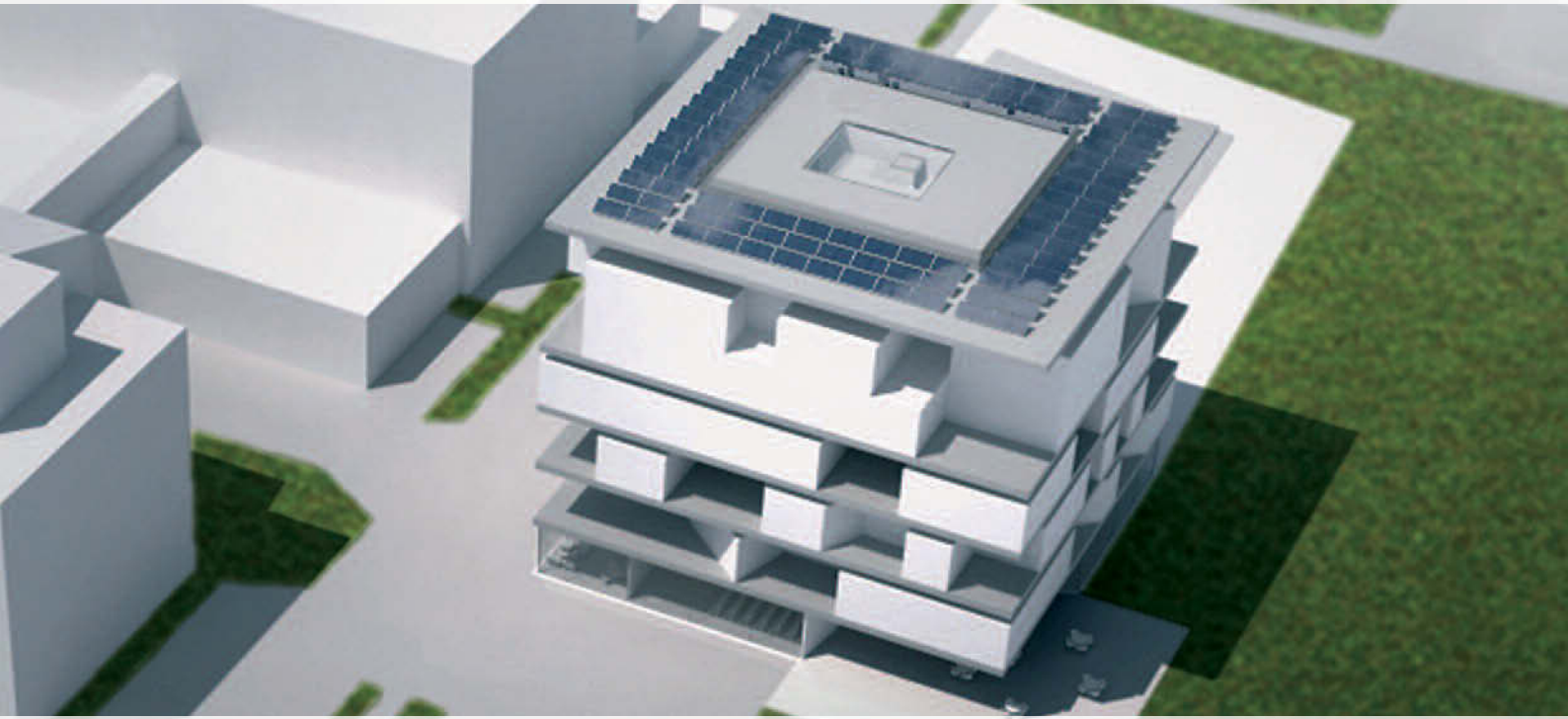
Annual Report 2011



EMPA

Materials Science & Technology

Our Vision.

Materials and Technologies for a Sustainable Future.

