 µm

in doing this is that the two instruments are laid out in very different ways. In the SFM the sample and scanning tip are located in a chamber with one or more damping systems to suppress unwanted oscillation between the tip and the sample. In the ToF-SIMS, on the other hand, everything from the ion beam guns to the cameras and more is static around the probe. From a purely geometric point of view it is impossible to study the probe simultaneously using both methods.

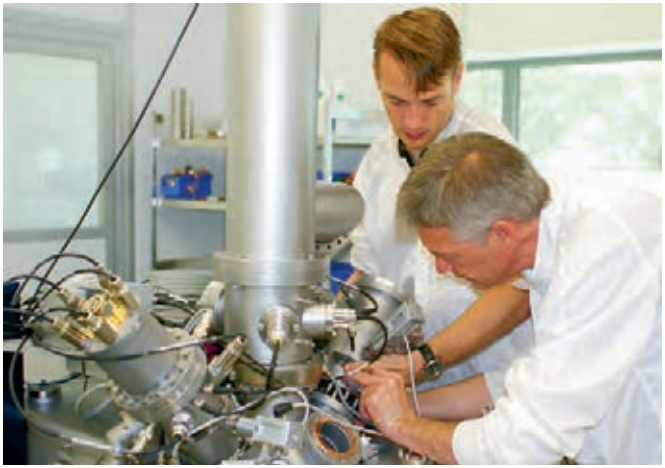
In the four-year EU financed "3D NanoChemiscope" project, Empa researchers together with international partners have developed a new instrument in which the SFM and ToF-SIMS are combined in an ultrahigh vacuum chamber and placed as near as possible to each other. The instrument is fitted with a novel transport system which moves the sample gently from the SFM to the ToF-SIMS and back using piezomotors, on tracks coated with a carbon layer similar to diamond. This ensures that the region of interest on the sample can always be located and does not "get lost" during the movement phase. When an electrical voltage is applied to a piezoelectric material it expands, and when the voltage is removed it returns to its original shape. If this process is repeated, it can be used to generate a continuous, gentle motion – the sample holder glides along as if on runners.

When developing the new instrument, the researchers took great care to ensure that the functionality of the two original instruments remained intact. The sample holder, for example, can move along five axes, allowing the sample to be analysed from any angle. In order for the scan to proceed as smoothly as possible and to allow molecular resolution, the sample is not moved under a fixed SFM tip as is usually the case. Instead, the tip scans across the sample, which is held stationary.

Project leader (right) and mechanical engineer discussing the construction drawing of a component.

Contact
Dr Laetitia Bernard
laetitia.bernard@empa.ch

With this new, technically very complicated solution, the Empa team went way beyond the originally planned project goals. More than creating a proof of principle instrument, they actually constructed a complete prototype which is now in operation. The ToF-SIMS part of the instrument was itself further improved. The industrial partner ION-TOF significantly improved the focus of the ion beam, allowing the ToF-SIMS to "see" fine detail much better than previously, though still not as well as the SFM. As a result, the ToF-SIMS has a resolution of down to 20 nm, while in the SFM the lateral resolution lies in the sub-nanometer range, depending on the sample and the tip used in the mode of operation. The project was completed in January 2013, and since then the prototype – an aluminium monster one meter long, 70 cm wide and 1.70 meters high – has been at ION-TOF's site in Munster, Germany, where it is being used by industrial clients and research partners. The construction of more instruments is being planned and several customers have indicated their interest. Not bad business prospects, considering that the cost of a 3D Nano-Chemiscope is several million Swiss francs!



Technicians setting up and adjusting the instrument.

An international collaboration between research and industry

The project was coordinated by the German company ION-TOF GmbH in collaboration with Empa, NanoScan, the Catholic University of Louvain, Belgium, the University of Namur (FUNDP), Belgium, the Institute of Scientific Instruments (ISI), Czech Republic, the Holst Centre, the Netherlands, and the Technical University of Vienna, Austria.

A turbocharger for fuel cells

Waste heat which is dissipated unused into the environment can be directly converted into electrical power using thermoelectric converters (TECs). These are modules made of semiconductor materials which are directly mounted onto hot surfaces such as oven walls and motor housings. When TECs are subjected to a significant temperature difference, charge carriers move from the warm to the cold side. Externally connecting the two sides allows a useful electric current to flow. These devices are most efficient where large temperature differences can be exploited; however conventional TEC materials are stable only to temperatures of up to about 300 °C. The operating temperatures of solid oxide fuel cells (SOFCs), which are used, for example, in fuel-cell based combined heat and power systems, are much higher than this – up to about 900 °C.

10

per cent increase in efficiency is quite possible, in the opinion of the experts, by the use of high-temperature TEC modules in SOFC systems.

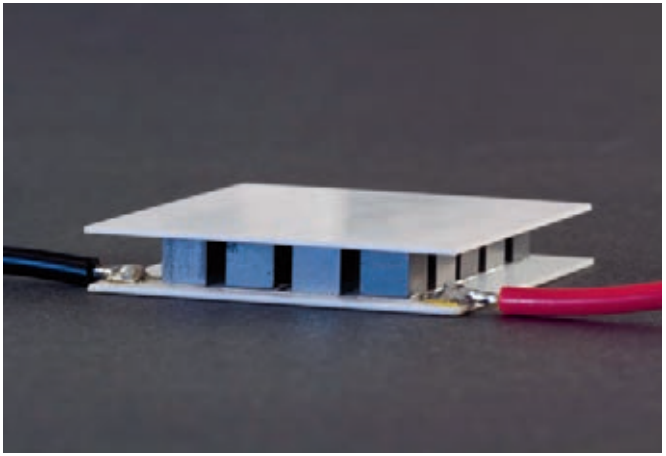
In the "HITTEC" (High Temperature Thermoelectric Converter) project Empa scientists, in a strategic partnership with Hexis AG, are developing a thermoelectric converter which can also withstand high temperatures. This will allow at least some of the waste heat which is generated in the SOFC process to be recuperated and reused by converting it into electrical power. This increases the electrical efficiency of the entire fuel cell process, thereby helping to save primary energy from both fossil and renewable sources.

Perovskite-like metal oxide is the ideal candidate

Suitable materials must not only be stable at high temperatures but also have a high thermoelectric efficiency. Perovskite-like metal oxides are considered to be the ideal candidates, since they are chemically and thermally stable, nontoxic and can be manufactured economically in large quantities. Calcium manganite, in which the manganese is partly substituted by tungsten, has proven to be a particularly promising substance.

In order to investigate various materials for their suitability in the HITTEC application, a novel setup has been developed at Empa in which the modules are exposed to extremely high temperatures. This allows the Empa scientists to determine the characteristics and power output of the modules, and also brings to light any weaknesses they might have.

A novel and unique setup has been developed at Empa solely to study high-temperature TECs.



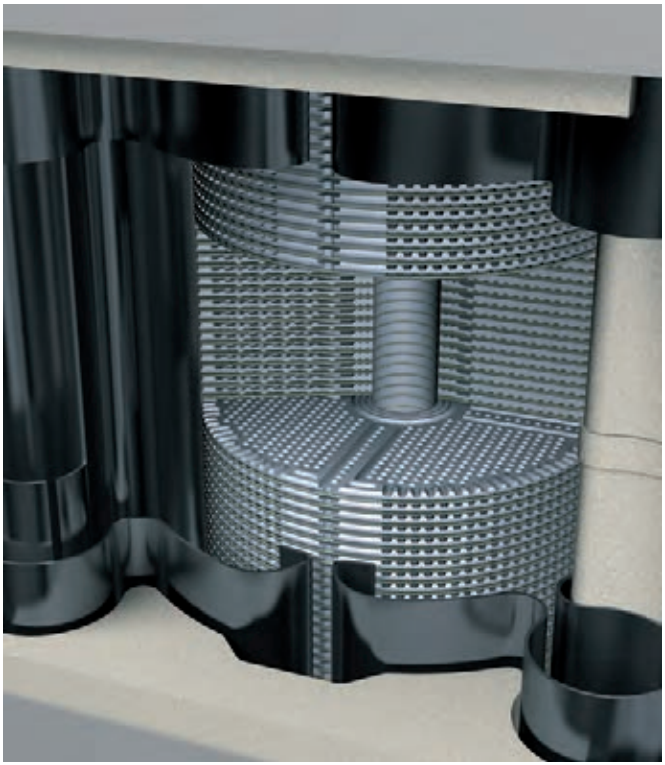
A thermoelectric converter is stuck like a plaster onto a hot surface, and can deliver supplementary electrical power.

Contact
Prof. Anke Weidenkaff
anke.weidenkaff@empa.ch

Integrating HITTECs in the SOFC system

The Empa material scientists have a slightly different vision of the future, however. They would like to place the TECs directly on one of the electrodes, that is, at exactly the spot where the chemical reactions occur in the fuel-cell. The materials used to make the SOFC electrodes are, in fact, a mixture of perovskite oxides which are stable at high temperatures.

Various other research partners such as the Zurich University of Applied Sciences, the EPF Lausanne and the ETH Zurich are also contributing their know-how to the project. They are modelling the material properties and optimizing the design of the modules, thereby determining how the modules may best be integrated into the SOFC. Following on from this basic research, a thermoelectrically optimized SOFC prototype can then be designed and constructed in collaboration with Hexis AG.



Up to 60 fuel-cells are stacked in the Hexis fuel cell system, offering a sufficiently large area to operate the TEC modules.

Solar hydrogen made by “artificial photosynthesis”

Every hour the sunlight shining on the earth provides it with more energy than its population uses in a year. One way of exploiting the sun’s energy is to convert it into electric power using solar cells. However, storing energy in an economic and efficient manner over a long-term period remains a major challenge. One must also remember that only the fifth of the world’s energy requirements are met by electric power, the remaining eighty per cent being derived from burning various fuels such as oil and coal. Or hydrogen, which can be used as an energy-storage agent in photoelectrochemical cells (PECs) and can be produced directly from sunlight and water. If the greenhouse gas CO_2 were also to be integrated into this process, then it would even be possible to produce synthetic fuels (“SynFuels” or “Solar Fuels”) in a sort of “artificial photosynthesis.” Our energy problem would be solved! Scientists have therefore been attempting to mimic the natural process of photosynthesis in photo-electrochemical cells. In support of this effort researchers from Empa’s “Laboratory for High Performance Ceramics” and “Laboratory for Biomaterials” have, together with colleagues from the University of Basel, the EPF Lausanne and from the United States, developed novel PEC hybrid electrodes in which low-priced iron oxide is functionalized by coating it with genetically optimized light-antenna proteins from blue-green algae.

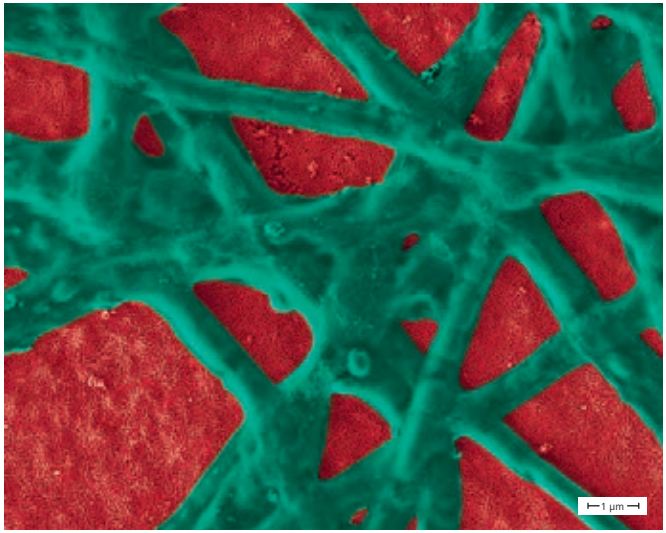
2.0

electron volts (eV) is the width of the band gap in hematite, a form of iron oxide. The band gap is the energy difference between the valence and conduction band of electrons. When excited by light electrons gain enough energy to cross the band gap, thereby causing the electrical conduction of a semiconductor to increase. Materials with a band gap around 2 eV are of general interest for solar applications.

An anode made of … rust!

Hematite, an iron oxide similar to rust, is a promising anode material for PECs; it absorbs sunlight over such a wide spectral range that it can theoretically convert 15 per cent of the absorbed light energy into hydrogen. In addition it is cheap, stable, environmentally benign and abundant. Its actual efficiency is however much less than theory indicates. This is due to the peculiar molecular structure of hematite, in which the electron-hole pairs created by the sunlight survive for only a very short time. In order to oxidize the water so as to evolve oxygen and hydrogen, the holes must diffuse to the surface of the hematite electrode; however the molecular structure of hematite "neutralizes" the great majority of these pairs after a very short time.

To solve this problem it is important to understand how electron holes behave near the electrode surface. Recently the Empa researchers and their international partners were able, for the first time, to monitor changes in the electron structure during the photoelectrochemical splitting of water in a specially constructed PEC, with the aid of a synchrotron based soft x-ray observation technique. In particular the researchers were able to identify two spectral signatures derived from iron and oxygen ions in the hematite.



A film of hematite nanoparticles (red) in a network of phycocyanin protein (green).
Image: Dr Elina Vitol, Argonne National Laboratory

A hematite film bearing a protein network with a fractal structure.

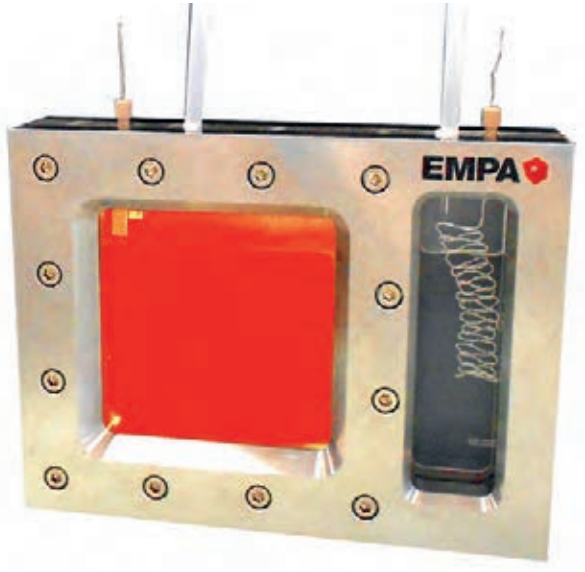

5 µm

Contact
Dr Artur Braun
artur.braun@empa.ch

The second important component: a protein derived from algae

The second component of the novel hybrid electrode is the protein phycocyanin, which "collects" sunlight like a light antenna for the photosynthesis process in blue algae. In fact hematite nanoparticles do absorb significantly more photons when they are covered in a layer of phycocyanin – the photocurrent in the hybrid electrode is doubled. Empa's biotechnologists were even able to genetically engineer phycocyanin in such a way as to optimize its adhesion to hematite, thereby eliminating one laborious step in the preparation process. One could say that the protein's tendency to cling to the hematite is inherited through its modified genes. Meanwhile, as a result of further progress it is now possible to use the bio-hybrid electrode with environmentally friendly pH neutral electrolytes.

The understanding at a molecular level of the processes involved in the photoelectrochemical splitting of water, and the combination of the technique with the natural light collecting substance derived from blue algae represent encouraging progress towards the realization of a practical process for economically producing hydrogen directly from sunlight.



The prototype of a novel photoelectrochemical cell (PEC) constructed at Empa, with which hydrogen can be produced directly from sunlight and water.

Making foam products fireproof – without toxins

Plastics made of organic polymers burn very well because they contain a high proportion of hydrocarbons. When made into foam they also catch fire very easily, generating a toxic mixture of gases such as cyanic acid and carbon dioxide whose exact composition depends on the kind of foam being burnt. Polyurethane foam and similar substances are very widely used in upholstery and mattresses, as insulation and packing material and in the building industry, and so must be made fire resistant.

62

seconds long is the maximum time, for which a sample of polyurethane foam may burn if it is to pass the standardized horizontal UL-94-Test. By comparison, without flame retardants the foam will continue burning until it is completely consumed.

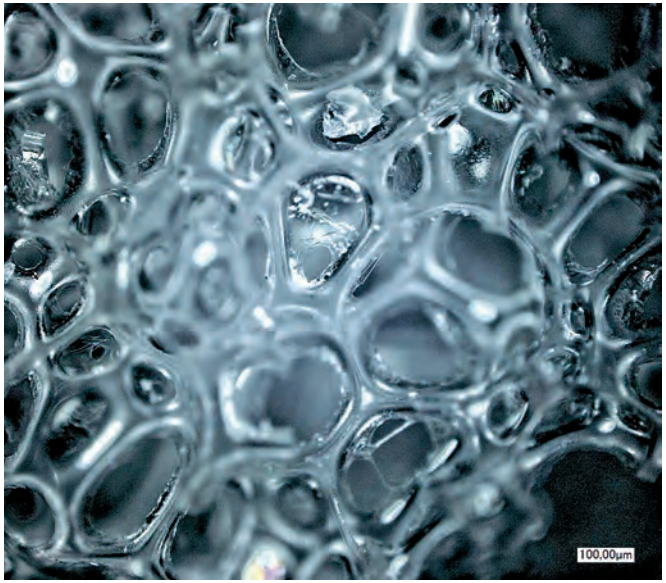
Conventional halogenated flame retardants such as Tris-(chlorpropyl) phosphate (TCPP) or some polybrominated diphenyl ethers (PBDEs) are suspected of causing health and ecological problems. Countless numbers of these products are extremely long-lived, accumulate in the environment, have hormone-like effects and are even regarded as carcinogenic. Harmless alternatives are therefore in demand, and these are exactly what Empa researchers, together with the Swiss company FoamPartner, have been developing in the course of a project financed by the Swiss Innovation Promotion Agency (CTI).

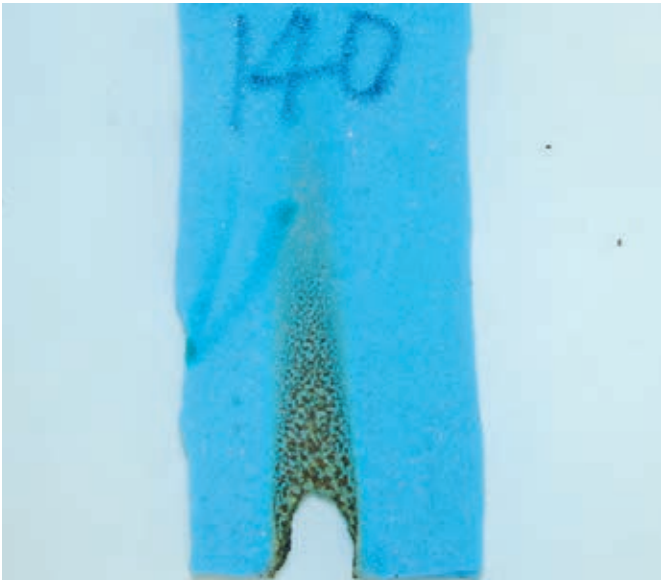
The new flame retardants are based on organic phosphor compounds, so-called phosphoramidates und phosphonates. The Empa scientists have synthesized several of these substances, each of which differs from the others in the way that hydrocarbon chains hang from the phosphor, and mixed them into polyurethane foam in increasing concentrations. The first results show that adding the flame retardant does not affect the foaming process.

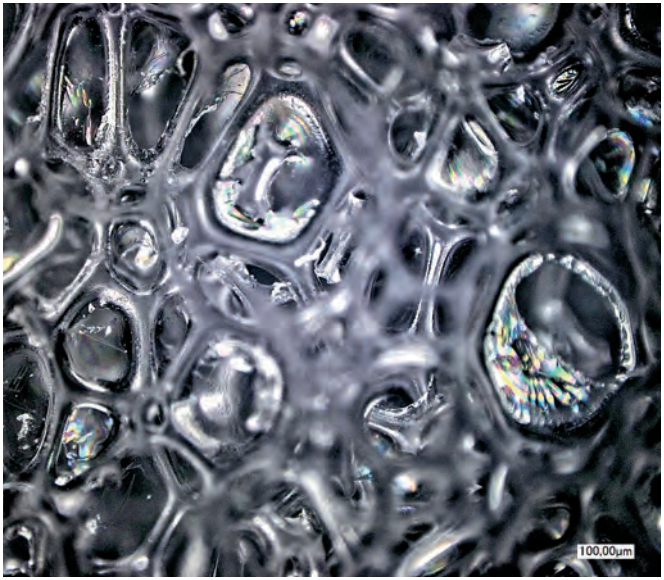
Contact
Dr Matthias Neisius
matthias.neisius@empa.ch

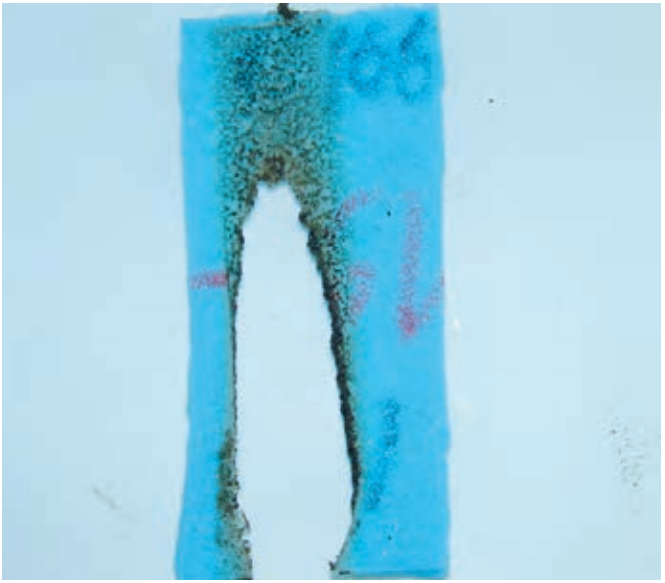
New flame retardants – safer and more effective

Subsequently the experimenters carried out a range of standardized flammability tests, comparing the fire resistance of the new products with untreated polyurethane foam, and with a foam containing TCCP. The data shows that if an unsaturated hydrocarbon (an "allyl radical") links to the phosphor then both phosphoramidates and phosphonates function as efficient flame retardants, offering in fact better protection than TCCP. By adding 10 per cent by weight of either of these types of material to the foam, the highest classification of fire resistance for foam can be achieved, something that to date has never been possible with conventional flame retardants. These additives and further new flame retardants such as phosphinamidates are not only safer than their halogenated predecessors but also more effective.