IMPRINT
Publisher: Empa, CH-8600 Dübendorf, 9014 St.Gallen, 3602 Thun. Editors: Communication, Empa. Design/Layout: Graphics Group, Empa.
Printing: Sonderegger Druck AG, CH-Weinfelden. ISSN 1660-2277 Annual Report Empa © Empa 2012

Energy technologies in the spotlight

Triggered by the disastrous events in Fukushima, 2011 was characterized by a re-evaluation of our work and objectives in energy research. As a result, I am delighted to say that we are very well prepared for the challenges lying ahead. This is because energy issues are, first and foremost, questions concerning suitable materials and technologies. In future, this will primarily involve developing sustainable, cyclical processes for energy conversion and storage. We are already working on forward-looking solutions for the energy sector, not only in our Research Focus Area “Energy Technologies”, but also in our other research areas. In total, around half of our federal funding is devoted to projects related to energy matters. This focus area has been pushed strongly in recent years, an effort which is now paying off. We can be proud of what has been achieved so far, which is the result of outstanding contributions by numerous research teams with their highly motivated staff.

The fact that Empa is concentrating on this important topic is also significant from another perspective: energy solutions need time. Typically it takes more than a decade to develop new energy systems, their implementation often even longer. This is in stark contrast to developments in other sectors, such as ICT where the pace with which new models of tablet computers and smart phones hit the shelves seems to be ever accelerating.

Our country will have to make great efforts in the coming years if it is to overcome the problems of satisfying an increasing demand for energy. As 75 per cent of energy consumption currently occurs in the areas of buildings and transportation, Empa is facing a particular challenge as these are two of its core areas. I am convinced that our research will yield significant results, such as the intelligent and efficient use of resources in construction, new heat storage systems based on ettringite or in the context of studies on urban development.

Please take this opportunity and let yourself be inspired by the examples featured in our current annual report. Our doors are always open to cooperation with academic and industrial partners, especially in the energy sector but also in our other research areas. The Swiss government’s energy strategy has been geared towards the year 2050. The objectives pursued by Empa should, however, deliver new impulses and ideas much earlier. For instance with demonstrators relating to energy-efficient construction such as "NEST" (page 54) and concept studies in mobility. I am looking forward to working with you on tackling these challenges.

Prof. Dr. Gian-Luca Bona
Director General

01

Co-operative Medtech research
In future, Empa will work closely together with the Cantonal Hospital of St Gallen, the University Hospital Zurich and the ETH Zurich in areas such as nano-safety, implant development and tissue engineering.

Cleaner air due to maintained roads
Clean, undamaged road surfaces help reduce the concentrations of fine particulates significantly, according to a study by Empa and the PSI. After all, engine emissions account for only about half the total fine particulates due to road traffic.

02

Building conference in the UAE
Some 300 participants drawn from 30 countries attended the event co-organized in Dubai, the Eldorado of innovative architecture, where they were updated on the newest trends in "smart" monitoring and renovation of buildings.

Atomically resolved nanoparticles – in 3-D
Researchers from Empa and the ETH Zurich have, for the first time, successfully determined the 3-D structure of a nanoparticle, atom for atom.
Page 15

03

There's a wind blowing
The institute's new wind tunnel allows researchers to simulate wind and temperature conditions in cities and to test ideas for improving urban climate by natural means.

1st Swiss Cleantech Report
Environmentally friendly technologies play an increasingly important role for Switzerland in terms of its economy and research activities, a finding confirmed by a "state of play" appraisal co-authored by Empa staff.

04

Chemistry in an electron beam
Using a focused electron beam Empa researchers have created surface structures on a nanometer scale, allowing, for example, lasers for optical data transmission to be improved.

New Empa Laser Center in Thun
The one-of-a-kind UV laser system makes it possible to process large surfaces with nanometer precision and can be used for the production of, say, optical security features or 3-D monitors, which function without spectacles.
Page 22

05

How sustainable are coffee capsules?
A life cycle analysis by Empa scientists found that this depends primarily on the coffee itself and less on the type of capsule system. The deciding factor is the environmental burden caused by growing the coffee.

CH NanoConvention, Part One
In 2011, together with the PSI and the ETH Zürich, Empa organized the 1st Swiss NanoConvention, a discussion platform covering all aspects of nanotechnology.
Page 96

Junior partner at IBM-ETH Nanocenter
The IBM Research Laboratories in Rueschlikon have opened their state-of-the-art nanocenter, where Empa scientists will also be able to conduct their research.

06

Web tool for assessing biofuels
Once hailed, many biofuels actually cause more harm to the environment. In order to evaluate their sustainability, Empa researchers have developed a web tool, the "Sustainability Quick Check for Biofuels".

Excellent Masters program
The Austrian business magazine "Format" has voted the international MNT Micro-and Nanotechnology Masters program, co-founded and co-organized by Empa, as the best university of applied sciences technical study course.

World record for solar cells
Empa scientists set two international records in 2011 for the efficiency with which their flexible thin-film solar cells convert sunlight into electrical energy.
Page 31

07

At the CS Innovation Luncheon
Together with the Fraunhofer Gesellschaft, Empa took the opportunity offered by a Credit Suisse "Innovation Luncheon" to present its newest ideas to interested clients and bank staff.

Summer camp for the youngsters
21 young researchers-to-be took part in the 2011 summer camp where (among other activities) they designed and made a working suspension bridge over the Chriesbach, a creek flowing through Empa's Duebendorf campus.

08

Successful finance bid for Empa spin-off
Compliant Concept, an Empa start-up, which is housed in the institute's business incubator "glaTec", has won a generous funding "voucher" from the CTI, the federal innovation promotion agency.

Awakening the spirit of enquiry
In the first children's laboratory set up at Empa, 20 elementary schoolchildren experimented to their heart's delight with such phenomena as electricity, liquid flow and light.

09

"WRF" provides stimuli
At the 2nd World Resources Forum, organized once again by Empa in Davos, every aspect of global resource usage – which continues to increase massively – was discussed in great detail.

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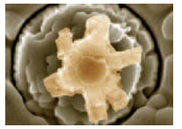


The beauty of the nano-cosmos
Images made by Empa staff using scanning electron microscopes won several awards last year for their aesthetic value – for example at the "NanoArt 2011".

All that glisters actually is gold!
A razor-thin gold covering lends ties and pocket squares real brilliance. The yarn, from which these items are woven, is coated using a plasma process developed at Empa – and is even machine-washable.

Switzerland's best start-ups
Success for Empa's "glaTech" business incubator: of the six start-ups it is currently housing, three made it into the TOP 100, with one, "Optotune", even gaining first place.
Page 89

11

"Vade mecum" for nanotextiles
With its "Nanotextiles" guideline, Empa aims at making the safe handling and usage of nanotechnology easier for firms in the textile and clothing industries.

The world's smallest e-mobile
The emission-free, silent, four-wheel-drive vehicle consists of just one molecule and rolls along on four electrically powered wheels.
Page 12