Polyurethane foam seen under the optical microscope: the flame retardant has no visible effect on the structure of the foam. Top: with flame retardant; below: without.

Normalized flammability tests show that substances containing organic phosphor (top) offer better fire resistance than the conventional, polluting substances such as TCCP in use today.

Accurately assessing the mobility of patients

Both the financial pressure in the healthcare sector and the demands in terms of quality of treatment are rising continuously, and this in turn increases the burden of responsibility on individual health care personnel. Intelligent solutions which help relieve personnel of this load while guaranteeing patients the same high quality of treatment are therefore very much in demand. In July 2012, a spin-off company from Empa and the ETH Zurich named "compliant concept" launched onto the market the first product of a comprehensive concept for analyzing the mobility and activity of bedridden patients.

1,257,233

patients were hospitalized in Switzerland in 2010 according to the Swiss Federal Statistical Office – in emergency units, and psychiatric, geriatric, and rehabilitation clinics.

An electronic assistant to prevent bed sores

The Mobility Monitor is a non-contact measuring unit located under the patient's mattress, which is linked to a monitor at the side of the bed and also to an illuminated call system. The measuring unit, a remote device which need not be in direct contact with the patient's body, collects and analyses motion data which it then evaluates. The measured values are shown on a small display at the bottom of the patient's bed. If the patient does not move for an extended period an alarm is sent to the nursing staff, thus preventing complications such as much feared bedsores, known in medical terms as decubitus ulcers. The results of the computerized analysis enable healthcare personnel to plan and document further treatment more efficiently. Since the "electronic assistant" is also ideal for collecting data on a patient's movements whilst sleeping, or monitoring the dosage of medi-

Contact
Dr Michael Sauter
michael.sauter@compliant-concept.ch

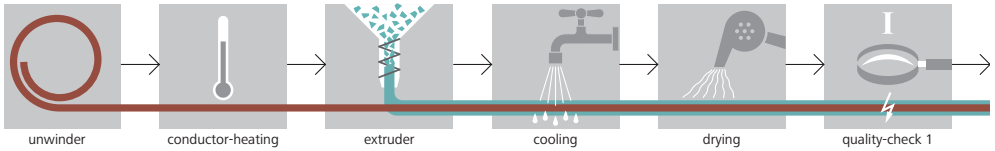
cation it can be used not just in nursing homes and hospitals but also in rehabilitation clinics.
In the first quarter since sales began "compliant concept," with offices in Empa's "glaTec" technology center in Duebendorf, has already achieved a turnover which exceeds the value predicted in the business plan by over 50 per cent. Initial customers have already bought further units and one of the Swiss market leaders is equipping all of its senior residence homes with the Mobility Monitor. Marketing of the device in Germany began at the beginning of 2013, with other countries to follow.

New investor found

The business idea and the product have also won over investors. "compliant concept" is no longer financially supported by private investors alone, since as of December 2012 the Debiopharm Group (a pharmaceuticals developer in Lausanne) and the Zürcher Kantonalbank (ZKB) have invested in the company. The new injection of capital will allow the young enterprise to grow and to establish a complete treatment bed system which mimics the movement of a healthy person as they sleep and so continuously and gently moves bedridden patients.

The Mobility Monitor is one component in an intelligent medical bed system intended to prevent pressure sores or, in medical terms, decubitus. The monitor uses a traffic light system to show the patient's current mobility level.

Creating "green" factories



Producing goods economically and, at the same time, in an ecologically responsible way has been to date a challenging task. Although many businesses do consider sustainability with regard to transport, marketing and administration, one critical aspect still remains neglected, namely the production processes themselves. Help is on it way in the shape of software developed, in the course of an Innovation Promotion Agency (CTI) supported project called "EcoFactory," by Empa scientists working together with industrial partners (Taracell Switzerland, Huber + Suhner AG, Knecht & Mueller AG, and Chocolat Frey AG), economists from the ETH Zurich and computer specialists from the University of Applied Sciences for Engineering and Economy (HTW) Berlin. The software, which is a world-wide one-off, not only simulates economic parameters such as utilization of capacity, timing, idle time – in other words the total economic efficiency – but also models and evaluates energy and material flows, including their environmental impacts. This allows users to harmonize the economic and ecological performance of the entire manufacturing chain.

3,500

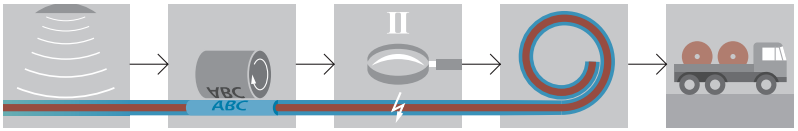
kilometers of high-tech cable are manufactured every week by Huber + Suhner – and every single production step is defined in detail, repeating every few seconds.

Empa database provides the foundation

One of the companies which would like to optimize its production processes is Huber + Suhner AG. Clearly, a "green" factory which makes no profit is hardly an attractive option and it is no easy undertaking to keep an eye on life-cycle balances, the careful usage of resources,

Top:
Functional block diagram showing the cable production process.

Contact
Dr Rainer Zah
rainer.zah@quantis-intl.com



CO_2 emissions and waste disposal, in addition to all the necessary economic factors. This is exactly where Empa makes its contribution. The expertise of its researchers, derived from years of experience in life-cycle analyses and the development of the "ecoinvent" database, adds critical information to the equation, allowing accurate forecasts to be created with the help of the latest modelling techniques. The economic models are linked directly to the methods and data used for life-cycle evaluation, allowing production experts to determine which machines run for how long during a process, and what materials are required for a particular manufacturing step. The ecological dimension extends far beyond mere energy saving, with pollution emissions, resource usage and wastage also being factored into the overall eco-balance.

A Huber + Suhner process technician goes through the factory with a fine tooth-comb, looking for the slightest case of energy wastage.

Industry's interest has been awakened

Initial feedback has been consistently positive, with industry showing great interest in "EcoFactory." The project therefore has a good chance of becoming commercially successful. A marketing strategy, at both national and international levels, is currently being planned. Working with industrial partners has been of great assistance in this respect, giving researchers an insight both into the opportunities the "EcoFactory" software offers as well as its limits. Use of the program does not make sense under all circumstances; it is most helpful to those companies which are already actively engaged in reducing their environmental footprint and who wish, as a final step, to ecologically optimize their production processes over the full life cycle. Manufacturing companies which have no prior experience with environmentally friendly technologies will find themselves out of their depth with the new software tool. Often, as a first step, it is sufficient to study a company's electric power consumption data and monitor the efficiency of its production machinery. This allows the specialist to suggest basic changes which, without any detailed analysis, will result in considerable improvement. The "EcoFactory" software can then be used to give the ecological focus of the business the ultimate fine tuning.

Leaky aerosol cans? Call in the quantum cascade laser!

Hair spray, hair-dye or shaving-foam aerosol cans have one thing in common – they contain a highly explosive mixture of propane and butane as propellant gas. In order to avoid accidents during transport or use, the manufacturer has to test each individual aerosol can for leaks by immersion into a hot water bath. Empa, in collaboration with the Wilco company based in Wohlen, Canton Aargau, a specialist producer of leak test machinery, has developed a new, very rapid, and highly sensitive method for propellant gas detection that is more energy and cost-efficient than the water bath test.

10^{-6}

is the sensitivity of the new aerosol can "sniffer." This system, based on a novel quantum cascade laser, can detect one molecule of propellant gas, such as propane or butane, among one million air molecules.

The new detection technique employs a quantum cascade laser which is similar to the one that has been used in a spectrometer to decipher the isotopic signature of CO_2 in the air over the Jungfraujoch. While the latter instrument must be able to very accurately differentiate between various isotopes, the new aerosol can leak detector need "only" identify traces of propane and butane, albeit extremely rapidly and with great sensitivity. According to the industrial partner's requirements, the system should be able to detect leaking gases at ppm concentrations – that is one molecule of propellant gas per million air molecules – within less than a tenth of a second, yet still be more economic than the water bath method.

Supported by the National Centre of Competence in Research "Quantum Photonics," Empa and Wilco have built a demonstrator, the performance of which has largely exceeded their expectations. A novel Fabry-Pérot quantum cascade laser, which was only developed in March 2012

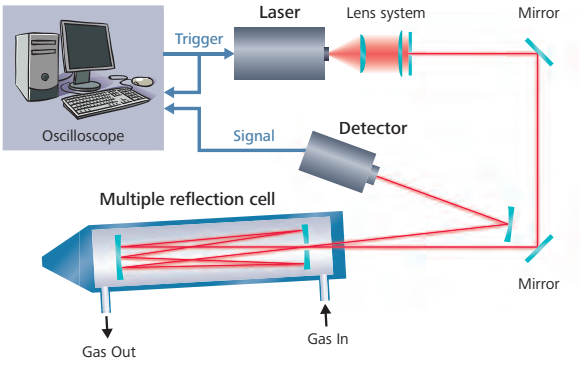
Empa and its industrial partner Wilco have built a demonstration unit to show how quickly and reliably the aerosol can leak testing can be performed.

Contact
Dr Jana Jagerska
jana.jagerska@empa.ch

at the ETH Zurich, is at the heart of the new instrument. In contrast to laser diodes that are widely used in the field of telecommunications, the quantum cascade laser produces light with a wavelength of 3 micrometers, which is ideally suited for the detection of organic substances such as propane and butane.

The gas sample to be measured is drawn off into a measuring cell and illuminated with pulses of laser light. If certain molecules are present – in this case propane or butane – they absorb some of the laser light, which leads to a reduction of the detected signal. In less than a tenth of a second the system sends out a signal to reject the leaking spray can. The demonstrator succeeded in checking up to 900 aerosol cans per minute instead of the originally required 500, while using only a fraction of the energy that the traditional water bath method consumes. A further bonus: the "Wilcomat" can be used not only to recognize trace quantities of propane and butane, but also to detect many other organic substances such as pharmaceuticals or solvents, in tiny concentrations. A patent has already been filed and a first complete system is under construction.

On detecting a leak, the system sends a command to reject the defective aerosol can within less than a tenth of a second.



The analyzer consists of a measurement cell, in which the propellant gas molecules are exposed to the laser, a detector to measure the intensity of the outgoing laser beam, and a computer to acquire and display the detector signal.

Improving the quality of concrete – at the computer

The cement manufacturing industry is responsible for 5 per cent of the carbon dioxide emissions worldwide, even though per tonne of cement much less CO_2 is set free than, for example, by the production of the same amount of steel or aluminium. The problem lies in the quantity – every year three billion tons of cement are produced throughout the world, and the trend continues upwards.

One way of reducing CO_2 emissions during cement production is by using raw materials with low carbon content. And, of course, if the structures built using the cement are made to last longer, and therefore are demolished later, then this too would be a step to reducing the CO_2 emissions.

50

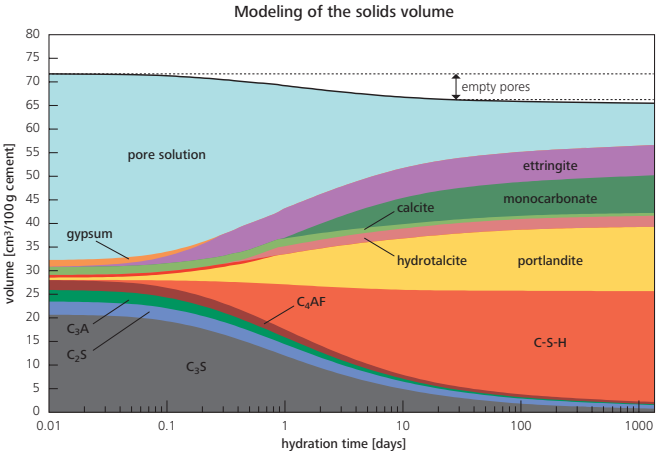
per cent calcium silicate hydrate (C-S-H) and 20 per cent portlandite – these are the most important products in the portland cement setting reaction.

Concrete with reduced CO_2 emissions

Concrete is a mixture of gravel, sand, cement, and water, and it owes its strength the reaction between the latter two components. As the cement sets, the setting reaction leads to the creation of a new solid phase and an increase in solid volume. At the same time the total volume is reduced, since the water is bound in the solid phase, thus increasing the total density. Empa has, for some time now, been conducting research to develop improved types of cement. Since, theoretically at least, there are an infinite number of different cements mixtures possible, each of a unique composition, the researchers are using a computer program developed by colleagues at the Paul Scherrer Institute (PSI) to predict the chemical reactions which occur during the setting process. The simulation software, which is named "Gibbs Energy

Contact
Dr Barbara Lothenbach
barbara.lothenbach@empa.ch

Minimization Selector" (GEMS), allows users to thermodynamically model which solids are stable and calculates how materials behave and change over time under a given set of circumstances. If the program is fed with data on the minerals and additives used in cement from Empa's comprehensive database on this subject, then any desired mixture can be manufactured at will on the computer – in a virtual sense, of course. In addition other properties of the material can also be modelled and its future behaviour predicted years in advance.



The composition of a sample changes as the concrete sets, and the computer simulation is invaluable in precisely predicting the final properties of the mixture.

Tunnels that last longer

One must not forget that over its lifetime concrete must often endure very difficult conditions. If groundwater seeps into a tunnel the sulphates it may contain will react with concrete to produce ettringite and thaumasite, two minerals which increase the total volume, leading to expansion and spalling. Engineers can use GEMS in the planning phase of a project to evaluate different types of cement and choose one which minimizes the formation of these damaging minerals under the given conditions. Fly ash can be mixed with the cement, for example, to increase its resistance to water containing sulphates.

The behaviour of concrete can therefore be predicted and optimized with the aid of a database and a thermodynamics program, helping to reduce CO_2 emissions and increasing the usable lifetime of a concrete structure. In terms of computer simulations of this kind, Empa is a worldwide leader.

A researcher indicates on screen how the simulation program predicts that the total volume of the sample reduces as the cement sets.


odellierung des Feststoffvolumens
Ettringit
Monosulfatanteil
Portlandit
C-S-H
Abbindezeit [Tage]
SAMSUNG
NTNU

Nanocellulose – the renewable all-rounder

Simple cellulose helps to protect wood surfaces against the elements, can be used to create replacement implants for spinal discs, keeps food fresh and filters CO_2 from the atmosphere. Empa's wood researchers have been investigating why this is so – and where else cellulose might find uses.

1,500

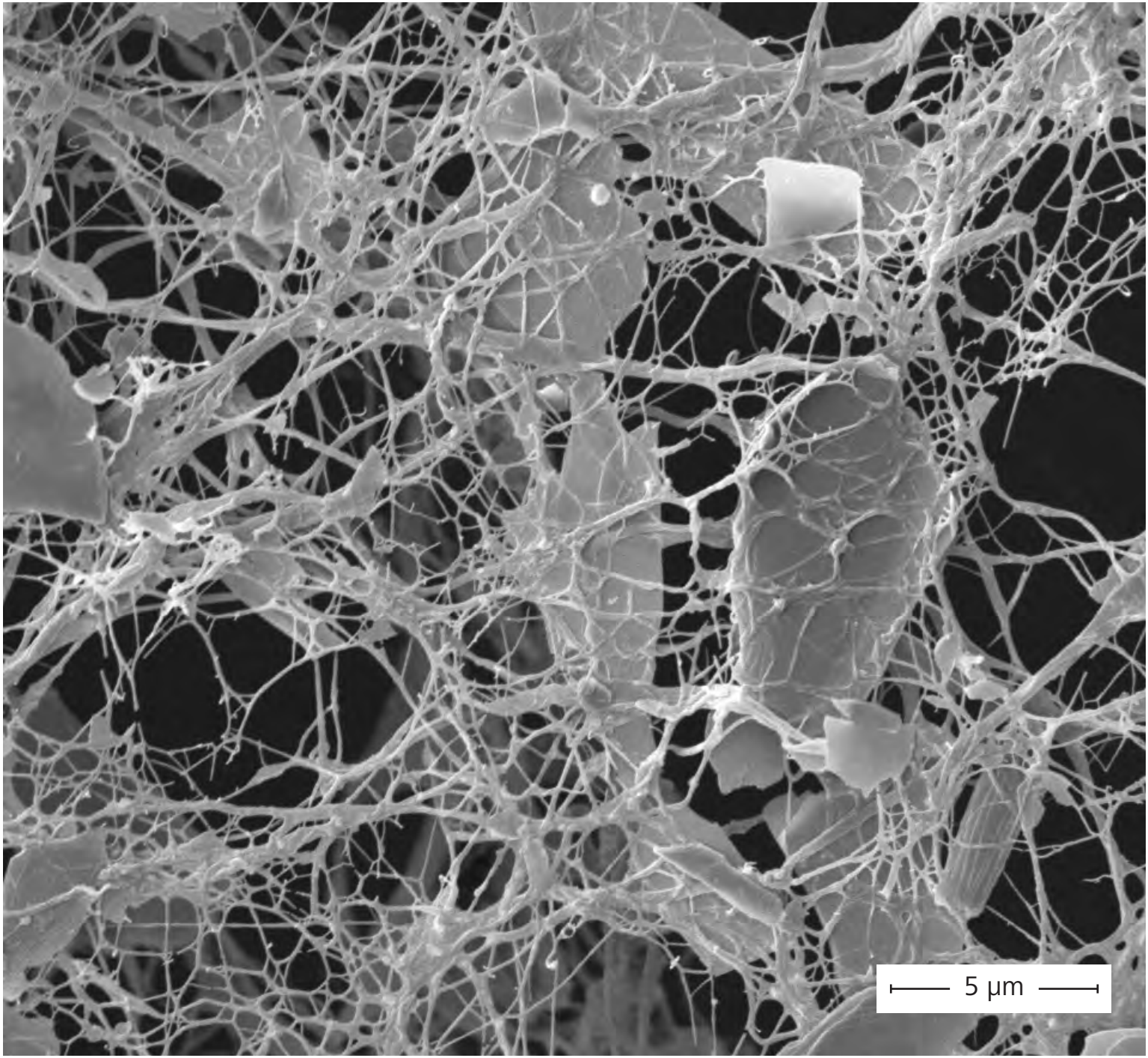
atmospheres of pressure and fine steel capillaries convert normal cellulose into nanofibrillated cellulose (NFC), a sought-after substance with many uses.

The metamorphosis from an industrial bulk product into a high-tech material with multifaceted applications begins quite simply – in an aluminium funnel filled with cellulose soaked in water. Tubes connect the funnel to a high-pressure pump which squeezes the cellulose fibers through thin, interconnected capillaries at up to 1,500 bar. The soft material, naturally, yields to this obstacle course of solid steel, emerging as "nanofibrillated cellulose," abbreviated to NFC, a material consisting of minute flakes of nanometer-thin cellulose fibers which boasts wondrous properties.

Replacing spinal discs…

One example: mixing just 1 or 2 per cent by weight of this substance with water creates a stable gel. For about ten years now researchers from Empa's "Applied Wood Materials Laboratory" have, together with other research institutions, been doing pioneering work at an international level in their studies of NFC. Over this period the Empa scientists have investigated quite a few applications using the new material. For example, the fibrils were used to reinforce wood adhesive and, in collaboration with the EPFL, this material was investigated

An electron microscope image of nanofibrillated cellulose. Clay particles are distributed throughout the cellulose matrix, visible in the form of tiny "particles" in the cellulose network.


5 µm

Contact
Dr Tanja Zimmermann
tanja.zimmermann@empa.ch

for its suitability as a replacement for the gelatinous core of spinal discs (the so-called Nucleus pulposus). Scientists at Empa St Gallen have succeeded in spinning NFC-reinforced polymer fibers, and the start-up company "Climeworks," in a technically elegant process, has used chemically modified NFC to extract CO_2 from the air. This latter process could, in future, be used to produce synthetic fuels (Synfuel).