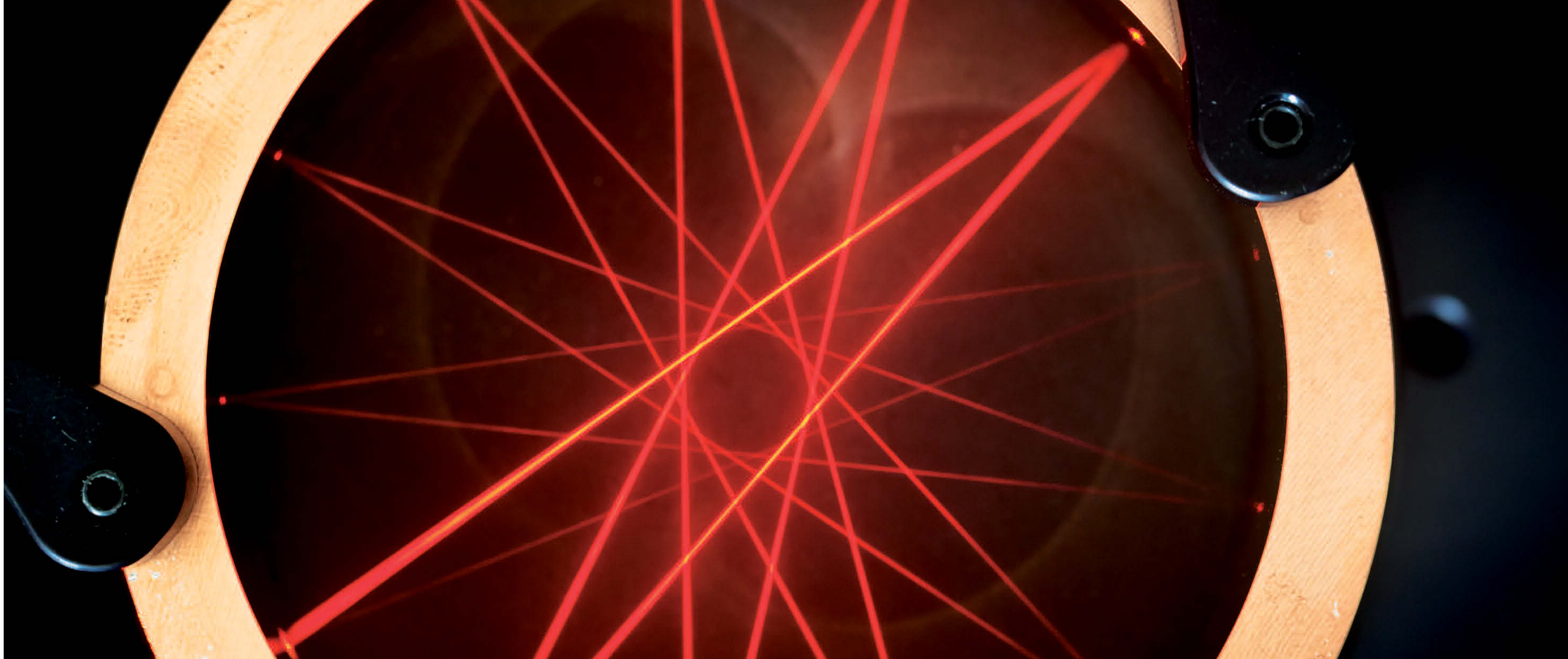
12

EU co-financing for Empa postdocs
Last year 22 young scientists received a two-year EU "COFUND" grant, and early in 2013 Empa will be awarding another 22 grants to talented postdocs.

Breaking through the "glass ceiling"
Brigitte Buchmann, Empa chemist and air pollution expert, has been elected by the ETH Council as the