We could soon even be coming across this wonder material in our refrigerator. NFC gel can be mixed with clay particles and hot pressed to a thin film which acts as a barrier to water vapour and atmospheric oxygen – an ideal material for use in food packaging. The advantage of the NFC clay film is that it can be burned and composted, since cellulose fibrils are biodegradable.

The conversion of cellulose into the high-tech product NFC begins in a metal funnel. Here two Empa researchers investigate the properties of the material.

...or coating wood

Recently, researchers have cast their eyes on another possible application, namely improving surface coatings for wood. Can a substance derived from wood or straw really be used to help protect wood surfaces from light and fungal attack? One must take into account in this context that every wood surface treatment is a compromise – the more transparent the paint, the less time it provides protection. Also the fact that wood naturally swells and shrinks over time represents a further problem, for every coating which is to last for several summer/winter cycles must adapt to the movement of the wooden substrate. If the paint becomes brittle and cracks then the wood becomes susceptible to damage from rainwater and attack by microorganisms.

This is exactly where NFC fibers can offer help, for UV absorbing materials can be embedded in the matrix of the fibers in the form of nanoparticles. And with the assistance of the fiber network the nanoparticles are also evenly distributed throughout the paint. Furthermore, the already established resistance to cracking of NFC fibers can additionally help strengthen the paint and reduce the formation of cracks in the surface. The first results show that the mechanical properties of coating films can indeed be modified in a controlled way by the addition of NFC.

Wood surfaces – a happening place

Wood is a building material which needs to be protected – to extend its useful life man first invented paint, then pressure impregnation, then later even baking to create thermotreated wood. Now another discovery has found its way out of the laboratory and into the real world: wood given a tailor-made surface through biological processes. Researchers from Empa's "Applied Wood Materials Laboratory" view this latest discovery as an opportunity to make out of wood – with all its "biochemical plug-in points" – exactly the material needed at any given moment, with properties such as an adhesive-friendly surface, an antifungal coating or even self-adhesive sawdust which can be used to make 100 per cent ecologically friendly fibreboard with practically no chemical additives.

12

weeks was the incubation time of spruce samples exposed to aggressive, wood destroying fungi. The samples treated with iodine survived this harsh treatment.

Initially, research was intended to find ways to counter damage to wood by fungal infection. But scientists have long since turned matters around – now they are using enzymes such as laccase, which is excreted by wood-destroying white-rot fungi, in order to induce tailor-made modifications in the surface properties of the material. The enzyme converts the hydrogen groups in lignin, a constituent of wood, into radicals, making the surface of the wood reactive. This opens the door to a wide range of functionalizing processes.

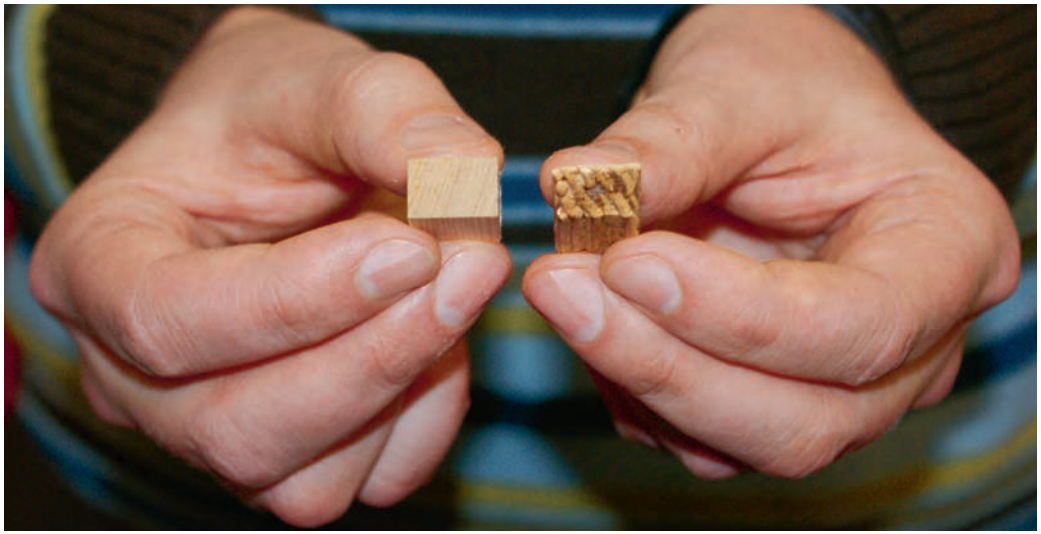
Protecting wood with an old household stalwart

But where does one start with a wood surface which is, in a manner of speaking, "ready for new ideas"? One possibility is creating a protective layer which is firmly anchored in the wood

surface, thus preventing bare wood from rotting. Together with their colleagues from Empa's "Biomaterials Laboratory", the researchers developed a method of giving wood a long-term antimicrobial effect. This involved a laccase-catalyzed oxidation of iodide ions (I^-) to molecular iodine (I_2) and the simultaneous iodization of the lignin in the wood. Iodine solutions are low-cost biocides which are effective against a large number of microorganisms such as bacteria, fungi and viruses. Trials using fungi which aggressively attack wood provided confirmation; whilst untreated test samples showed serious signs of rot after twelve weeks of exposure, test samples which had been treated withstood the attack well.

Making fibreboard without chemicals

This experiment proved two things simultaneously. On the one hand, the laccase treatment really did allow useful quantities of



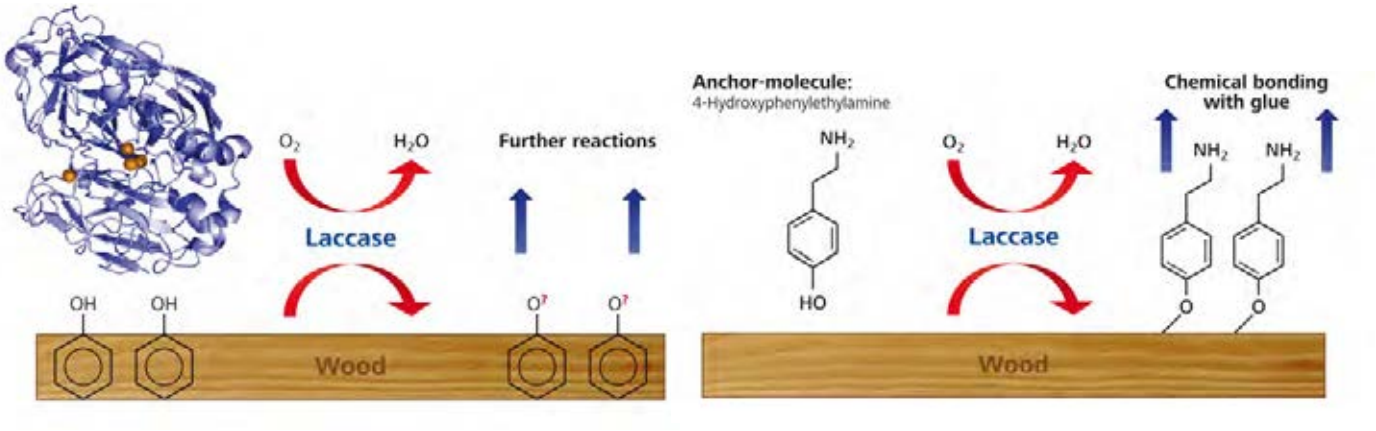
A comparison between treated (left) and untreated wood samples.

Contact
Prof. Dr Linda Thöny-Meyer
linda.thoeny@empa.ch

Dr Mark Schubert
mark.schubert@empa.ch

a substance to bind chemically to the wood surface. On the other, it showed that with the help of laccase it is possible to make adhesive-free fibreboard. If wood fiber which has been pre-treated to activate certain radicals is compressed, then chemical bonds can be formed between neighboring fibers. This would allow the manufacture of so-called fiber insulation board almost entirely without using chemical binders such as resins or isocyanate. The Empa scientist are now on the lookout for an industrial partner with whom they can further develop the antimicrobial wood treatment process to a marketable level.

And, just in case you were wondering, there is no reason to be afraid of laccases. These proteins are biodegradable, nontoxic to humans and animals, and cause no problems on skin contact. Another plus point – they work on wood at room temperature without the need for pre-treatment using acids or alkalis.



Enzyme treatment: the laccase uses chemical "docking stations" on the surface of wood and thus makes the wood reactive.

A hard shell with a soft core

Protective clothing is indispensable in today's world, be it during sport, on the road or at work. The drawback is that protective clothing is often heavy and stiff, limiting the wearer's movement. A solution is now in sight, promised by a completely new fiber with a liquid core with which Empa scientists intend to develop the protective garments of the future. This very special new fiber does not impede slow movement in any way, but instantly stiffens when subject to rapid movement or an impact. The core of the fiber is filled with a so-called dilatant liquid, the key to this project being carried out by Empa's Advanced Fibers laboratory.

500

micrometers is the average thickness of the different filaments with liquid cores, which have so far been produced in the laboratory.

Through thick and thin

The basic idea behind the "Rheocore" project, which is supported by the "Intelligent Materials" National Research Program (NFP 62), is to spin a hollow polymer fiber which contains just such a dilatant or shear thickening liquid. If the filament is kinked or bent, the fluid it contains is forced to flow through narrow canals in the middle of the fiber. The dilatant liquid reacts to these sudden shear forces by thickening, causing the filament to stiffen and thus damping the movement. Slow movement is not hindered because the liquid filling remains low viscosity state.

As a first step the project team has created a laboratory model to understand the processes involved in creating the "fiber with filling." The liquid core must be "injected" simultaneously with the solid polymer sheath, and the required hollow structure must be created at the same time. In laboratory trials the Empa researchers have carried out these individual steps. The

Contact
Dr Rudolf Hufenus
rudolf.hufenus@empa.ch

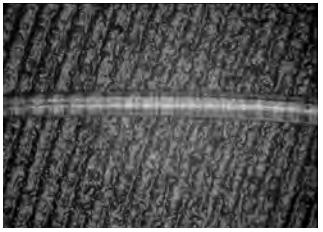
Dr Laura Gottardo
laura.gottardo@empa.ch

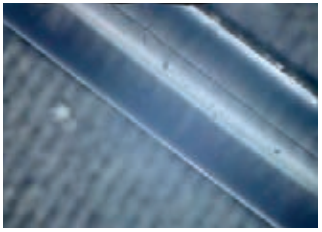
difficulty lies in creating the correct shape of cavity to contain the dilatant liquid.

Some hollow spaces are better than others

Individual drops of liquid which are separate from each other do not produce the required effect, since when the filament is bent liquid cannot flow anywhere. The cavities must therefore be interconnected like a series of caves through the center of the fiber. However, several cavities linked like a chain of pearls are also useless because their shape is too regular. Ideally the cavity should be of irregular shape – narrowing and expanding randomly – so that the required shear forces will be developed in the dilatant liquid.

In the meantime the project team has succeeded in manufacturing a liquid-filled fiber. Now the challenge is to understand the structure of the filament, particularly the internal hollow areas which are well hidden and difficult to view under the microscope. Using a computer tomograph (CT), however, it is possible to differentiate the polymer sheath of the fiber from its liquid core, and the first results look very promising. Currently the team is working on evaluating possible projects in which the "Rheocore" fibers might be used for industrial applications and in everyday life. Initial discussions with possible partners are underway. The potential is in any case enormous.





Above: two samples of "Rheocore" fibers seen under the microscope.
Left: A researcher experimenting in the laboratory with various dilatant liquids.

Functional textiles for cardiac regeneration

It may soon be possible to repair damaged heart muscle, such as occurs after a myocardial infarction (heart attack). A research project, conducted at Empa in collaboration with the University of Fribourg and the University Hospital Bern provided important milestones towards muscle tissue regeneration.

12

nanometers thick (actually thin!) is the polymer layer which is applied to the fleece and on which the living cells are grown.

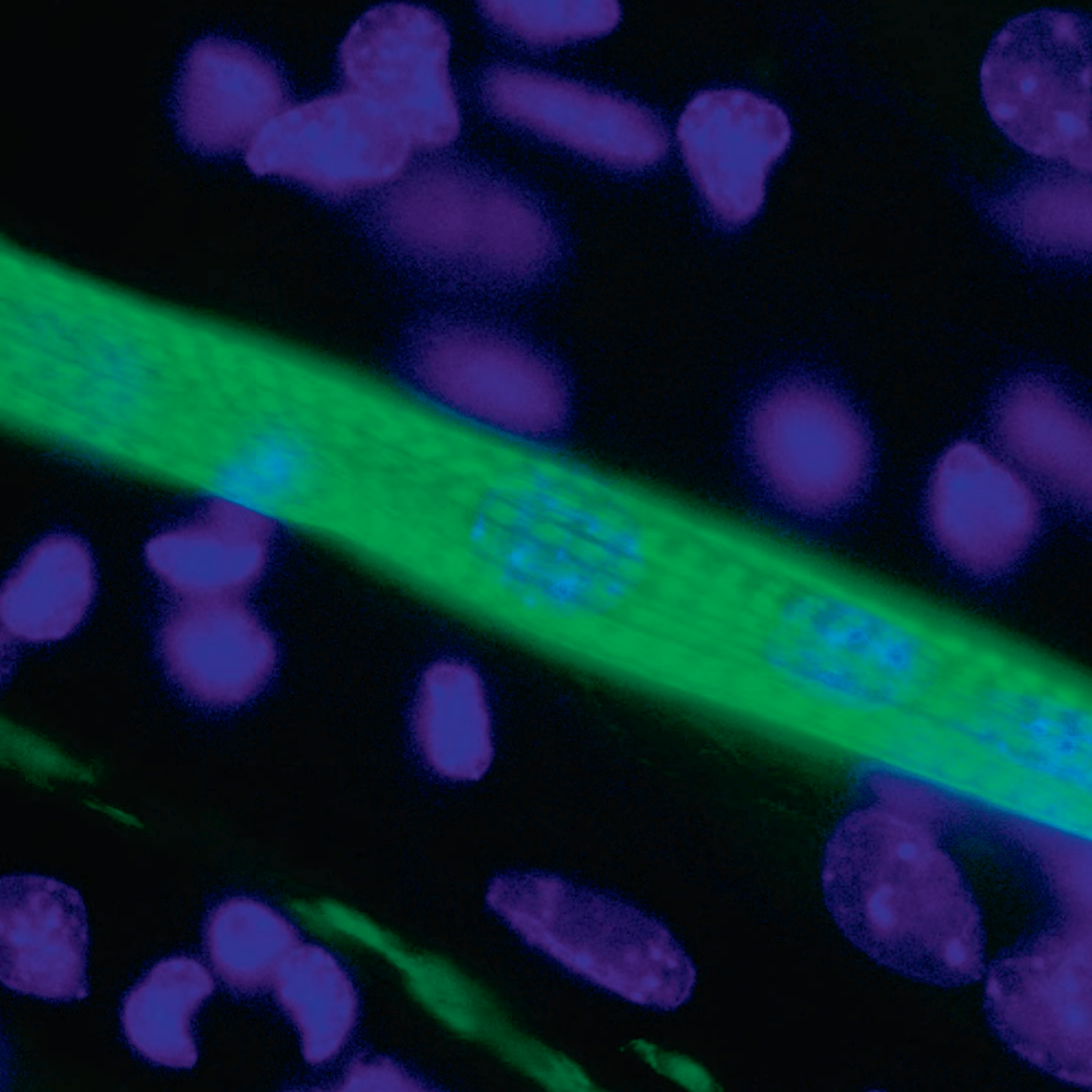
The goal of the project was to develop a new method by which muscle or stem cells can be cultured on electrospun textiles, providing biografts that can be implanted into damaged heart tissue. This should induce muscle tissue regeneration, for example after a heart attack – still the major cause of death in industrialized countries.

The basis for the "cell friendly" non-woven material is the so-called electrospinning process, in which biopolymers are spun into thin fibers with diameters on the micro- or nanometer scale. To achieve this, a polymer solution is provided by a thin cannula and introduced into an electrostatic field. Depending on the viscosity of the solution, it is possible to draw thin polymer fibers of different diameters by the applied electric voltage. In the lower part of the spinning apparatus, the fibers form a chaotic motion, assembling on the base plate in form of a large area of a flat fleece (non-woven), made of ultrathin polymer threads.

A thin-film for cell cultivation

In order to be able to cultivate cells on the fleece material, it must first be plasma coated. Particularly, an additional functional plasma polymer coating is applied – whereas plasma

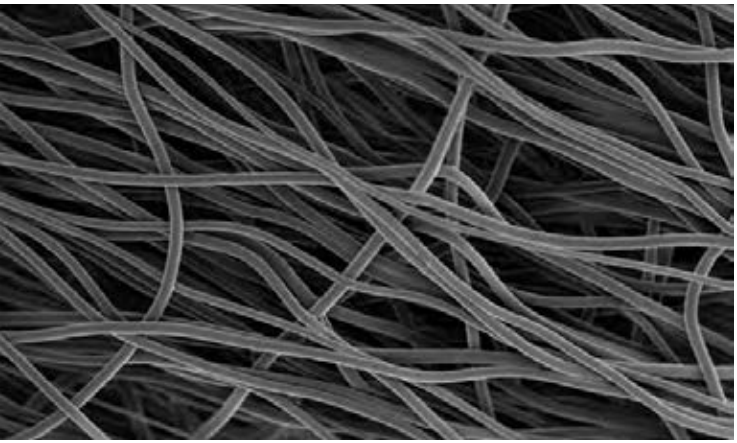
Fluorescence microscopy image of muscle cells on electrospun fibers (blue: cell nucleus; green: myosin, one of the motor proteins of muscle cells).



Contact
Dr Anne Géraldine Guex
geraldine.guex@empa.ch

Dr Giuseppino Fortunato
giuseppino.fortunato@empa.ch

process parameters and the layer composition need to be adjusted according to the application. This additional layer exhibits only a few nanometer thickness and is designed to modify the surface characteristics of the fleece while leaving other basic properties, such as its stability and tear resistance, unchanged. Empa research has shown that coatings with ethene (C_2H_4) and carbon dioxide (CO_2) provide optimal properties for cell cultivation. These specific coatings are extremely stable, are easily reproduced and well tolerated by the body's immune system.



Scanning electron microscope image of electrospun fibers.

Empa – a specialist in electro-spinning

The interdisciplinary research project has already provided important information on the interaction of fiber materials with cells and the new technique shows great promise in terms of the development of a new therapy. Before the first patients can be treated, however, important questions must be answered, such as the point in time of the implantation, and which fundamental mechanisms are involved in the heart's own regeneration process.

Empa is also developing functional fibers made by electrospinning for other purposes. Due to the very small fiber diameter and high porosity of the non-wovens, such products can be used for a wide range of applications. These include patches designed to gradually release drugs, cell-bearing implants, breathable, and waterproof membranes for use in high performance garments, or as catalysts in filters.

Self-healing asphalt

Resurfacing work on Swiss roads not only costs a huge amount of money, it also tries the patience of thousands of motorists for whom the ensuing traffic jams have become a daily torture. Time, therefore, for Empa to step in and take on the challenge of developing a road surface which is both easier to repair and has a significantly longer service life than those currently in use.

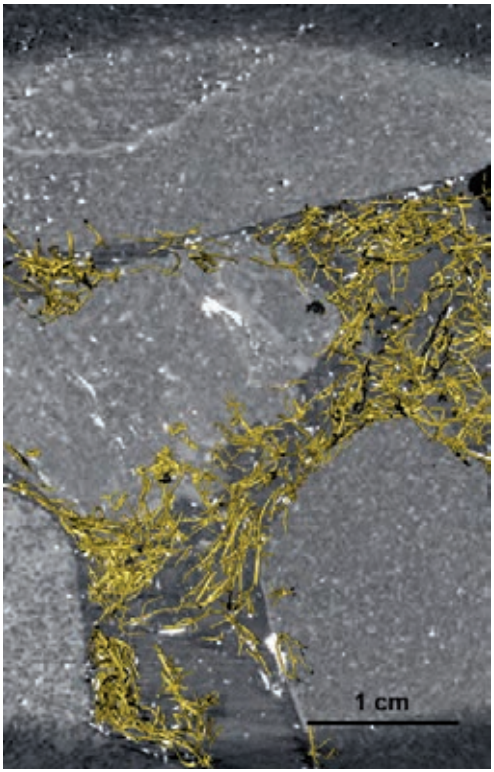
15–20

years of equivalent traffic load is what Empa's Road Tester inflicts on the test surface – in less than a week!

Road surfaces are subject to enormous loads on a daily basis. Temperature fluctuations, aggressive chemicals and de-icing salt take their toll on the tarmac, making it brittle and causing it to crack. When the temperature falls below zero the water in the cracks freezes and expands, destroying the road in slow motion. After 15 to 20 years of this, complete replacement of the road surface is necessary. Even if the cracks are quickly and continuously repaired, this "sticking plaster" approach does not stop the process from occurring, since by the time the cracks are visible to the eye the damage has already been done to the road surface.

Bitumen is the sticky solution

Researchers from Empa's "Road Engineering and Sealing Components Laboratory" have come up with the answer: seal off the cracks when they are still microscopically small. The question is how? To achieve this the scientists exploit the properties of bitumen, a complex mixture of long chain hydrocarbons which acts like an adhesive, gluing stone and sand together to create asphalt. Empa researchers have added the finest steel wool fibers to this mixture. When the



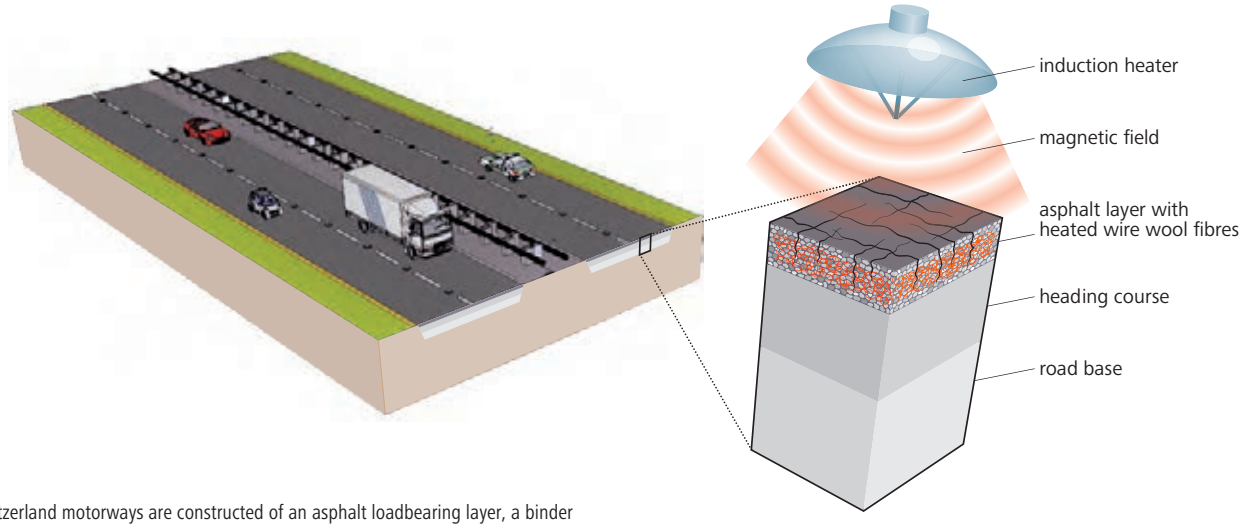
Steel wool fibers in the asphalt
make the road surface practically self-healing.

first microcracks appear in the new surface, it is treated using an induction heater. Just like the induction hob in a modern kitchen, this device generates an electromagnetically induced alternating current in the metal fibers, which is converted into heat. This in turn warms the bitumen, and at about 80 °C the asphalt begins to melt. On cooling, the surface hardens to a closed mass – almost as if it has repaired itself!

Contact
Dr Alvaro Garcia
alvaro.garcia@empa.ch

Special mixture for Switzerland

At the moment the new process is being tested on Dutch roads in collaboration with the Technical University of Delft. For two years now traffic has been flowing over a 300 m stretch of motorway which was surfaced with the special asphalt. In about 12 to 13 years the surface will be "freshened up" using induction heaters. This is considerably earlier than would be the case in Switzerland, the reason being that Dutch roads are constructed differently to those in this country. The results from the test in the Netherlands cannot therefore be directly applied here, and Empa scientists must therefore first develop the correct asphalt mixture for Swiss conditions. To do this they have been mixing asphalt samples containing variable quantities of stone, sand, bitumen and steel fibers using a mixing device which works like a large dough kneading machine. The next step is to test a length of roadway surfaced with the new mixture using Empa's Road Tester, a device specially designed to mistreat the roadway so badly that it will need to be "melted" back into shape a lot sooner than in 20 years of normal use.



In Switzerland motorways are constructed of an asphalt loadbearing layer, a binder layer and a covering layer. Thanks to the very fine steel wool fibers in the covering layer, it can be heated inductively. This causes small cracks in the layer to simply "melt" away.

Really CLEVER – a natural gas powered hybrid

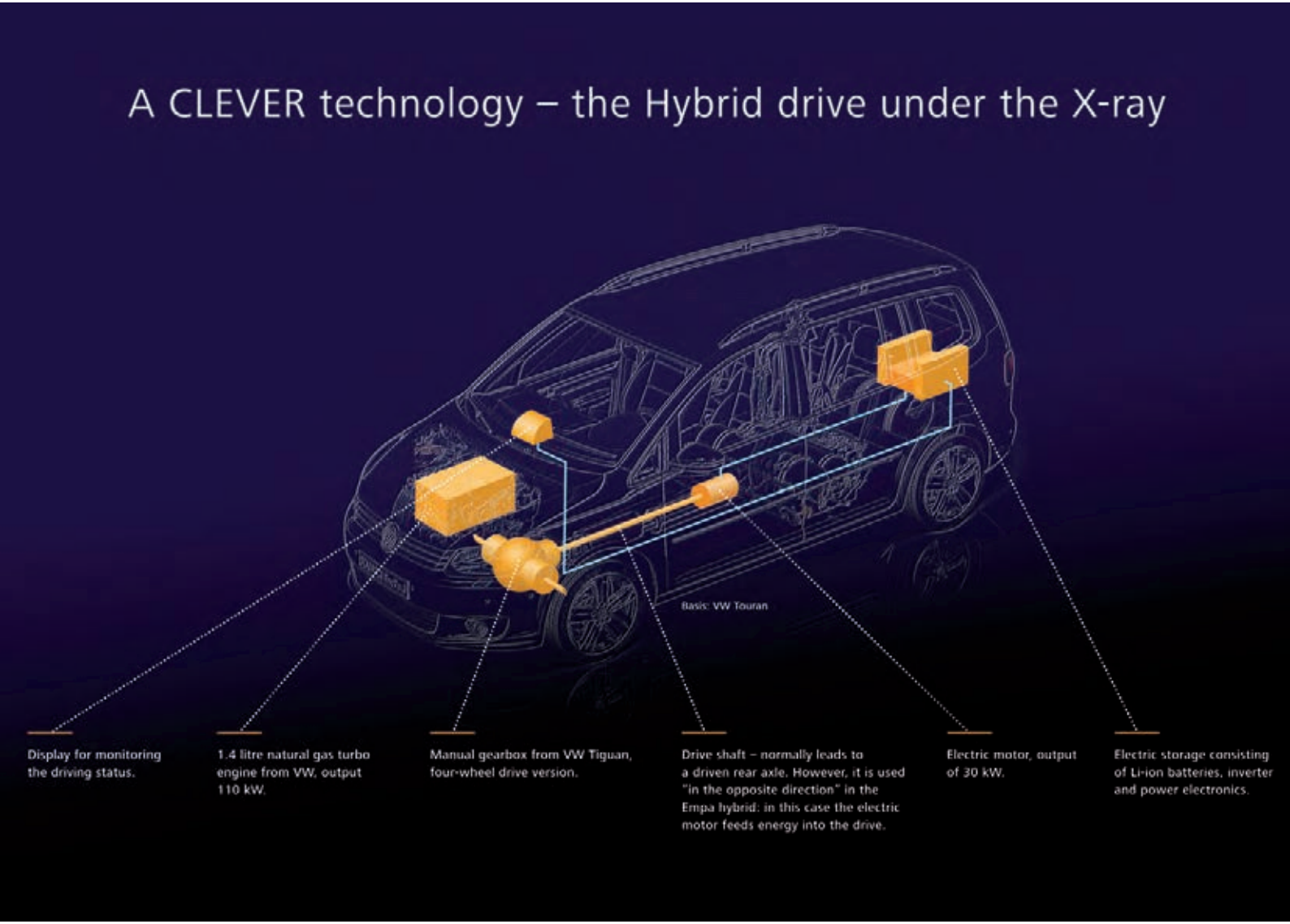
For more than a decade Empa has played an important role in the research and development of natural gas engines. For example, one of the world's first gas-powered turbo-charged engines was developed in the "Engine Laboratory" in Duebendorf – a device which impressively demonstrated the potential of gas as a fuel in terms of minimizing CO_2 and pollutant emissions. Meanwhile, turbo-charged gas engines can be seen on the roads – VW, Opel and Fiat offer reliable, powerful cars with turbo-charged gas-engines boasting low fuel consumption. Environmentally friendly gas-fuelled engines are not, however, in demand for automobiles alone; they have also caught the eyes of truck manufacturers and are being used in stationary applications such as combined heat and power plants too. This is yet another area in which Empa is active.

45

per cent CO_2 is how much less the natural-gas fuelled hybrid car emits when compared to the conventional petrol fuelled equivalent – without increasing the total costs over the service life of the vehicle.

The project currently in progress once again concerns the automobile. The engine experts have created a natural-gas fuelled full hybrid vehicle with a manual gearbox, based on the VW Touran – a combination which to date remains unique. For the researchers of the institute's "Internal Combustion Engines Laboratory", a vehicle with a manual gear shift has the advantage that it can be built cost-efficiently. The car is not just a simple object of study, though – it is part of a vision which will make automobile manufacturers sit up and take notice. Compared to an equivalent petrol engine, the natural-gas hybrid emits 40 per cent less CO_2 if operated with fossil natural gas. The vehicle even achieves a CO_2 benefit of 45 per cent in

A CLEVER technology – the Hybrid drive under the X-ray



Contact
Dr Patrik Soltic
patrik.soltic@empa.ch

Switzerland because of the Swiss addition of climate neutral biogas. What is also interesting is that the lifecycle costs have not increased in relation to the purely petrol fuelled engine version, in fact for heavy usage they are actually lowered. This is, of course, of particular interest for vehicle fleet owners who must keep in mind not just the purchase costs but also those incurred over the entire lifetime of the cars they operate, a parameter known as Total Cost of Ownership (TCO).

Collaboration with the ETH Zurich

Instead of modelling the entire vehicle from a purely theoretical standpoint, the project team decided to build the real thing, something that could actually be driven on the street. The ETH Zurich is playing a role as project partner too. Prof. Konstantinos Boulouchos' research group is investigating the fundamentals of the combustion process by simulating the flow and combustion behaviour of fuels in the cylinders of the engine. Other scientists from Prof. Lino Guzzella's group are providing the theoretical basis required to dimension and control the hybrid system in an optimal way. And industrial partners Volkswagen and Bosch, with their experience in mass production techniques, ensured that the vehicle, named CLEVER, could actually be put together.

On board computer ensures efficient operation

Test drives have shown that it takes a little bit of time to absorb the philosophy behind the new design and suitably adapt one's driving style. The on-board computer selects the operating mode so as to ensure that the gas motor always runs at its most energetically efficient point and the battery is operated under net charge sustaining conditions. However, getting all the technical parameters right is not enough – subjective impressions such as driving characteristics and acoustics must be evaluated by human beings! And here lies the real significance of CLEVER; the test car with the natural gas hybrid motor is intended not just to help research into new technologies, but also to demonstrate whether test persons without an engineering degree can drive them comfortably too.

Display monitoring the vehicle condition (right).
The CLEVER car – Empa's natural-gas fuelled hybrid research automobile based on the VW Touran.

Future Mobility

The time-line for the Swiss government's energy turnaround calls for research results that can be implemented rather sooner than later. The ability to transfer scientific findings into marketable innovations requires, however, the help of suitable research and technology platforms. Empa is currently building up just such a platform for the mobility sector, an area which is responsible for about a third of the country's energy consumption. The so-called "Future Mobility" demonstrator allows new, sustainable fuels such as hydrogen, synfuel (synthetic natural gas or petrol), and hythane (a mixture of natural gas or biogas and hydrogen) to be manufactured and proven in practical driving tests. These energy-rich fuels, which are produced with the help of photovoltaics, wind power, and surplus electrical power, can be stored easily and used in a range of vehicle types, each with its own optimized drive concept.

Use-inspired Research

Innovative Developments

Knowledge and Technology Transfer

Services and Expertise

Advanced Training and Education

Future Mobility: which fuels will we use in the future?

"Energy turnaround" is not just a buzzword for the generation of electricity; it is also an important factor regarding mobility. Clean, renewable fuels, efficient power trains, and lightweight vehicles are absolutely essential if we wish to achieve the ambitious CO_2 targets in future mobility. This is an area in which Empa's research has been successfully positioned for a long time. We have developed, among other things, more efficient combustion processes for internal combustion engines and novel battery technologies, as well as providing new ideas for the manufacture of alternative fuels.

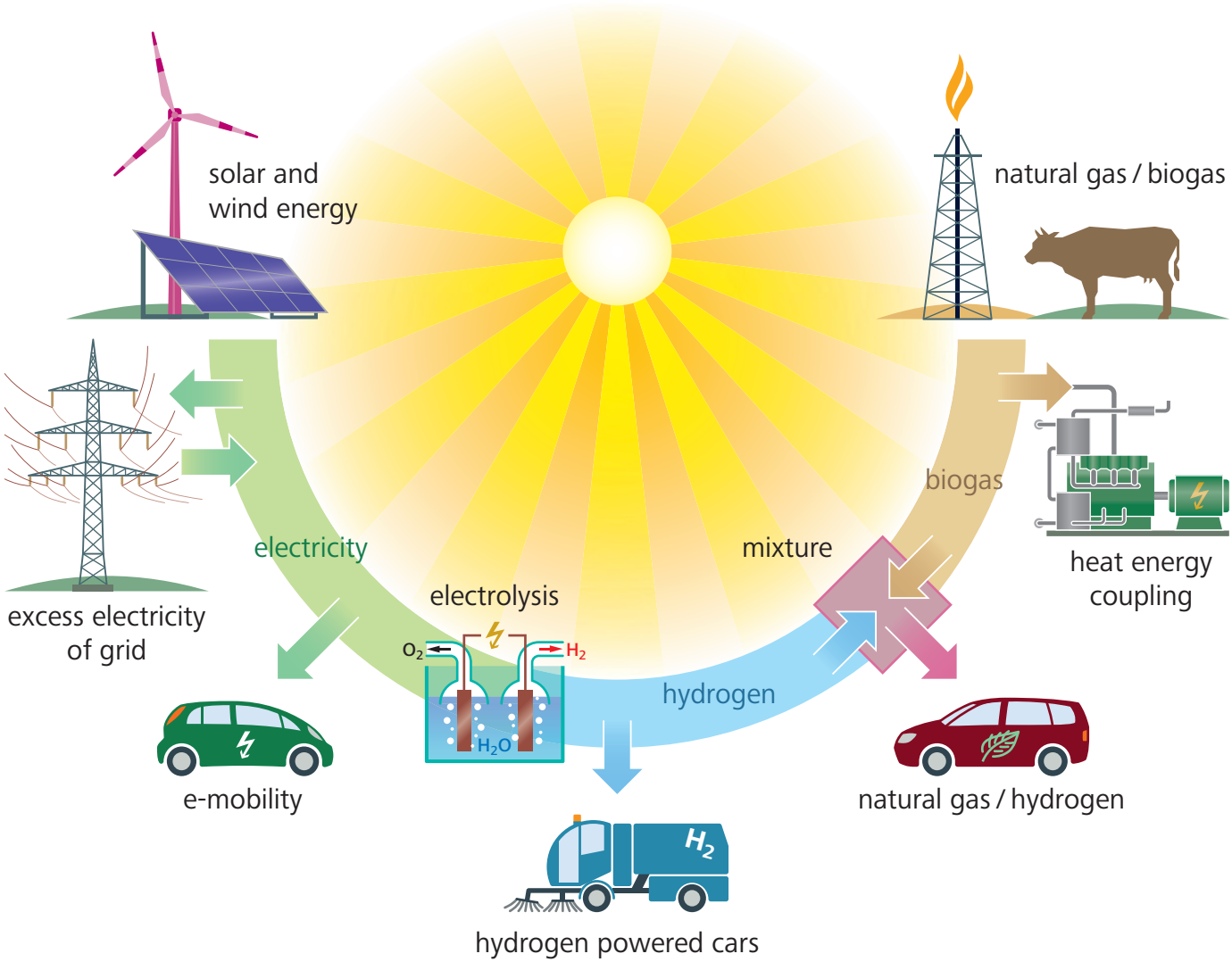
20

per cent of the vehicles on the road (so called frequent drivers) are responsible for 45 per cent of all kilometers driven. Half of all registered cars are medium-sized vehicles.

The car is becoming green

Currently, the burning question is: what is the fuel of the future? Empa's research on this topic is guided by the newest results from mobility studies, market requirements, and the energy strategy of the Swiss Federal Government. Micro-census studies on the mobility behavior of Mr and Mrs Swiss show, for example, that just 20 per cent of all drivers are responsible for almost half of the overall kilometers driven. Each of these "frequent drivers" covers more than 20,000 km on average with their vehicles. Also, market analyses show that medium-sized vehicles such as station wagons and minivans make up around 50 per cent of all vehicles sold. Bearing this in mind, natural gas/biogas electro-hybrid drives with a range of well over 600 km, which are suited for "frequent drivers" mentioned above, are currently at the center of our engine research activities. They are ideal for medium-sized vehicles, their engines are much lighter and

Which fuel will we use in future to power the "omnivorous" automobile?


solar and
wind energy
natural gas / biogas
excess electricity
of grid
electricity
electrolysis
O_2
H_2
H_2O
mixture
biogas
heat energy
coupling
hydrogen
e-mobility
natural gas / hydrogen
H_2
hydrogen powered cars

they emit significantly less CO_2. Even if fossil energy carriers will likely continue to be available in sufficient quantities, one thing is clear: renewable energy will play an increasingly important role in our mobility, not least because more and more consumers demand it.

Exploiting surplus electricity

One very promising possibility is to convert short-term excess energy from renewable sources into storable energy carriers such as hydrogen. With the increasing integration of large solar and wind power plants into the power grid, these excess supplies will in future occur on a large scale. Hydrogen can then be used as a fuel, either on its own or together with natural gas/biogas. This is in fact exactly the vision of "Future Mobility," the planned Empa demonstration platform designed to use excess electricity to generate hydrogen, which will then be used to power cars with a range of different drive concepts. To achieve this, "Future Mobility" combines three energy sources which, depending on the time of day (and, therefore, the load on the power network) make varying contributions to powering the test fleet. The three sources are:

- electric energy from solar and wind power plants as well as from combined heat and power units
- surplus electricity from the grid
- natural gas/biogas

More specifically this means that "Future Mobility" will, whenever possible, use electricity from large photovoltaic systems to directly charge up the batteries of electric vehicles. If these vehicles are on the road the solar power will be used to generate hydrogen which will be used "straight" to power fuel cell vehicles or mixed with up to 25 per cent of natural gas/biogas to fuel gas-powered vehicles. A beneficial side effect is that mixing hydrogen with natural gas/biogas makes the gas engine more efficient and cleaner, reducing CO_2 emissions (which in gas-fuelled vehicles are in any case about 25 per cent less than in a comparable petrol-fuelled vehicle) even more.

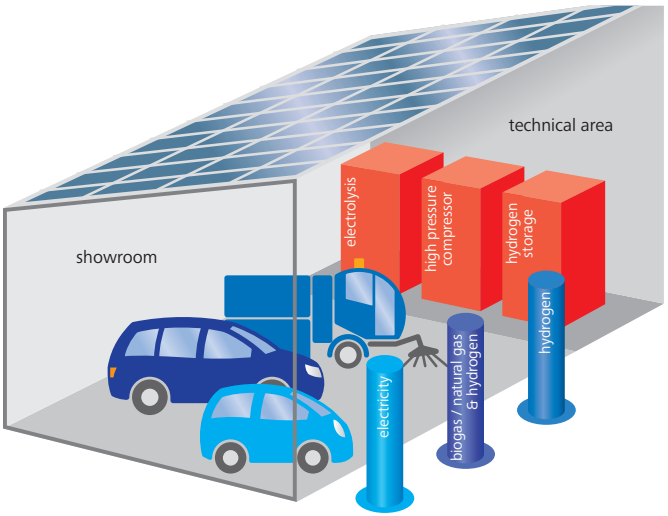
An ecological solution –
even in the greater scheme of things

"Future Mobility" combines a number of different ideas to yield a significantly more sustainable integrated concept. The practical realization of the demonstrator to create a scalable and usable system generates know-how, on the one hand through the linking of the electricity and gas markets and on the other through the coupling of renewable electric power production with mobility. What's more, "Future Mobility" demonstrates how energy excess from wind and solar power plants can be stored in a decentralized, economic, and efficient manner, and it also indicates which techniques for reusing the stored power are most energy-

Contact
Dr Brigitte Buchmann
brigitte.buchmann@empa.ch

efficient. This means: in the future, energy production can run nonstop, that is, without the interruptions that are currently necessary as soon as (non-exploitable) overcapacities occur. The storage and exploitation of surplus electricity reduces the dependency on imported fossil energy carriers and provides a long-term guarantee for resource-saving, environmentally friendly and energy-efficient mobility.