first woman to join the institute's Board of Directors.

In the spotlight

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 1100 contri - butions 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 & Technology Transfer
Services & Expertise
Advanced Training & Education

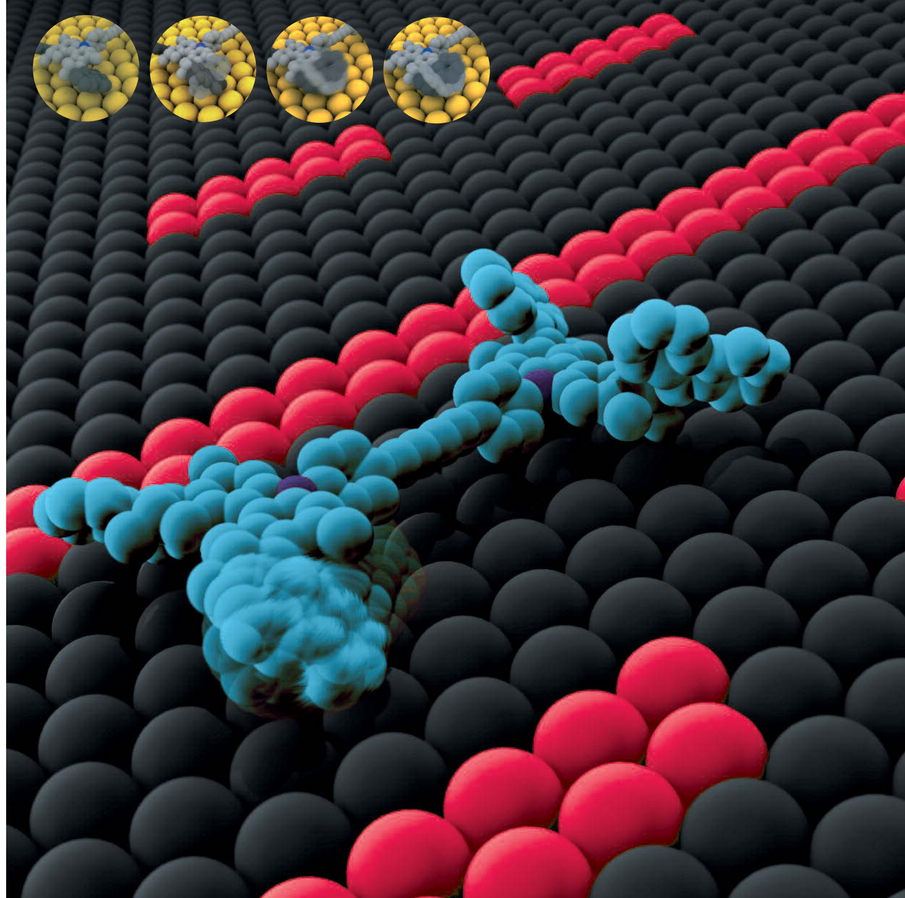
A nano car with molecular four-wheel-drive

They don't make them any smaller: the emissions-free, noiseless vehicle Empa researchers have developed with Dutch colleagues. Consisting of just a single molecule, it rolls on four electrically driven"wheels" in an almost straight line across a copper surface. The principle has been borrowed from nature – in cells "motor proteins" glide along other proteins like trains on rails, burning the biological "fuel" adenosine triphosphate (ATP) while doing so. The nano car is a synthetic molecule consisting of four motor units, which require neither fuel nor rails to operate, being powered by electricity instead.

4 x 2

nanometers is the size of the nano car – about a billion times smaller than VW Golf. The synthetic molecule consists of a simple C-C bond (the chassis of the vehicle) and four motor units (the car's wheels), which are driven electrically.

The tiny electromobile, which is just 4 x 2 nanometers in size, is charged up via the tip of a scanning tunneling microscope (STM). This requires a potential of at least 500 mV. Electrons "tunnel" through the molecule and produce structural changes in the four motor units, causing each wheel to make half a rotation. If all four wheels rotate simultaneously, the vehicle moves forward in a straight line, at least theoretically. The difficulty is to excite all four motors at the same time. After being excited 10 times by the STM the tiny auto has moved six nanometers. However, after each half rotation of the wheels the vehicle must be recharged. A further experiment proves that the molecule actually does function as predicted. The central axis consists of a simple C-C bond, around which the front and rear of the car can rotate freely.



The nano car is charged up using the tip of a scanning tunnel microscope. A single charge is sufficient to rotate each wheel half a turn. After ten "fill ups" the vehicle has moved six nanometers.

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The molecule can therefore land “the wrong way round”, in which case the rear wheels try to drive it forward and the front wheels try to move it backwards – and the vehicle remains stationary. If the molecule lands with the correct orientation, all four wheels rotate in the same direction and the vehicle moves forward.

The aim of the project is to develop molecular transport machines for tasks on the nanometer scale. The researchers from the University of Groningen and Empa have made a decisive step forward by managing to prove that individual molecules can take up electrical energy from an external source and convert it into a specific motion.

The results of the research project were published in the scientific journal “Nature”; the nano car even made it onto the front cover.

Counting atoms – in 3D

Using a newly developed method researchers from Empa and the ETH Zurich have managed for the first time to determine the spatial organization and the number of individual atoms in a nanoparticle. The report on their work, conducted together with Dutch colleagues, was published in the renowned science magazine “Nature” in February. Nanoparticles demonstrate different chemical and physical properties than their microscopic and macroscopic “siblings”. Because they consist of just a few atoms they possess a very large surface area in relation to their volume. This can lead to quantum effects occurring, which may modify material properties. For example, ceramic made of nanomaterial is flexible; gold nanoparticles shine with a reddish hue.