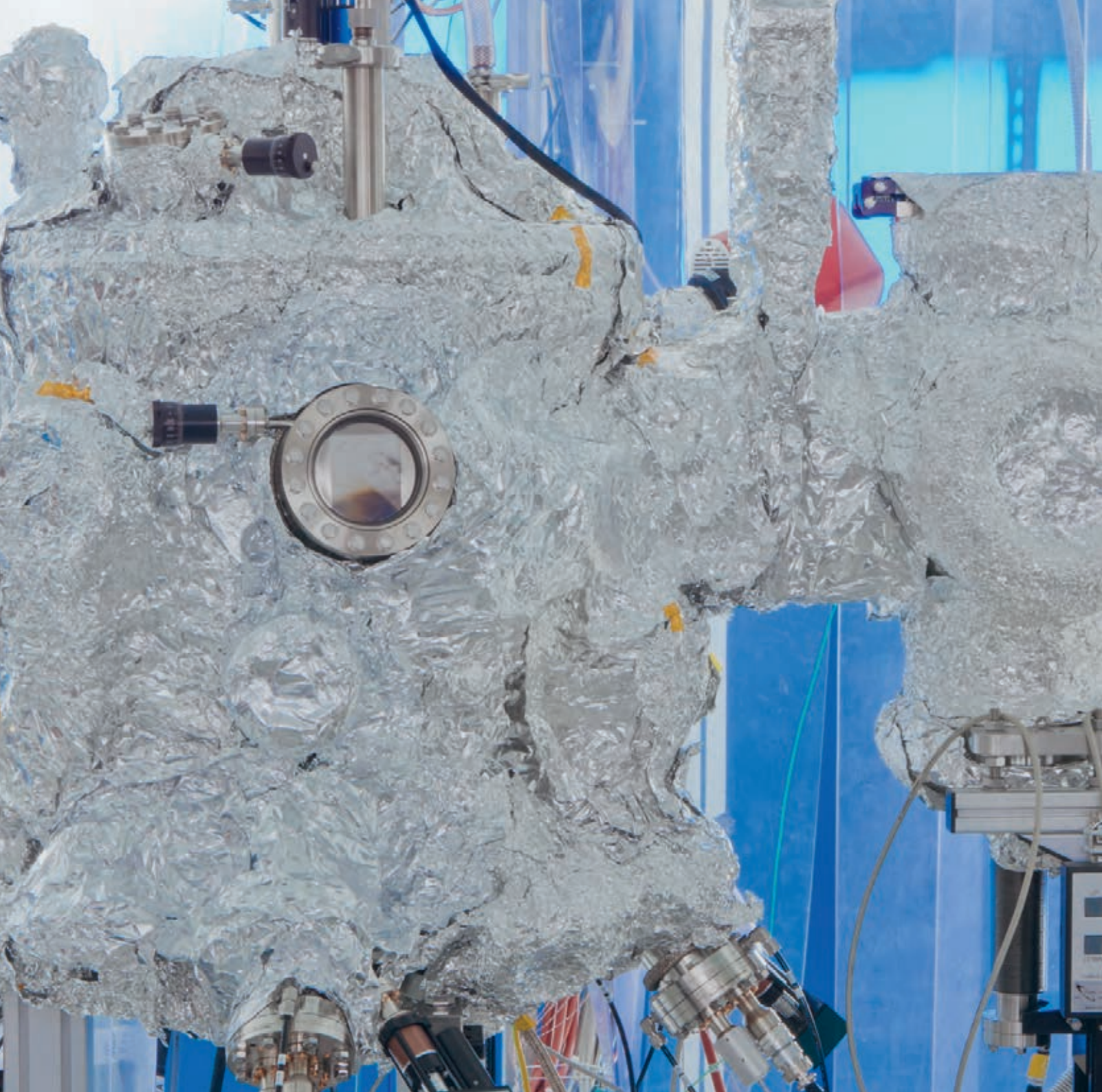
Empa is providing know-how to the "Future Mobility" project in the areas of photovoltaics, hydrogen generation and storage, vehicle drives, energy systems, and automation. Other collaborators include the Paul Scherrer Institute (PSI), ETH Zurich, EPFL and the Zurich University of Applied Sciences, as well as partners from industry. Besides providing technological solutions and ideas for possible applications, the project also covers basic research aspects such as developing novel catalysts for the electrolytic processes or investigating ignition phenomena in internal combustion engines fuelled with methane-hydrogen mixtures.



The electrolyser converts solar energy and surplus electricity from the grid into hydrogen, which is compressed and stored. At refuelling stations the hydrogen is made available either pure (for fuel cell vehicles) or mixed with natural gas/biogas (for gas-fuelled vehicles).

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 30 research laboratories to create practical solutions for industry and society.



Use-inspired Research

Innovative Developments

Knowledge and Technology Transfer

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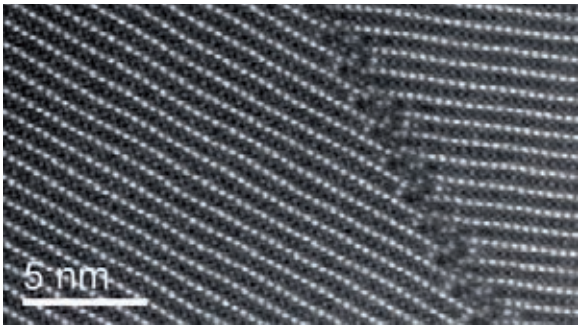
Advanced Training and Education

Nanomaterials – an analytical challenge

Nanostructured materials are composites consisting of several nanoscale components (or "phases"), in which the boundaries between two components must be considered as individual phases in their own right. This is because it is frequently phenomena occurring at the phase boundaries which are responsible for the unique physical properties of nanostructured materials. One example is the magnetic field-dependent electrical resistance in multilayer systems composed of alternating magnetic and non-magnetic nanometer-thin layers, based on the Giant Magnetoresistance effect (GMR). Others include the extreme toughness of super-hard nanocomposite anti-wear coatings of silicon and titanium nitride, and the enormous reduction in melting point of aluminium silicide solder when used in the form of an aluminium silicide/aluminium nitride nanocomposite. These are all material systems currently under thorough investigation and development in Empa's Research Focus Area "Nanostructured Materials."

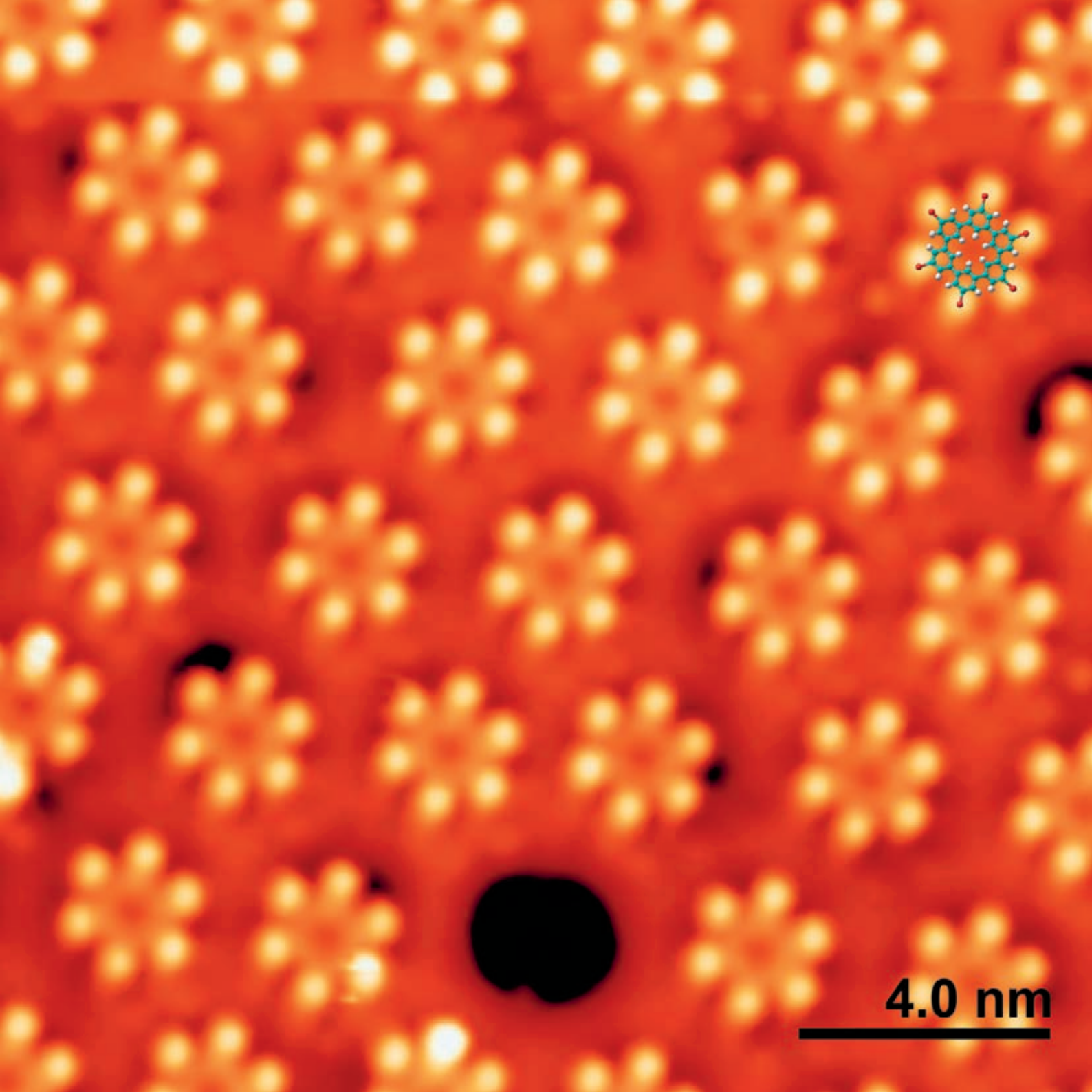


A scanning transmission electron microscope image with atomic resolution of a particle boundary in a perovskite material used in thermoelectric converters.

Material analysis down to the (sub)atomic level

The structural and chemical characterization of nanomaterials calls for analysis methods with nanoscale or even atomic resolution – a feature, of which only very few systems in use today can boast. It is, therefore, crucial for Empa to develop new analytical methods and processes, or further develop currently available techniques. With this in mind, Empa scientists last year presented two new analytical systems developed in collaboration with industrial partners.

Nano-pores made of hexagonal boron nitride on a rhodium mono-crystal form the ideal substrate for the adsorption of individual organic molecules such as, here, cyclohexaphenylene (with a superposed chemical structure). Scanning tunnel microscope image.


4.0 nm

The first one, known as 3D Chemical Imager, is a combination of a Focused Ion Beam (FIB) instrument and a Time of Flight Mass Spectrometer (ToF-MS). The former device is used for homogeneous material ablation, while the latter is used for chemical surface analysis. The combined system allows a three-dimensional characterization of the chemical composition of any chosen material to be carried out in a very short time – a sort of chemical depth profile with a voxel resolution of 40x40x10 cubic nanometers.
The second new development is the 3D NanoChemiscope, which consists of a Time of Flight Secondary Ion Mass Spectrometer (ToF-SIMS) in combination with a Atomic Force Microscope (AFM). This instrument has the unique ability to simultaneously determine the topography, the chemical composition and mechanical properties (such as hardness or elasticity) of nanoscale surface structures (see also page 12).

Hardly possible without industry partners and the EU

The development of such analytical systems is extremely costly and today, in practical terms, only possible within EU projects with a strong industrial partnership. The 3D NanoChemiscope was developed in the course of the eponymous EU project in collaboration with the German company ION-TOF GmbH, one of the world's

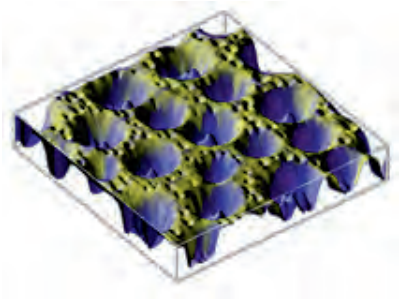
The 3D Chemical Imager, a unique combination of a Focused Ion Beam (FIB) system and a Time of Flight Mass Spectrometer (ToF-MS).

Contact
Dr Pierangelo Gröning
pierangelo.groening@empa.ch

leading manufacturers of ToF-SIMS instrumentation. The 3D Chemical Imager was developed as part of the EU project "FIBLYS" in cooperation with the Swiss company Tofwerk AG and the Czech firm Tescan.

Collaboration with IBM on transmission electron microscopy

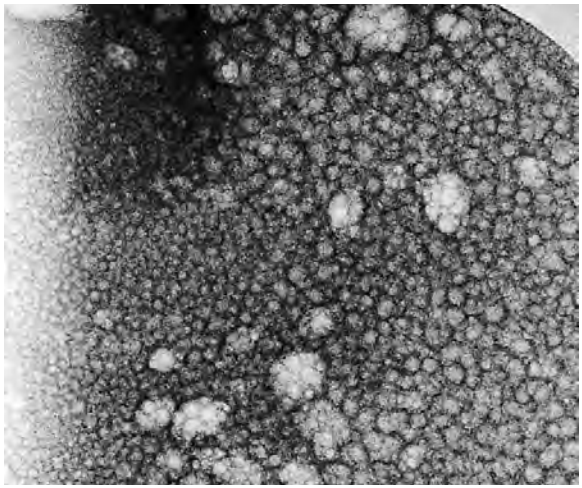
In 2012 the IBM research laboratory in Rueschlikon, near Zürich, and Empa signed a long-term cooperation agreement, in which the purchase and operation of a high-resolution transmission electron microscope (TEM) was agreed upon. In March 2013, under the scientific leadership of Empa, the most powerful TEM in Switzerland will begin operating at IBM's "Binnig and Rohrer Nanotechnology Center." Using this microscope, a JEM-ARM200F model with a resolution of 0.08 nanometers, it should be possible to chemically characterize individual atoms. In other words, it will be capable of determining the chemical bonding state of a single atom – a quantum leap in terms of the structural and chemical characterization of nanomaterials.



Surface structure of a bi-component polymer:
the area under investigation measures merely 7.5x7.5 nm^2.

Moving towards energy-sufficient buildings

Switzerland's building stock, in other words all the buildings in this country, plays a pivotal role in the energy strategy 2050. The long-term goal is to convert it from the prime energy consumer into a self-sufficient entity, if not an actual energy supplier. This enormous challenge demands engagement at all levels – from materials, systems, buildings, and neighbourhoods all the way to entire cities.



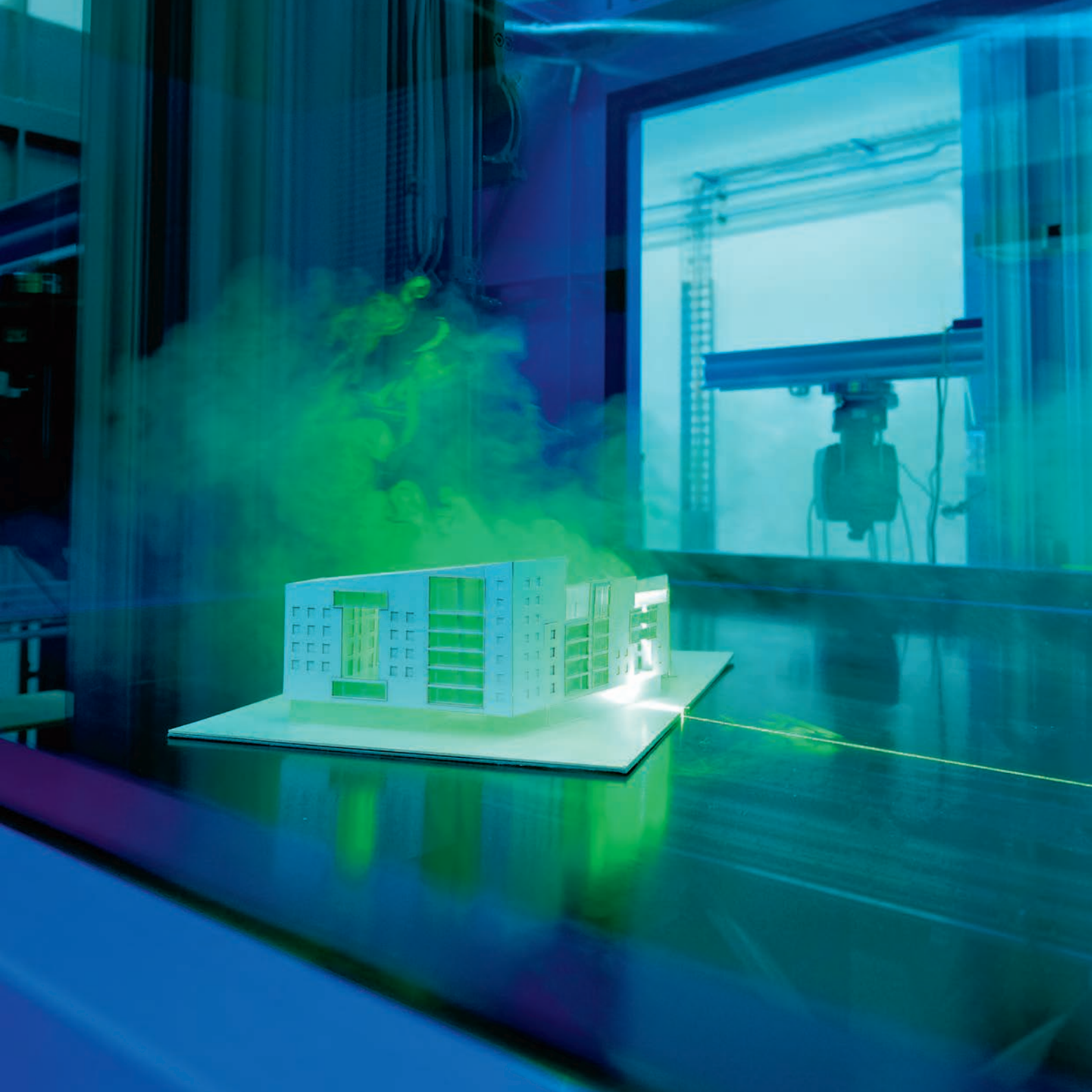
Foamed bitumen under the microscope: the foam contains around 1 per cent water and is created when bitumen at about 160 °C is mixed with water.

Improving the insulation of existing buildings

A large number of projects focus on minimizing the thermal conductivity of the shells of existing buildings. Since early 2013, a new product has been available on the market – an Aerogel plaster – which, due to its excellent insulating capabilities even when applied in thin layers, is particularly useful for renovating historical buildings. With it, the thermal insulation of old buildings can be vastly improved without physically changing their character and appearance.

After many years of development on vacuum glazing systems, for which Empa has created a novel edge seal, activities in the EU-funded project "Winsmart" are progressing towards industrialization. The intention is to produce a vacuum window panel which not only possesses excellent insulating properties but, thanks to switchable glass, can also regulate how much light it transmits, allowing the user to dim their surroundings at the push of a button.

Research for a better climate in tomorrow's cities: a model in Empa's wind tunnel.



Contact
Dr Peter Richner
peter.richner@empa.ch

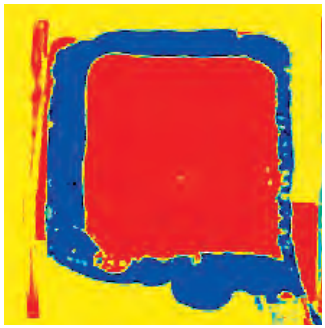
Integrated energy networks within neighbourhoods

While this kind of project is very specific and focused on a particular object, others dealing with integrated energy networks at the neighbourhood level are more speculative. The central question is whether energy can be saved by constructing a local energy network to distribute heating, cooling and electrical power, and if so how much. The hub located at the center of such a network is responsible for regulating energy distribution, conversion and storage. Computer models provide an important basis in this context, but they must be validated within Empa's Research Focus Area "Sustainable Built Environment" by means of pilot trials on "real-life" buildings using a range of different conditions.

New materials with potential

In infrastructure too, for instance in road construction, lies a considerable potential for energy-saving. One example is the use of foamed bitumen for road surfaces, allowing the temperature of the mixture to be reduced from 160 °C to about 120 °C. However, this only makes sense if the resulting surface is of comparable quality to that obtained using conventional methods. Foamed bitumen is made by mixing water with bitumen at a temperature of 160 to 180 °C. The foam generation process is very complex; temperature, pressure, mixing ratios and type of bitumen all play a role. In order to produce a foam that is as stable and homogeneous as possible, Empa researchers have been investigating and quantifying the influence of these parameters using various techniques. High-speed cameras visualize the onset of bubble formation, and x-ray tomographic methods allow the bubble size distribution and stability to be analysed. By taking into account a range of physical and chemical parameters, bubble formation can also be simulated on a computer.