50

picometers – about half an atomic diameter – is the resolution of the electron microscope used to image the silver particles. This capability made it possible to count the individual silver atoms in the crystal lattice.

In addition to the surface characteristics, the three-dimensional structure of a nanoparticle, as well as the orientation of the atoms within it, determine its properties. The researchers of Empa and ETH Zurich were able for the first time to image the exact three-dimensional structure of single silver nanoparticles, with a resolution down to individual atoms. To do so they used an extremely high performance electron microscope capable of imaging structures just half an atomic diameter in size – or, in figures, less than 50 picometers. Colleagues at the University of Antwerp then used the data to create models to sharpen up the images, which allowed the Swiss team to count the individual silver

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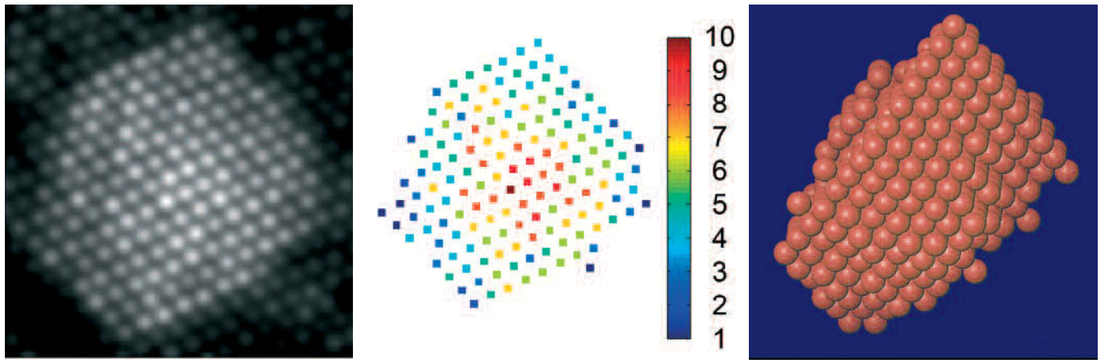
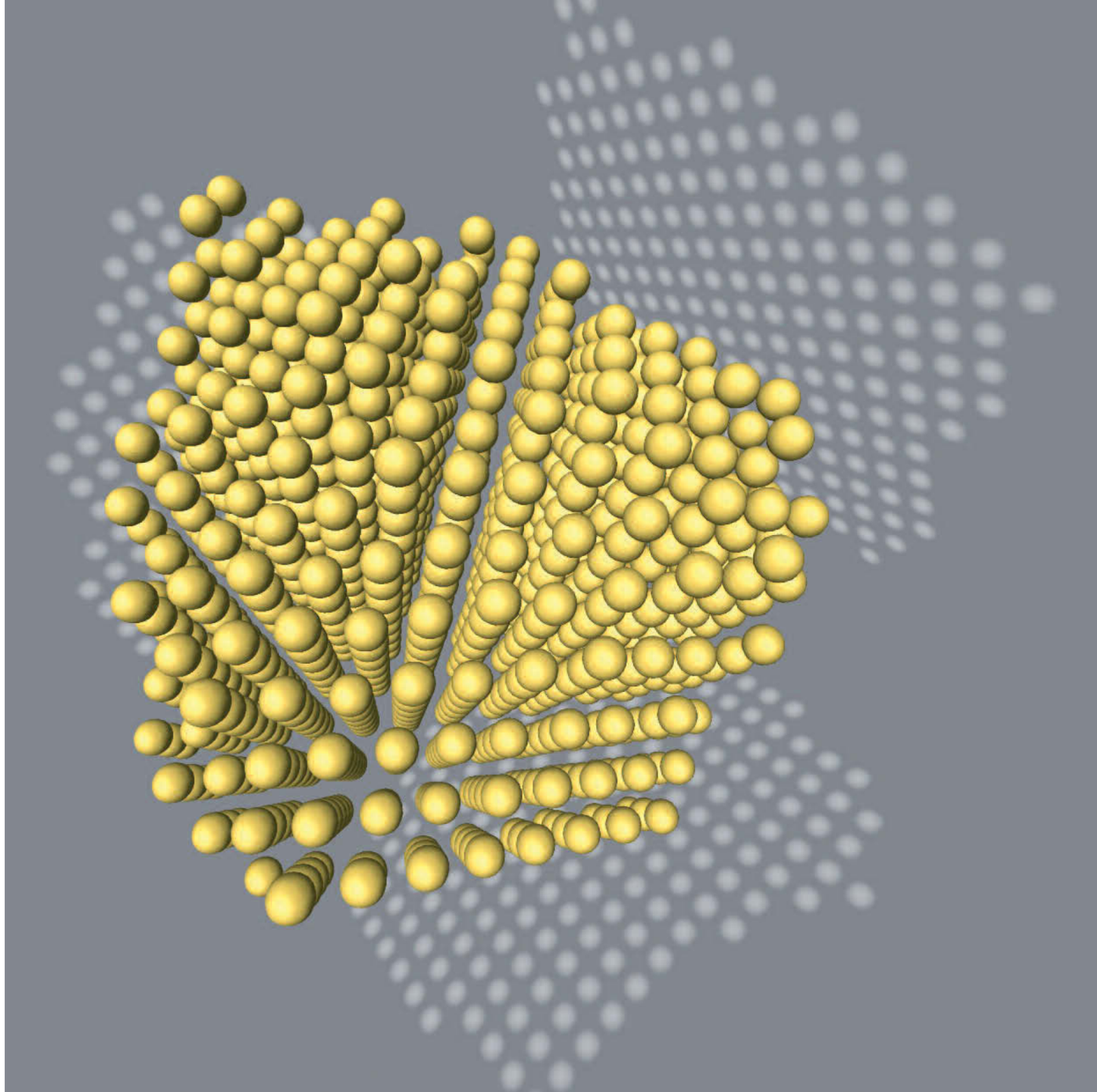
atoms in the crystal lattice. Finally, in order to determine its three-dimensional structure, the Dutch specialist tomographed the nanoparticle and reconstructed the orientation of its constituent atoms using special mathematical algorithms. Two images were enough to enable the reconstruction of a nanoparticle consisting of 748 atoms.