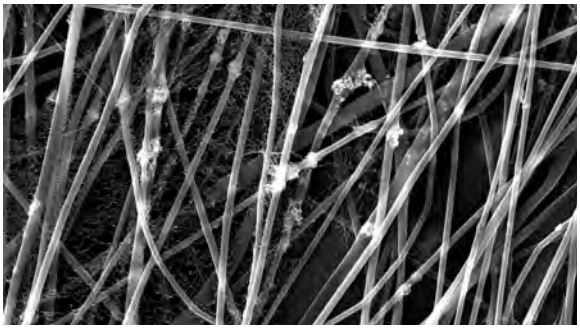
With a fundamental understanding of the foam generation process, it is possible to develop an optimized "recipe" for producing foamed bitumen for road surfaces, allowing the temperature of the mixture to be reduced, thereby saving energy without sacrificing the quality or durability of the road surface.



Vacuum glazing offers excellent thermal insulation but the panels must remain vacuum-tight for decades. Empa has developed a method of permanently sealing together two panes of glass using a tin alloy.

Analyze, reduce, avoid – for the benefit of the environment

Our society consumes an excessive amount of raw materials and other natural resources, whilst simultaneously emitting a substantial quantity of pollutants. The aim of Empa's Research Focus Area "Natural Resources and Pollutants" is to reduce both effects. In general this is a question of enhancing the efficiency of technical processes in terms of material usage and energy consumption, investigating alternatives to critical resources as well as developing more effective ways of treating waste air and water.



A scanning electron microscope image of filter material made of nanofibers with embedded photo-catalytically active titanium dioxide, which in addition to filtering out pollutants the "normal" way also catalytically decomposes them.

Analyzing emissions and quantifying environmental impact

The ozone-depleting substances banned by the Montreal Protocol have been substituted in industry by other products. Second-generation alternatives such as the cooling agent R-1234yf, however, bear the risk of creating trichloroacetic acid (TFA), an incredibly stable decay product. Extrapolations made by Empa show that, by 2020, between 11,000 and 19,000 tons of R-1234yf will have been emitted. Simulations run on the institute's high-performance computer have made it possible for the first time to predict the quantity of TFA expected to be generated in the environment. First results indicate that the concentration will remain just below the threshold for damaging most sensitive sweet water algae.

A functionalized filter for cleaning (waste) air

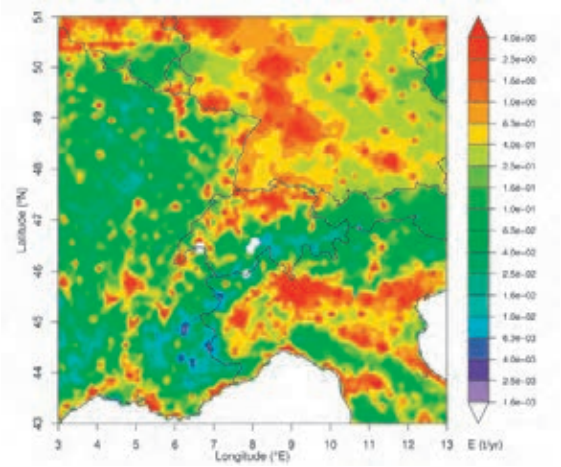
In Empa's new wind tunnel researchers are investigating the behavior and the concentrations of nanoparticles in waste air flows. Their intention is to develop more effective (nano)

Contact
Dr Brigitte Buchmann
brigitte.buchmann@empa.ch

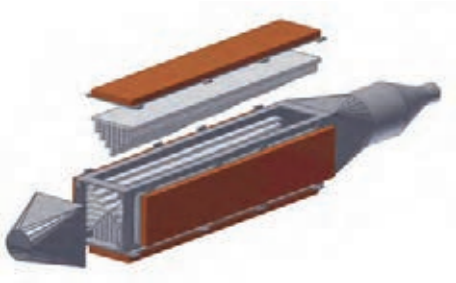
filters. Filter materials with a fiber layer in which photo-catalytically active titanium dioxide (TiO_2) is embedded, boast an enormous advantage: in addition to the "normal" filtering process catalytic decomposition occurs, making the filter overall significantly more efficient. However, the nanofibers must not be too densely packed otherwise the filter efficiency drops. Modeling calculations made a significant contribution to the development of the filter.

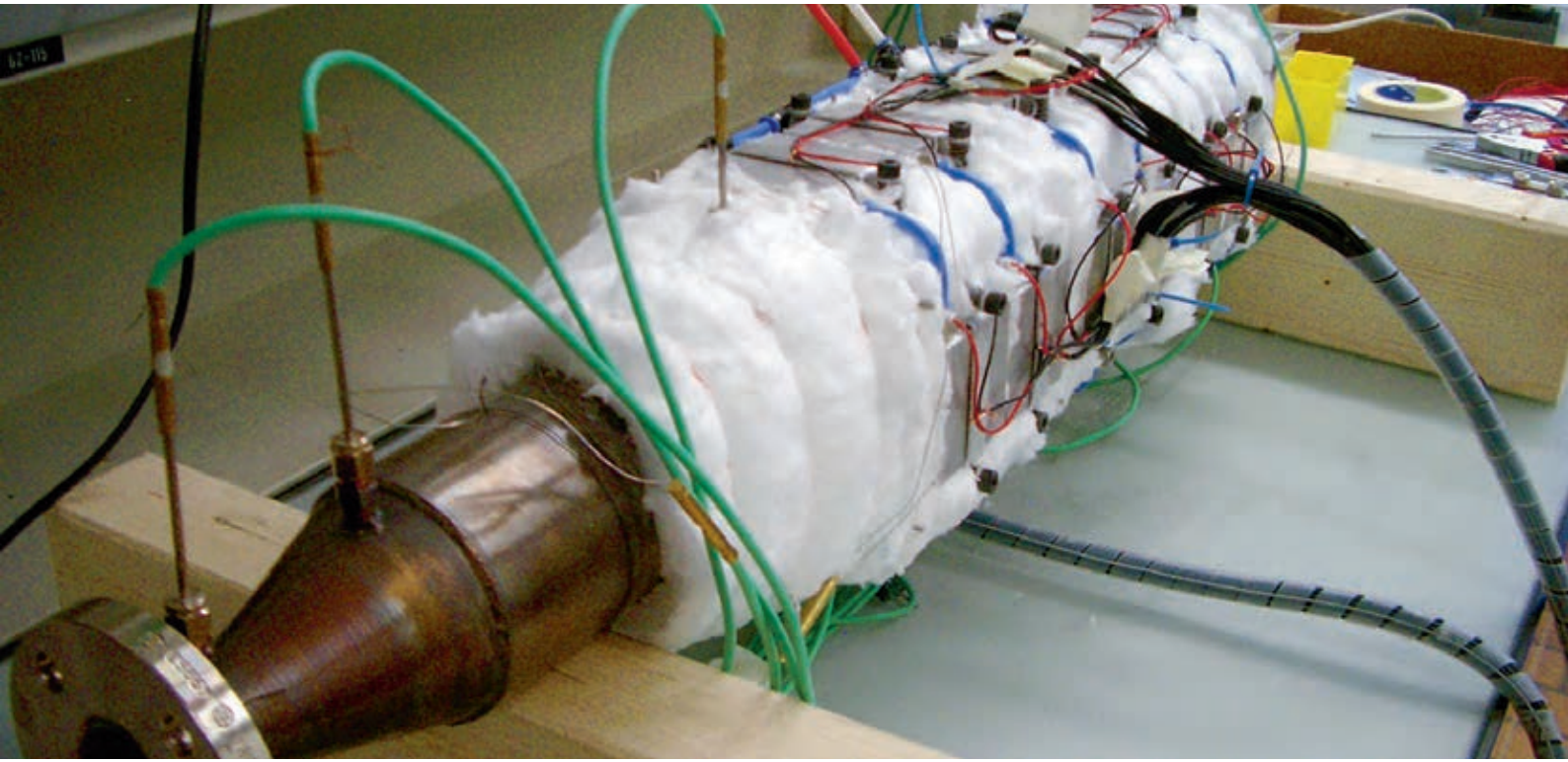
Treating waste gas – utilizing waste heat

Because of tighter legal requirements concerning carbon dioxide (CO_2) emissions, the energy-efficiency of cars is becoming ever more important. In addition to focusing on directly raising the efficiency of the internal combustion engine itself, researchers are increasingly looking at the potential uses of waste heat, which to date remains more or less unexploited. Currently only a small proportion of the heat generated by the motor is used, for example for activating the catalyst or heating the car's interior. Using thermoelectric converters based on metal oxides and half-Heusler alloys, Empa scientists have succeeded in making better use of this waste heat (see also page 16). With an exhaust temperature of about 450 °C, it was possible to recuperate some 70 Watts of energy – a doubling in performance compared to conventional thermoelectric modules. Although at first glance this may not seem much, thermoelectric power generation can actually reduce fuel consumption of a car by up to 5 per cent because the current efficiency of the on-board power generating system is very low. At higher temperatures, such as are normal in engine exhaust gases, these new materials allow significant improvements in the utilization of waste heat.



The computer simulation indicates where high emission levels of the cooling agent R-1234yf are to be expected. "Hot spots" are predicted in the metropolitan areas of Stuttgart, Zurich, Geneva and Milan.

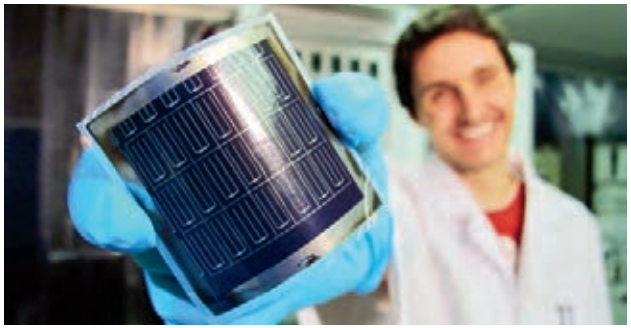




A thermoelectric converter works by converting waste heat generated by burning fuel into electric power, thereby reducing the overall energy consumption of the vehicle by up to 5 per cent.

Innovative technologies for the “energy turnaround”

The recent decision by the Swiss government to phase out nuclear energy, and the accompanying change of focus on alternative energy sources, will only be possible when innovative renewable energy technologies associated with novel materials are developed and practically implemented. Only then can both power consumption and CO_2 emissions be simultaneously reduced.



Closing the gap on silicon solar cells

Scientists and engineers all over the world are attempting to develop solar cells which are highly efficient and also simple and economic to manufacture in large quantities. Empa researchers have succeeded in creating flexible, thin-film solar cells with a record efficiency of 20.4 per cent, based on so-called copper indium gallium di-selenide semiconductors (CIGS). The new record efficiency is about the same as the one reached by conventional polycrystalline silicon solar cells. In developing the flexible devices, Empa scientists also managed to further optimize the properties of the light-absorbing CIGS layer at low process temperatures. The next step is to scale up the technology from the laboratory to permit industrial levels of production. Manufacturing using roll-to-roll processes will allow further cost savings. Flexible CIGS solar cells therefore have an enormous potential to make solar power affordable in the near future.

Highly efficient, flexible CIGS solar cells
on polyimide film developed using a new process.

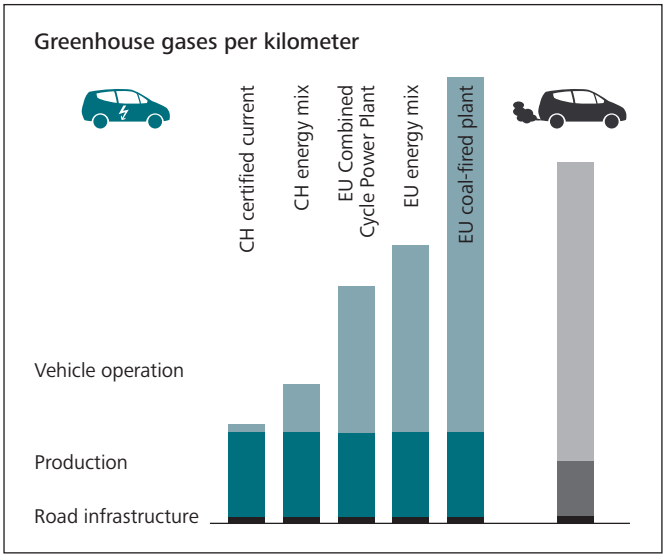
Contact
Dr Xaver Edelmann
xaver.edelmann@empa.ch

Splitting water using solar energy

Using solar energy to generate hydrogen by electrolysis – splitting water molecules – has long been a beacon of hope for providing a sustainable energy supply. An international research team headed by Empa staff has succeeded in observing the structural molecular changes occurring in an iron oxide electrode during electrolysis. Iron oxide is a very promising electrode material for use in photo-electrochemical water splitting, not least because it is cheap, stable, environmentally friendly and available in large quantities. This offers the possibility of cheap hydrogen production using solar energy (see also page 19)

Electromobility – opportunities and risks

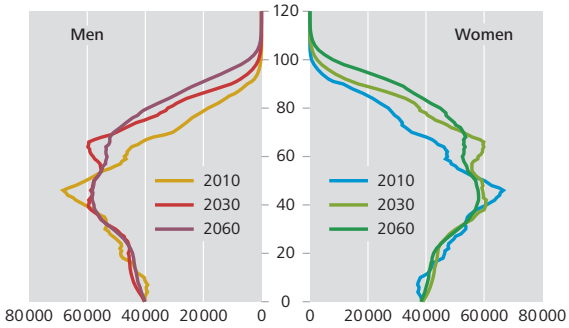
Electric cars are a promising alternative for mobility with a low environmental impact. By recharging the batteries with renewable energies, they can be operated independently of fossil energy sources, thereby helping to reduce road traffic emissions. However, the limited operating range and battery lifetime still acts as an obstacle to the rapid popularization of electric vehicles. A study headed by Empa scientists has thrown light on the opportunities and risks associated with e-mobility. The authors recommended that energy-efficient vehicles should be favoured during the process of registering new cars. Such an impact assessment should, however, not just include the energy consumption during the car's operating lifetime but also the environmental impact during its entire lifecycle – from cradle to grave, so to speak. In order to avoid negative feedback effects, the study also recommends that overall mobility should be made more costly, in order to prevent an increase in total traffic due to the availability of cheap, environmentally friendly vehicles.



When electric cars are powered using fossil energy,
they are no better in environmental terms than petrol engined vehicles (right).

Innovations for medical applications and patient comfort

Every single day each of us is bound to come in contact with an enormous range of very different materials. Of particular interest are those in direct contact with the human body or possibly even implanted into it, since they must meet very stringent requirements regarding longevity and, of course, safety. Empa's vision with respect to applying new materials in medicine and in close proximity to the human body, for instance in textile applications with special properties, is thus "Innovative materials for a healthy future".



The age pyramid for Switzerland indicates a clear majority of over-fifties.
Source: Swiss Federal Statistical Office.

Enhancing the quality of life for senior citizens

The population of Switzerland, and of other European countries too, is enjoying an ever increasing life expectancy. At the same time birth rates are declining. As a result, forecasts clearly show that over the coming decade the majority in these countries will be aged over fifty. The increasing average age of the population means, however, that medical conditions relating to old age will tend to predominate. Empa's research is, therefore, increasingly focused on new materials which will primarily be of help in maintaining the health of the elderly, or in alleviating the discomfort caused by age-related ailments. Together with an industrial partner, Empa researchers have for instance developed an incontinence system which, thanks to its minimal thickness, is unobtrusive and yet offers excellent protection due to its ultra-efficient absorption layer. The new garment, which has been on the market since the beginning of 2012, offers a significant improvement in the quality of life to a large number of people.

The incontinence system developed at Empa is unobtrusive yet offers the wearer reliable protection.

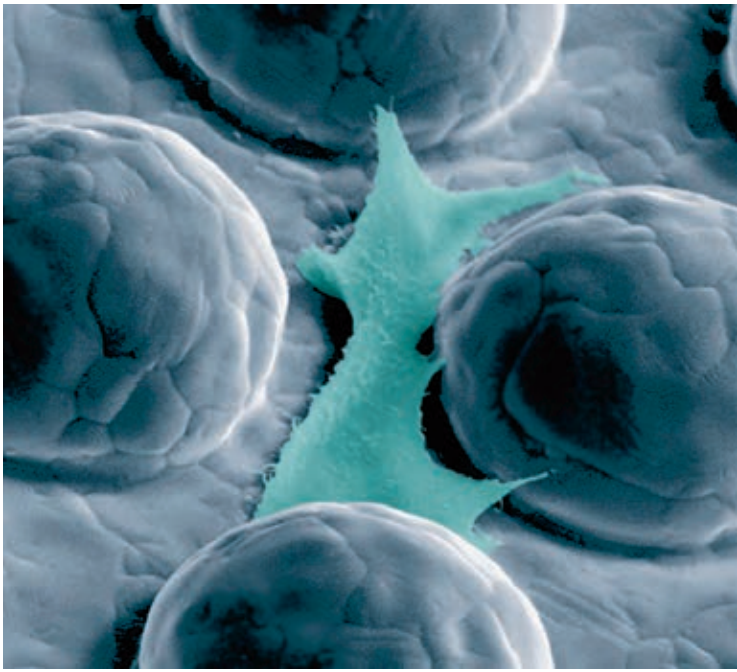
Contact
Prof. Dr Harald Krug
harald.krug@empa.ch

Fibers help tissue regeneration

Fiber and textile-based materials are also increasingly finding use in medical applications. An example of this is the populating of biodegradable fibers with human cells in order to grow replacement tissue to help damaged or injured organs to regenerate. This principle of "Tissue Engineering" is being used in heart surgery, among other fields. Together with Bern University Hospital's Heart and Vascular Surgery Clinic, Empa is working on a project to investigate heart muscle regeneration following a heart attack, in a project funded by the Swiss National Science Foundation (SNSF). Biopolymers are spun using an electrospinning process into nanometer or micrometer thin fibers, which are used to create a fleece-like material. The researchers then grow muscle cells on this fiber mat, which can later be transplanted back into the patient as functional tissue (see also page 44).

Safety – the highest priority for new materials

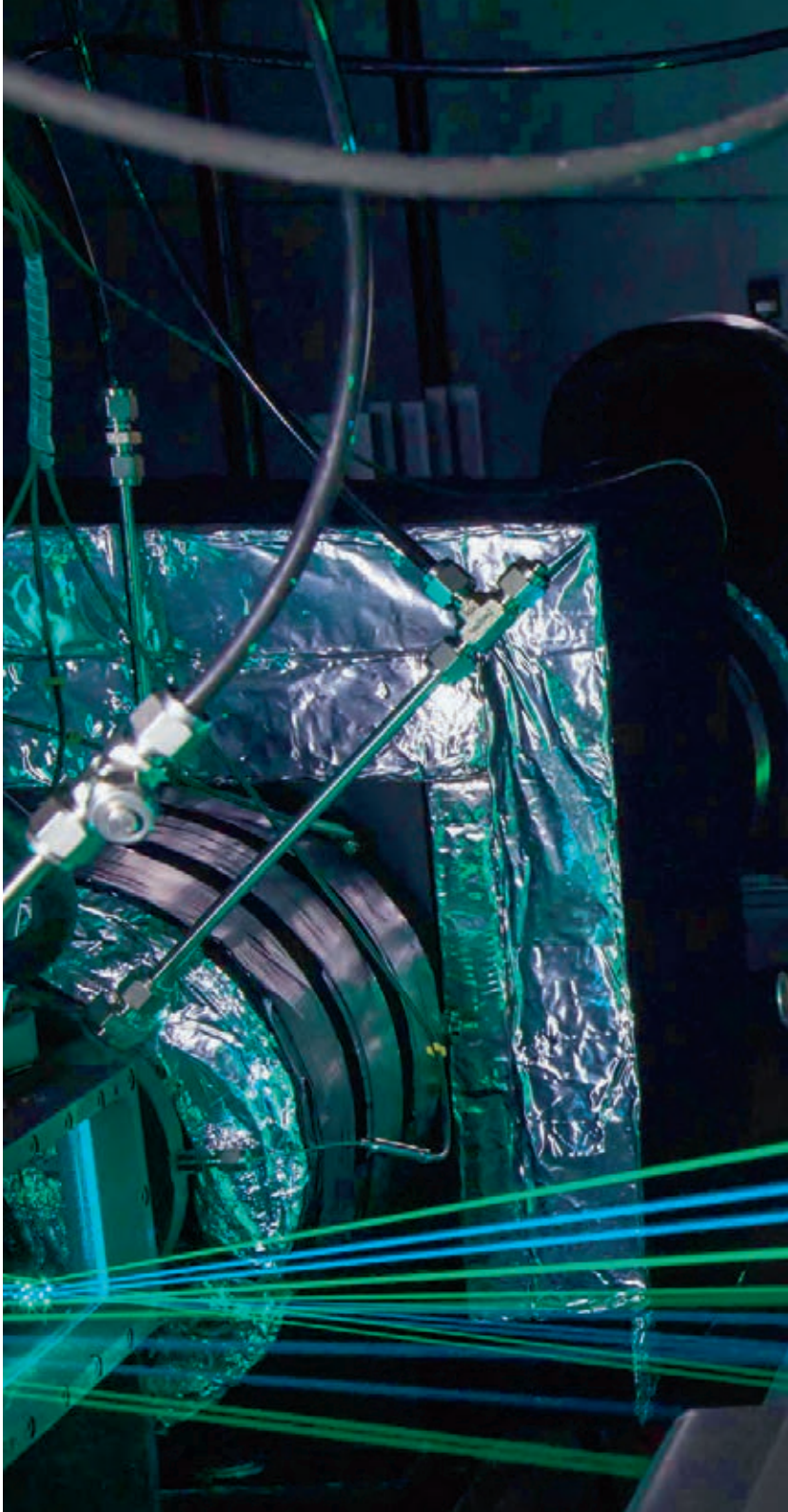
Newly developed materials for medical applications must be safe above all else. To this end Empa is involved in numerous projects such as the «National Action Plan for Synthetic Nanomaterials" and European initiatives to harmonize toxicological methods, with the aim of making the results of such studies comparable on an international level. A particular highlight in this respect has been the publication of a handbook with standardized methodologies for nanosafety research which was drafted in the course of the EU-funded "Nanommune" project. Empa is internationally one of the leading institutions participating in a worldwide interlaboratory investigation of these methods, thereby making a significant contribution to being able to guarantee its partners the highest possible safety standards.

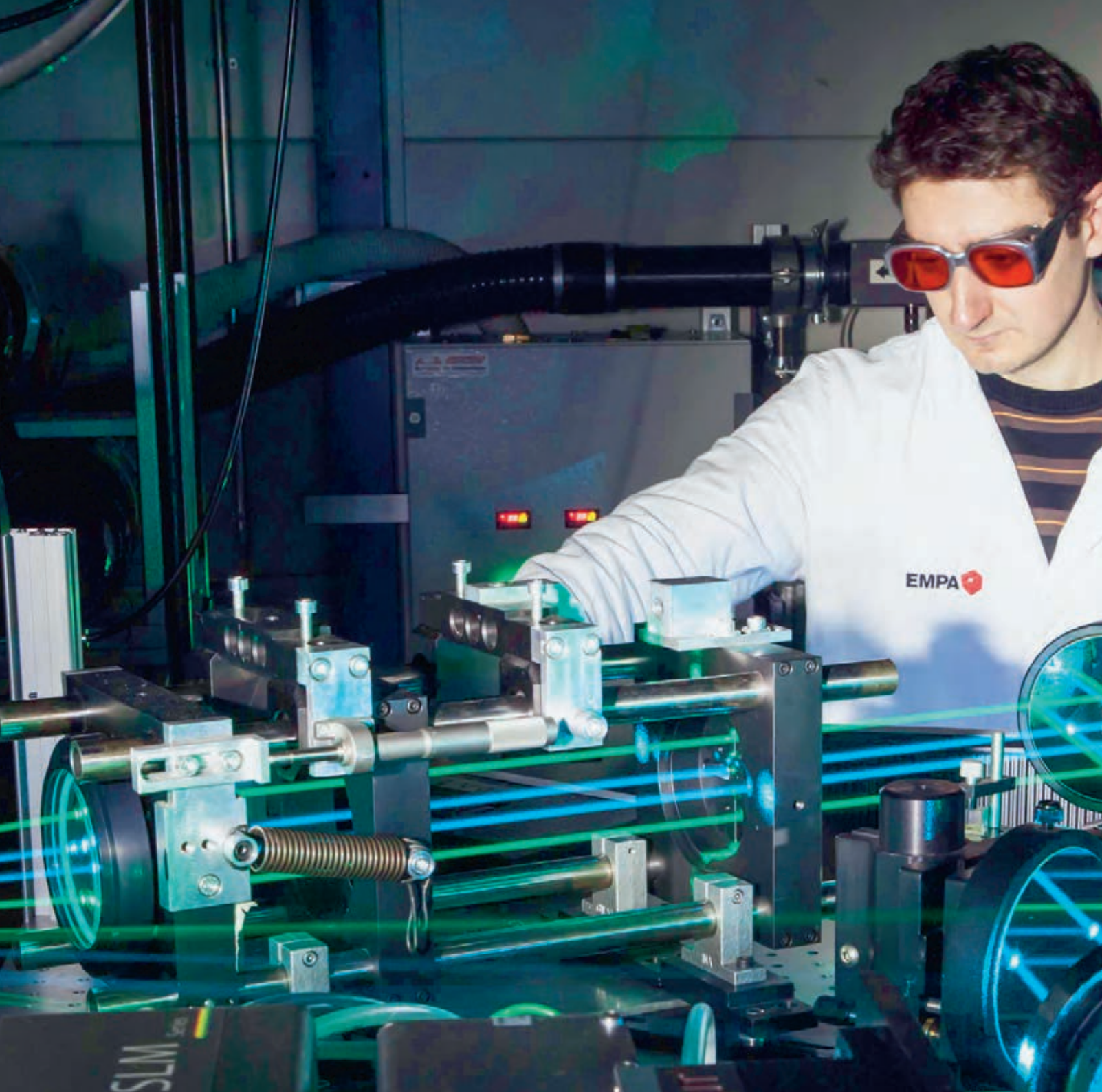


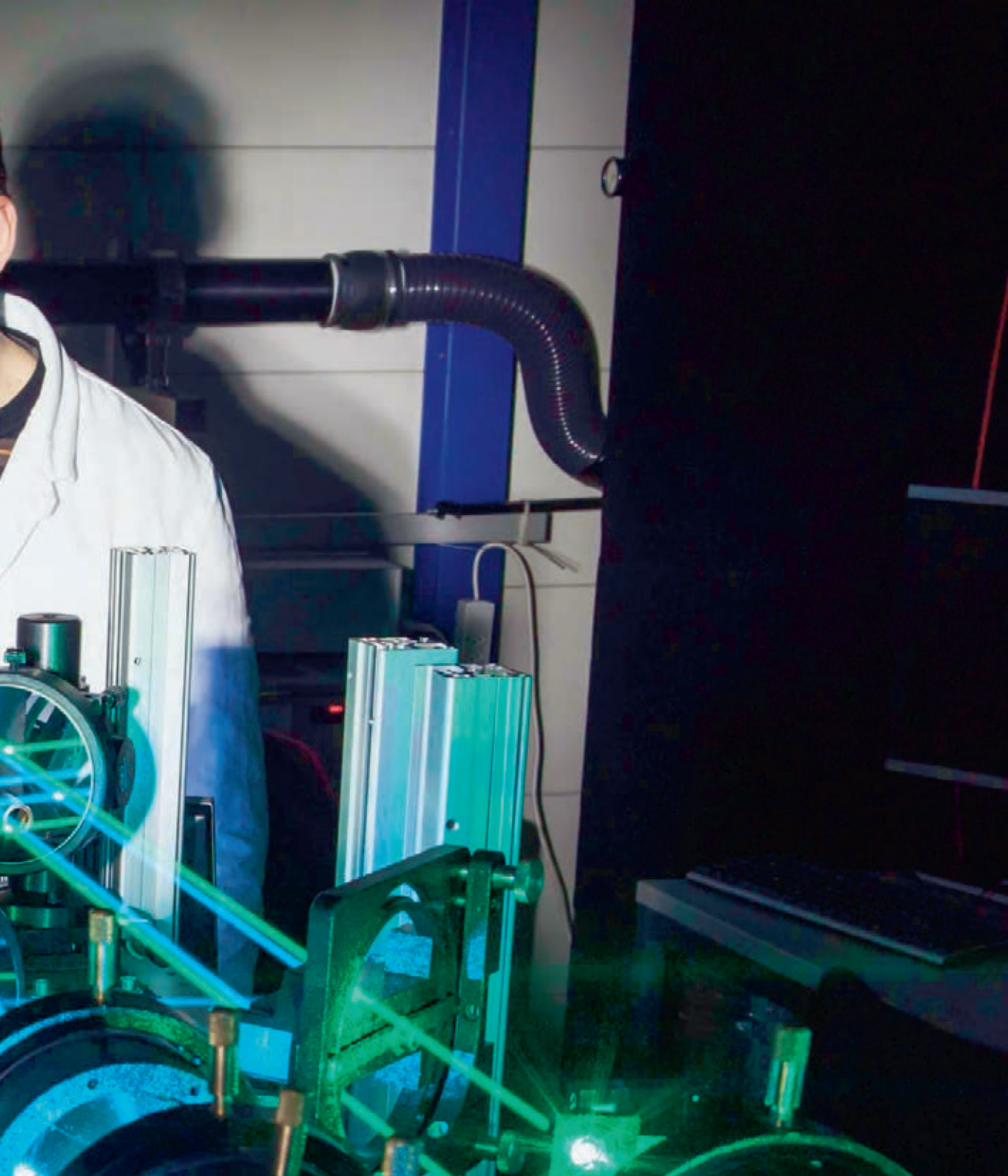
Structured implant surfaces offer human cells favorable conditions for growth. This, in turn, helps the implant to better integrate into the body's tissue, thereby significantly improving the device's lifetime.

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!




EMPA



Use-inspired Research

Innovative Developments

Knowledge and Technology Transfer

Services and Expertise

Advanced Training and Education

Empa innovations on their way to market

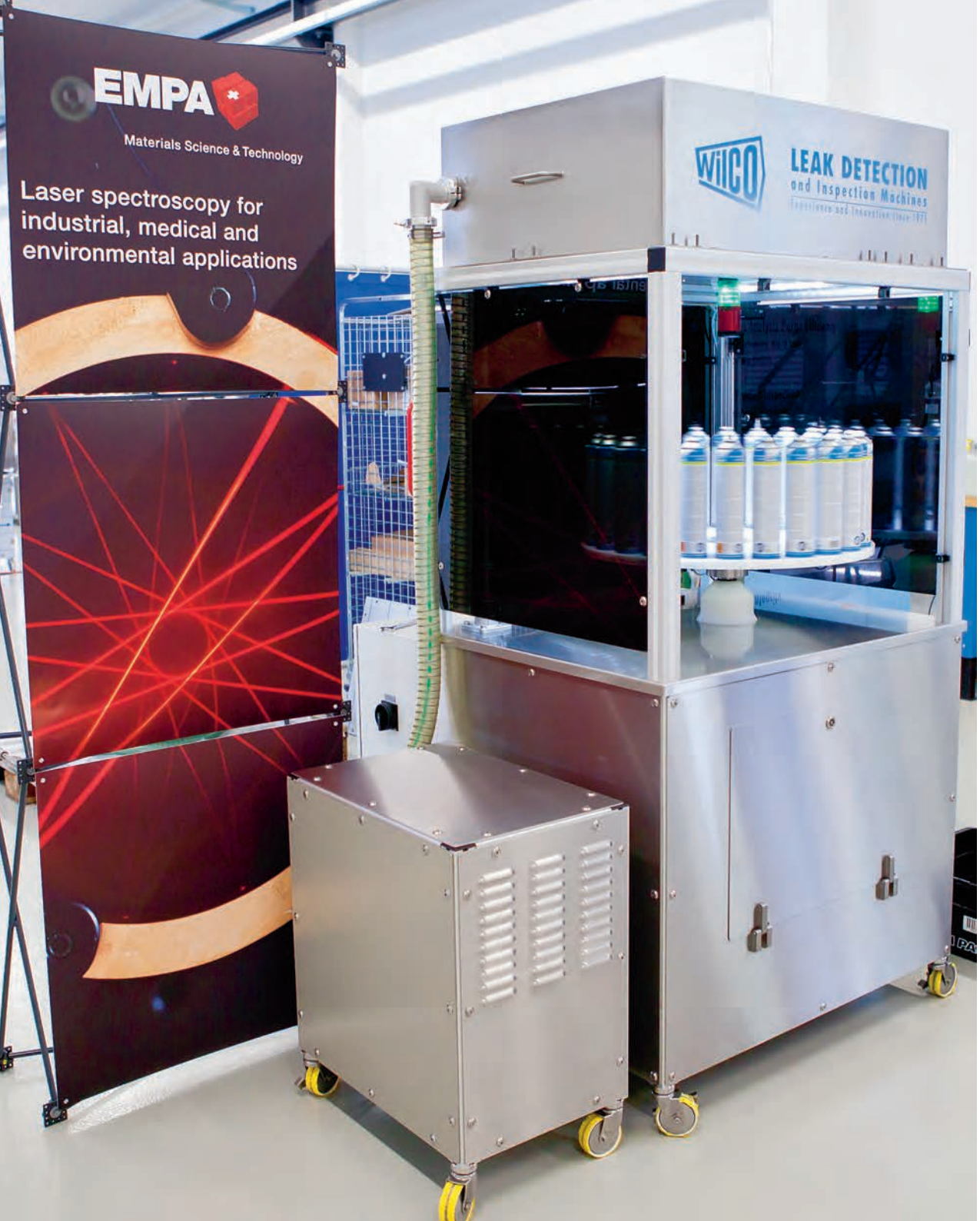
The "Technology Transfer Office" is the interface between Empa and its partners, responsible for helping to transfer the research results won in Empa's laboratories into marketable, innovative products. This is quite laborious given Empa's numerous industrial contacts, covering tasks ranging from the negotiation of collaborative agreements all the way to the safeguarding and exploitation of the institute's intellectual property. The number of new cooperative research projects with private and public institutions, for instance, has risen by 50 per cent and now lies at 150. In addition, 33 new license agreements and technology transfer contracts with industrial partners were signed and 18 new patents were applied for to secure Empa's intellectual property rights.

"Green" chemistry with a scent

At Empa's "Biomaterials" laboratory in St Gallen scientists are working on the manufacture and applications of laccases. These enzymes are very promising biocatalysts which may find use in a wide range of industrial processes as a result of their ease of use and the large number of possible reactions they are capable of catalyzing. They also boast the advantages of being nontoxic, producing few unwanted side products, and operating under mild conditions – making "green" chemistry possible. In a collaborative project with Givaudan Corporation, supported by the Swiss Innovation Promotion Agency (CTI), the Empa researchers have developed an entire "toolbox"

3D-structural model of a bacterial laccase: the balls represent copper atoms at the active center of the enzyme where the oxidation of the mediator molecules takes place. An example of a mediator molecule is shown in the model: grey – carbon, yellow – sulphur, red – oxygen.

Givaudan is using enzymes such as laccases to develop
new scents and for manufacturing authentic aromas.
A scientist measures laccase reactions using a spectrophotometer.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Contact
Marlen Müller
marlen.mueller@empa.ch

of laccase systems, which makes it possible to oxidize a large number of precursor molecules to create the desired end product – perfumes – on a laboratory scale.

A "sniffer" for aerosol cans

For many years Empa researchers have been involved in developing laser-based measurement instrumentation to detect air pollutants with extremely high sensitivity. This technique, however, is also suitable for use in medical and industrial applications. As an example, a sensor has been developed together with Wilco Corporation to detect leaks in aerosol cans. The instrument responds reliably and within a fraction of a second to the presence of propane and butane – gases used as aerosol propellants – and yet is more economic than conventional test methods for identifying leaking cans during the production process. This successful collaborative project gave rise to a product which is ready for market entry and meets all the safety requirements and tests for aerosol spray cans (see also page 30).

Chemical imaging in 3D with nanometer resolution

As a result of the inventive combination of a Time of Flight – Secondary Ion Mass Spectrometer (ToF-SIMS) with a Scanning Electron microscope (SEM) and a Focused Ion Beam (FIB) system, Empa scientists have succeeded in developing a novel surface analysis instrument. Not only does the new apparatus provide information on the three-dimensional structure of the sample and its surface chemistry, it also boasts a significantly higher resolution – in the nanometer range – and is considerably more economic than the X-ray spectroscopy-based instrumentation normally used for this purpose. The new technique offers particular advantages for the analysis of light elements and organic materials. The integration of a tailor-made ToF-SIMS in a commercial SEM was carried out in collaboration with two industry partners, Tescan and Tofwerk, within the framework of an EU-funded project. Two prototypes are now in use at Empa and the first commercial systems have already been sold by the Czech company Tescan, each containing an integrated ToF-SIMS instrument from the Swiss company Tofwerk (see also page 66).

The aerosol leak detector at a trade fair: the first system is already being used in an industrial environment.

Where smart business ideas reach maturity

Over the past year eleven Empa spin-off projects were launched and eleven start-up firms were given support in the institution's two business incubators, glaTec und tebo. The young companies operate in close research cooperation with Empa, and the majority of them have already successfully launched their first products onto the market.

Making marketable products out of prototypes

One such product is the Mobility Monitor developed by the spin-off compliant concept. This device records the finest movements of bedridden patients through the mattress without contacting their body. The device monitors and analyses whether the patient is moving sufficiently to avoid the development of bedsores, thus helping medical staff to prevent this feared condition from developing in the first place. In addition, an integrated warning system sets off an alarm if the patient gets out of bed (see also page 26).

Another example is the flexible robot grippers developed by another spin-off, Monolitix, which offer a welcome alternative to conventional mechanical gripping devices and are opening up new fields of application. The grippers are made out of a single piece of elastic material which deforms when in operation – they possess no moving parts such as joints or linkages. This

The late Heinrich Rohrer, Nobel Laureate in physics, was the embassador of the "SimplyNano 1®" kit.

means that they are maintenance and friction-free, and exhibit no play. They are also easy to clean and if necessary can be replaced quickly and economically.

The QSorter Explorer produced by QualySense transports, analyses and sorts grains of cereal, seeds or beans at high speed. Each grain is sorted individually on the basis of its properties such as protein, moisture and oil content, color, or fungal contamination. Users of the system achieve a continuous and reliable level of quality control, allowing them to optimize production processes while at the same time minimizing risk.

Die Innovationsgesellschaft GmbH is a company located at tebo on Empa's St Gallen site which has, together with the Simply-Science Foundation, developed an experimental kit called "SimplyNano 1®" designed for school children. The kit is intended to encourage interest in and understanding of scientific and technical topics – and in particular to raise awareness of nanotechnology. The kit in the nano-case contains easily understandable instructional and teaching material, harmless chemicals, and the laboratory equipment for eight interesting experiments. Subjects such as nano dimensions, nanoparticle reactivity and nanosurfaces are introduced in a simple and attractive manner. Already more than 350 teachers are using the "SimplyNano 1®" case.

The QSorter Explorer, a robotic system for cereal quality monitoring.

Contact
glaTec
Mario Jenni
mario.jenni@empa.ch

tebo/Startfeld
Peter Frischknecht
peter.frischknecht@empa.ch

Taking off

Startfeld, the platform for supporting the founding of innovative enterprises in Eastern Switzerland, continues to run on schedule. As one of the first new enterprise ideas, the "Polarmond" project for an air-insulated and ultralight "all-in-one" tent concept has received financial support from the Startfeld foundation. Therefore, the project, which is also supported by the Swiss Innovation Promotion Agency (CTI), is ready to take off. Project partners are Empa and the HSR Hochschule für Technik Rapperswil.

Also successful is the Flisom start-up, located on Empa's Duebendorf campus. This company has developed the technologies required to manufacture flexible thin-film solar cell modules on a CIGS basis (copper indium gallium [di]-selenide). At the end of last year the company secured financing for the construction of a production plant in Switzerland with an annual capacity of 15 megawatts. Flisom is working in close collaboration with Empa researcher Ayodhya N. Tiwari, whose flexible CIGS cells hold the world record for energy conversion efficiency, namely 20.4 per cent.

In order to be able to support potential entrepreneurs even earlier, Empa is taking part in a newly created program called "CTI Entrepreneurship," which, under the leadership of the TECHNOPARK® Zurich, offers five-day courses on "Business Creation and Development".

The elastic properties of compliant systems means they can be used to gently handle sensitive objects.

On the way to a full-fledged production plant: to the left is a roll of polyimide, which Flisom uses as substrate for their flexible, vacuum coated, thin-film solar modules (© Flisom AG).

Close links to industry

Empa's excellent ties to industry are shown by, among other activities, the fact that in 2012 120 new research contracts were signed with industrial partners. About forty per cent of these were market-oriented research and development projects supported by the Swiss Innovation Promotion Agency (CTI).

CTI special measures are boosting collaboration

Last year, Empa initiated a total of 27 new projects within the framework of the special measures taken to counter the strong Swiss franc, for which CTI poured out an extra 100 million francs. Empa was awarded a total of 12.5 million francs, which made it rank third behind EPFL and the Centre Suisse d'Electronique et de Microtechnique (CSEM). Particularly encouraging was the fact that around forty per cent of the projects involved companies with whom Empa had never collaborated before. Many of these are SMEs, one example being Douglas Textiles, an innovative one-woman company, which has developed transparent, yet noise-absorbing curtains in collaboration with Empa and the Weisbrod company. The curtains, sold under the name "Silent Space," are already being marketed internationally with great success.

Historic timber framed houses in Kreuzlingen: conventional insulating panels can often not be used for these kinds of buildings without changing their appearance. In such cases the new aerogel plaster is the solution.

Contact
Gabriele Dobenecker
gabriele.dobenecker@empa.ch

Award-winning: a special, highly insulating plaster

At the beginning of 2013 an innovative new product became available on the Swiss market – a new high-performance insulating wall plaster, developed by Empa, together with Fixit, in the course of another CTI-funded project. Thanks to the use of so-called aerogels the new material offers up to three times better thermal insulation than conventional plaster. This innovative product allows historical buildings to be renovated to improve their energy efficiency while leaving their appearance unchanged. Plans are currently being made to market the product in other European countries. As a result of the technical success and market maturity of the product, the project was awarded the Empa Innovation Award 2012.

Showing what Empa can do

The insulating plaster was presented at the "Swiss Energy und Climate Forum" in Bern last September. Likewise, Empa also exhibited the newest concepts and results from its laboratories at other Swiss technology fairs such as "Cleantec City" in Bern, the "World Medtech Forum" in Luzern, and the "Swiss Innovation Forum" in Basel. These events also presented the opportunity to establish new contacts for future collaborative research projects.

Empa presents its multifaceted activities at the "World Medtech Forum" in Lucerne.


EMPA
Materials Science & Technology
simulation and
l testing of implants
medical devices
Medtech made by Emp
CENTER OF ATTENTION

Innovative and cooperative – Empa's networks

Why do everything yourself when you can reach your goals faster and more efficiently by working in partnership with others? This is a maxim Empa has closely followed for many years, collaborating with countless national and international partners from both research and industry. Each completed project proves the point yet again: the better the network, the smoother the teamwork – and, therefore, the more successful the partnership.

Federal Counselor Johann Schneider-Ammann is opening the annual meeting of the European Association of Research and Technology Organizations (EARTO), jointly organized by Empa and the Centre Suisse d'Electronique et de Microtechnique (CSEM).

Success at the European level

An appraisal conducted in 2012 on behalf of the Swiss State Secretariat for Education, Research and Innovation (SERI) reviewed projects funded by the EU Framework Programs with Swiss participation. The study underscores the degree to which Empa is integrated in international networks; the only other institution in Switzerland involved in more EU projects than Empa is EPFL. One such project, launched by Empa researchers, is "Winsmart", funded to the tune of about 4 million euros and dedicated to developing intelligent windows for the buildings of tomorrow. In the area of photovoltaics Empa is simultaneously involved in several EU collaborations: the 10 million euros "SCALENANO" project and the 7 million euros "R2R-CIGS" project both dedicated to the development of solar cells that are more economic and more efficient, as well as the "TREASORES" project, which has been awarded 14 million euros in funding. The latter is devoted to research into organic electronics and is led by Empa researcher Frank Nueesch. There was also encouraging news from Brussels regarding the decision on the EU flagship initiatives. In addition to the "Human Brain Project" led by EPFL, the

A high-performance transmission electron microscope (TEM) will be installed in a noise-free lab at the new "Binnig and Rohrer Nanotechnology Center" in Rueschlikon. Image: IBM Research

"Graphene" flagship headed by Sweden's Chalmers University of Technology, with the participation of Empa scientists, was also selected. Both projects are expected to enjoy substantial funding from Brussels over the next ten years. At the same time and with financial support from the US Office of Naval Research, Empa's graphene experts are working on the bottom-up synthesis of graphene nano-ribbons from suitable precursor molecules, with the aim of using them in in nanoelectronic circuits.

Swiss TV anchorman Stephan Klapproth interviews Empa CEO Gian-Luca Bona at the opening of "Rhysearch," the new research and innovation center in Buchs. Image: "Der Rheintaler"

Talking of nanoscience, late last year saw the completion of the new "Binnig and Rohrer Nanotechnology Center" at the IBM research laboratory in Rueschlikon near Zurich. Empa scientists are also working at the center, which is jointly managed by IBM and ETH Zurich. They are working on a range of projects which demand the exact structuring of substrates. One example is the development of new X-ray images – of the highest resolution – based on carbon nanotubes (CNTs), which "grow" in a regular pattern on pre-structured substrates. In order to allow exact chemical analyses at defined locations, a high-performance transmission electron microscope (TEM) is currently being installed in one of the center's noise free labs. Empa experts played a leading role in evaluating instruments and will be operating the instrument to exploit its capabilities to the utmost.

Cooperative projects in national and international networks

At the beginning of May Empa, together with the Centre Suisse d'Electronique et de Microtechnique (CSEM), invited sister institutes from all across Europe to the annual meeting of the European Association of Research and Technology Organizations (EARTO). The aim of conference, which was opened by Federal Counselor Johann Schneider-Ammann, was to discuss the role of research institutions in the innovation process in an era of increas-

Contact
Prof. Dr Gian-Luca Bona
gian-luca.bona@empa.ch

ing globalization, but also specialization. One of the meeting's conclusions: real "impact" and the successful exploitation of synergies only occur within a network of strong partners.
The next big meeting is already in the offing – Empa staff are hard at work preparing for the 5th Symposium of the World Materials Research Institutes Forum (WMRIF), which will take place in May 2013 on Empa's Duebendorf campus. Around fifty-plus sister organizations from throughout the world are expected. With its motto of "Materials meet Life" the meeting reflects the spirit of the most modern medical and medicinal technologies and materials.
In 2012 the go-ahead was given for yet another network – "Rhysearch," the new research and innovation center in Buchs, where Empa scientists will work together with staff from ETH Zurich, CSEM, the University of Applied Sciences and Technology Buchs (NTB), and the University of Liechtenstein. The goal of "Rhysearch" is to link interdisciplinary, high-tech research with practical implementation thereby reinforcing the innovative strength of Swiss companies. By the end of the year the center will begin operations on the NTB campus.

Working at the "brain gain" by encouraging young scientists

In order to attract talented young scientists to Empa, the second round of the "EMPA POSTDOC" program has been running since January 2013. Once again Empa will be awarding at least 22 two-year grants, co-financed as COFUND projects by the EU as a part of its Marie Curie Program.
The Master's program "MNT Micro- & Nanotechnology," organized by Empa together with the Zurich University of Applied Sciences (ZHAW), the NTB, and the University of Applied Sciences Vorarlberg/Austria, has once again been recognized as Austria's most promising applied-science program in the technical field.

Good grades for the Empa Academy

Last year the Empa Academy organized about 100 events. 2,400 professionals from industry as well as experts from trade associations and governmental bodies participated in more than 30 symposia. Over 30 scientific conferences, courses and lectures attracted some 1,400 researchers and gave them the opportunity to catch up on the latest developments in their specialist fields. What's more, the events were very well-received, as 93 per cent of the participants graded them as either "good" or "very good," resulting in an average grade of 5.4 out of 6.

"Briefings" struck a chord

The five events in the "Technology Briefing" and "Industry Briefing" series were met with great interest by well over 500 attendees. Of particular interest was the main event at the "Tage der Technik", devoted to "The City of the Future – the Future of the City"; at the end of October, close to 300 experts met to learn more about intelligent urban planning and construction in a complex world where the economy, ecology, politics, and society all play important and sometimes conflicting roles. Before the meeting participants had the opportunity to pay a visit to "self," the prototype of an energy-autonomous living module, as well as to Empa's testing facility for lightweight constructions and to the wind tunnel. The latter allows researchers to simulate wind and temperature conditions in towns and to test ways of improving urban climate by natural means. Besides specialist lectures presenting Empa's medtech activities, the "Industry Briefing" on the

The events organized by the Empa Academy were well-received by participants. On average they were awarded a grade of 5.4 out of 6. Photo: Heidi Hostettler

Contact
Dr Anne Satir
anne.satir@empa.ch

topic of medical technology also featured a speed dating session; participants were able to discuss topics of interest face-to-face with Empa experts, make new contacts or renew and reinvigorate old ones. Feedback from all briefings showed that in organizing these events Empa had touched a chord and was responding to a real need felt by its industrial partners. Participants graded the usefulness of the events for their own organization with a straight 5 (out of 6). In terms of the opportunity to establish contacts, the grade rose to 5.3, and overall, the briefings even received a grade of 5.4 out of 6.

International exchange of know-how

In 2010 and 2011 the "Fiber Society Spring Conference" was held in Bursa, Turkey and Hong Kong, respectively. Last year, in May, it was Empa's turn to play host, giving international specialists in fibers and textiles an overview of current trends in research and development. The interest was overwhelming – twice as many proposals for expert lectures were submitted as could possibly have been considered. Altogether more than 200 scientists from 20 countries visited St. Gallen.

The "Annual Seminar for Building Chemistry" at Empa was devoted to the question of sustainable building materials. This event is organized by the Expert Group on Building Chemistry of the Association of German Chemists (Gesellschaft Deutscher Chemiker GDCh) and was hosted for the first time in Switzerland.

"Tage der Technik 2012": the main event, on the topic of "The City of the Future – the Future of the City" was held at the Empa Academy. Photo: Heidi Hostettler

Research and innovation for everyone

It is one thing to produce cutting-edge research results and create innovative technologies. To describe the effect they have on our daily life in a way that can be understood by every man (and woman) is quite another issue – and no less important. For Empa has just declared its aim of helping pave the way to a sustainable future through its research activities.

Found in unusual places

Some highlights from Empa's laboratories could also be found in places where they would not normally be expected. For instance at the closing ceremony of the Paralympics 2012, held on 9 September in London's Olympic Stadium, when a 14 meter-long Tensairity element suddenly appeared, floating as light as a feather over the heads of the 80 000 or so spectators. The three half-moon shaped flying objects were arranged to resemble the "Agitos," the official symbol of the Paralympics, although there were actually designed by Empa scientists to operate at altitudes of up to 1,000 m as high-flying wind energy generators.

Another example is Jungfraujoch where, since last summer, a permanent exhibition of scientific work carried out at the world's highest research station reachable by public transport is on display as part of the Jungfraujoch railway centenary celebrations. Empa has been measuring numerous air pollutants at the Sphinx Observatory since 1973, and this work has helped to determine and improve air quality, not just in alpine regions but all over Europe.

The EmpaNews app is now available for the iPad as well as for Android tablets. It offers numerous extra features such as videos, audio podcasts, animated graphics, and web links.

QR codes:
Link to EmpaNews app for iPad (right) and Android tablets (left).

Somewhat closer to the ground was the "Die Sonne bewegt" exhibition at the Swiss Transport Museum in Lucerne. This show, which closed at the end of October and was dedicated to the topic of sustainable mobility, included among other things a very special "mobile" – an exhibit with nine rotating solar cells, some transparent and some multi-colored. These so-called Graetzel cells collect sunlight with the help of organic dyes (some of which were developed at Empa), as opposed to silicon crystals in conventional solar cells. They offer a number of advantages: the cells can be transparent, they also function with diffuse light and can be manufactured in a resource-friendly manner.

Governments should be cautious when closing bilateral agreements covering resource exploitation, particularly those which tie-in developing and threshold countries. Far better would be the creation of an neutral, international platform for resources analogous to the International Energy Agency (IEA). This recommendation forms a part of the chairman's summary given at the close of the World Resources Conference which was held in Peking from 21 to 23 October. This annual conference was organized by the WRF Secretariat, an Empa spin-off founded in April. This year's event was hosted by the Chinese Academy of Natural Sciences in collaboration with the WRF, with over 700 persons attending. The conference enjoyed the support of various governments, business organizations and respected figures in the resources field from all over the world.

Highly popular with visitors

After the annual number of guests visiting Empa exceeded 2,000 for the first time in 2011, last year the figure reached 2,900. The visitors, who took part in some 100 guided lab tours, were able to gain a personal impression of numerous Empa innovations. The guests came from a broad range of organizations: the interna-

Empa has been measuring numerous air pollutants at the Jungfraujoch since 1973. In 2012 the institute presented its work in the world's highest research station reachable by public transport.

QR code: video about Empa's research at Jungfraujoch.

To present research results and innovations made by Empa in an appealing way, Empa set up a showroom at its St. Gall site – a prime location overlooking the city.


OIL

Contact
Dr Michael Hagmann
michael.hagmann@empa.ch

tional climate alliance, the governments of the cantons of Thurgau und Appenzell Ausserrhoden, the Swiss Administrative Court, not to mention the annual general meeting of the St. Gallen Economic Region and various expert groups from Swissmem, the umbrella organization for the Swiss machine, electrical, and metal industries. Overall, interest was so high that not everyone who wished to visit could be welcomed at Empa; the institute thus decided to develop a new visitor concept for the future.
About 200 participants attended the three science apéros, which Empa regularly organizes on topical subjects and are designed to appeal to the wider audience. Subjects included, for instance, climate change and its effects on Switzerland. Ways of measuring emissions were described, and the effects climate change might have on national agriculture were discussed.

Empa research for iPads and the like

But even those who are not in a position to visit Empa in person can now keep themselves fully up to date on the latest news from Empa's laboratories – interactively, of course, using multimedia functions – with the new EmpaNews app for both iPad and Android platforms. This makes the research magazine even more attractive and always available wherever you are. In addition it now offers numerous extra features such as videos, audio podcasts, animated graphics and active links for follow-up information.

QR code:
YouTube video "Empa Solar Windows at the Swiss Transport Museum."

Empa installation at the "Die Sonne bewegt" exhibition on sustainable mobility at the Swiss Transport Museum in Lucerne.


sonne
energie
transparenz
farbe
soleil
énergie
transparence
couleu

A new home for guests from all around the globe

With research staff from over 50 countries, Empa really is an international institute. In order to be able to offer scientists from all over the world a home for the duration of their stay, Empa and its sister institute, Eawag, have had a new guest house constructed which was completed last year.

The new guest house on the Duebendorf campus offers Empa's academic guests accommodation in the immediate vicinity of their workplace.

Encouraging young scientists at all levels

Alongside international staff exchanges, the support and encouragement of young scientists and engineers plays an important role at Empa. The annual Summer Camp, which the institute has organized for several years now, and the National Future Day highlight Empa's efforts to waken the interests of children – as early as at primary-school age – in natural sciences and technology. Older children were able to show their ability in the Swiss heat of the Physics World Cup held at Empa last year. And with programs such as "Fix the leaky pipeline!" and "EMPA POSTDOCS," the institute offers active support in career path development for young scientists.

Ladies Lunch relaunched

The "Women meet Women" business lunch has, after a rather long break, been resuscitated with a new concept. The need for a professional network for women is still as large as ever and the new platform provides opportunities for female staff to exchange ideas, get to know each other and offer mutual support. The reconciliation of family and career as well as career planning are important pillars in the new concept. With

Contact:
Dr Christiane Löwe
christiane.loewe@empa.ch

last year's appointment of Brigitte Buchmann as Head of Empa's Mobility, Energy and Environment Department, once again a woman takes a place on the institute's Board of Directors.

Lenny Winkel (right) presents her impressions of what it means to work abroad at the "Women meet Women" business lunch.

Organizational chart 2013

Research Focus Areas

Nanostructured Materials
Dr Pierangelo Gröning

Sustainable Built Environment
Dr Peter Richner

Health and Performance
Prof. Dr Harald Krug

Natural Resources and Pollutants
Dr Brigitte Buchmann

Energy
Dr Xaver Edelmann

GENERAL MANAGEMENT

Director General	Deputy	Members
Prof. Dr Gian-Luca Bona	Dr Peter Richner	Dr Pierangelo Gröning | Dr Brigitte Buchmann | Prof. Dr Harald Krug | Dr Xaver Edelmann | Dr Urs Leemann

Media Technology
Prof. Dr Klaus Simon

DEPARTMENTS

Advanced Materials and Surfaces
Dr Pierangelo Gröning

Electron Microscopy Center
Dr Rolf Erni

LABORATORIES

High Performance Ceramics
Prof. Dr Thomas Graule

Joining Technologies and Corrosion
Dr Lars Jeurgens

Nanoscale Materials Science
Prof. Dr Hans Josef Hug

Advanced Materials Processing
Prof. Dr Patrik Hoffmann

nanotech@surfaces
Prof. Dr Roman Fasel

Mechanics of Materials and Nanostructures
Dr Johann Michler

Thin Films and Photovoltaics
Prof. Dr Ayodhya N. Tiwari

Functional Polymers
Prof. Dr Frank Nüesch

Civil and Mechanical Engineering
Dr Peter Richner

Center of solid-state kinematics and actuation
Dr Flavio Campanile

Road Engineering/Sealing Components
Prof. Dr Manfred Partl

Applied Wood Materials
Dr Tanja Zimmermann

Structural Engineering
Prof. Dr Masoud Motavalli

Mechanical Systems Engineering
Dr Giovanni Terrasi

Building Science and Technology
Prof. Dr Jan Carmeliet

Mechanics for Modelling and Simulation
Prof. Dr Edoardo Mazza

Center for Synergetic Structures
Dr Rolf Luchsinger (PPP Empa – Festo)

Concrete/Construction Chemistry
Prof. Dr Pietro Lura

Acoustics/Noise Control
Kurt Eggenschwiler

Materials meet Life
Prof. Dr Harald Krug

Protection and Physiology
Dr René Rossi

Advanced Fibers
Prof. Dr Manfred Heuberger

Materials-Biology Interactions
Dr Katharina Maniura/Dr Peter Wick

Biomaterials
Prof. Dr Dr h. c. Linda Thöny-Meyer

Electronics/Metrology/Reliability
Dr Urs Sennhauser

Knowledge and Technology Transfer

Empa Academy
Dr Anne Satir

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 Gian-Luca Bona

Portal

E-Mail portal@empa.ch
Phone +41 58 765 44 44
www.empa.ch/portal

Mobility, Energy, and Environment

Dr Brigitte Buchmann

- **Solid State Chemistry and Catalysis**
  Prof. Dr Anke Weidenkaff
- **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**
  Dr Christoph Bucher
- **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

Bodies of Empa

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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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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.

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Christiane Ziegler Prof. Dr, Technical University Kaiserslautern, Germany

Facts and figures

Excellence in research and close ties to industry – last year Empa once again demonstrated that these two are not contradictory. An analysis by the University of Leiden, for instance, shows that in terms of scientific output Empa has reached values placing it among the Top 20 universities worldwide. Moreover, an independent appraisal of EU projects in Switzerland has emphasized Empa's high level of international integration – only EPFL is involved in more EU projects. Likewise, the number of Empa projects funded by the Swiss Commission for Technology and Innovation (CTI) rose from 80 to 108. This is primarily due to special measures by the Swiss government to counter the strong Swiss franc. Thus, second and third party funding increased by 15 per cent compared to 2011. Simultaneously, Empa has extended its technology transfer activities, filing 50 per cent more patent applications and signing 150 R&D agreements.

SCIENTIFIC OUTPUT

	2011	2012
ISI publications	500	509
Conference contributions	1094	1043
Doctoral studies completed	40	44
Docoral studies in progress	146	160
Teaching activities (in hours)	3637	3500
Prizes and awards	27	37

EMPA ACADEMY

	2011	2012
Empa events	91	95
Participants	5000	4000
Scientific conferences	11	9
Events for industry	38	31

KNOWLEDGE DISSEMINATION & TECHNOLOGY TRANSFER

	2011	2012
New R&D Agreements	103	150
Active exploitation contracts	67	87
New exploitation contracts	15	33
New patent applications	12	18

STAFF (AS OF 31. DECEMBER 2012)

	2011	2012
Scientific staff	523	519
of which professors	27	27
of which Ph. D. students	115	119
of which sci. staff excl. profs. & Ph. D. students	381	376
Technical & administrative staff	436	446
of which apprentices	41	42
Total	959	965

CURRENT PROJECTS

	2011	2012
Swiss National Science Foundation (SNSF)	94	99
Commission for Technology and Innovation (CTI)	80	108
EU-Projects	51	64

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

	2011	2012
Companies total	32	29
thereof Spin-offs	11	15
Employees total	166	197
thereof Employees of Spin-offs	63	87

MEDIA EXPOSURE

	2011	2012
Radio & TV	120	88
Print	1097	945
Online	1773	1938
Total	2990	2971
Languages	32	34

PROFIT AND LOSS ACCOUNT (IN MILLIONS OF SWISS FRANCS)

	2011	2012
Revenue		
Federal founding contribution	96.9	97.8
Measures "strong Swiss Franc"	2.5	0.0
Third-party funding	51.7	59.4
Of which income from services	13.1	13.3
Miscellaneous income	5.0	2.6
Financial income	0.0	0.0
Total revenues	**156.1**	**159.8**
Expenditure		
Personnel costs	103.1	105.8
Material costs	5.6	6.0
Operational expenses	39.0	35.9
Changes in performance bond	3.2	3.3
Reserve increase for projects	2.2	3.8
Total expenditure for corrent activities	**153.1**	**154.8**
Balance	**3.0**	**5.0**
Investment		
Fixed assets	2.9	3.8
Movable assets	10.1	8.4
Information technology	1.0	0.2
Total investment	**14.0**	**12.4**

Use-inspired Research

Innovative Developments

Knowledge and Technology Transfer

Services and Expertise

Advanced Training and Education

Empa. Materials Science and Technology.

Materials Science & Technology

CH-8600 Dübendorf
Ueberlandstrasse 129

Phone +41 58 765 11 11
Telefax +41 58 765 11 22

CH-9014 St. Gallen
Lerchenfeldstrasse 5

Phone +41 58 765 74 74
Telefax +41 58 765 74 99

CH-3602 Thun
Feuerwerkerstrasse 39

Phone +41 58 765 11 33
Telefax +41 33 228 44 90

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