Empa and ETH are now planning to use the same technique to characterize doped nanoparticles in order, for example, to determine which atomic configurations are active on the particle surface when it demonstrates toxic or catalytic properties. Generally speaking the new method should help to better understand the properties of nanoparticles.



Left: electron microscope image of a silver nanoparticle. Each mark represents the projection of an atomic pillar. The image shows a model of the raw data, which is used in the quantifying process. **Center:** a novel, quantitative analysis of the image contrast allows the structure of the silver atom to be deciphered. The color coding counts the atoms in each pillar passing through the particle. **Right:** a different view of the reconstructed silver nanoparticle.



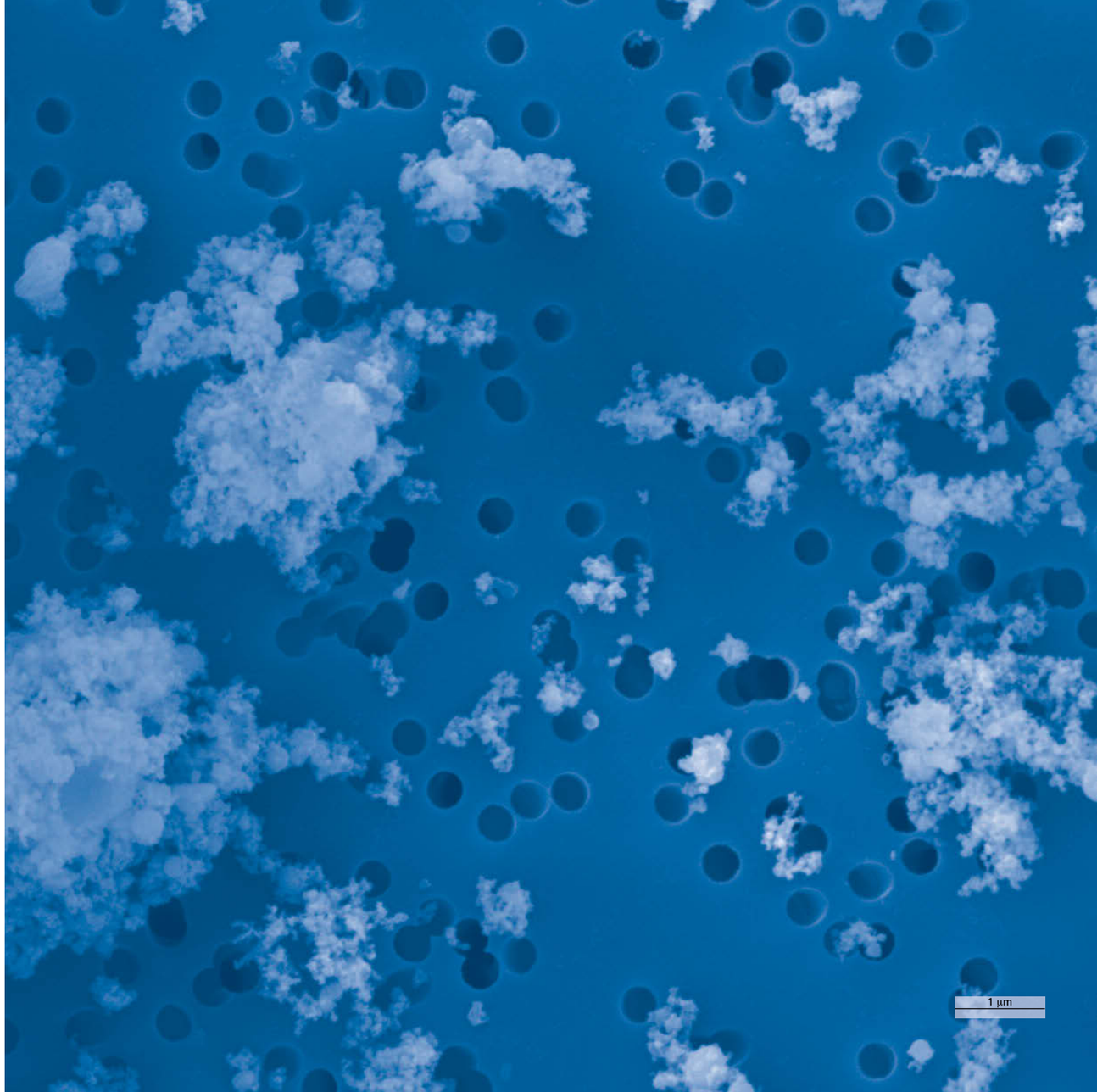
For the first time researchers have been able to determine the number of individual atoms and how they are organized in a nanoparticle. The silver particle has a diameter of about two nanometers.

Nanoparticles in the air – largely unexplored

There's still way too little known about exactly what happens to airborne nanoparticles – be they industrially produced or unintentionally released, for instance by combustion processes or abrasion. Therefore, while cleaning production facilities for nanopowders, workers often protect themselves by way of precaution with space-suit-like clothing. In order to characterize and investigate nano-sized particles suspended in air Empa set up a special laboratory including a wind tunnel. The wind tunnel is an excellent instrument for studying nanoparticles under well-defined conditions. Thanks to fans, heating and humidification, it is now possible to precisely control wind speed, temperature, humidity and other test parameters. In field studies, these parameters are largely unknown. Researchers at Empa manufacture nanoparticles themselves and thus have a precise knowledge about their size and nature. As soon as the particles are "set free" in the wind tunnel, they are very mobile and remain in the air flow for a long time – in contrast to larger particles, which settle to the ground more quickly because of their higher weight. So the researchers investigate how long they remain in the tunnel's airstream under exactly defined conditions, how they propagate, whether they agglomerate and in this way change their size and whether they react with each other chemically (or with other atmospheric constituents). At various spots in the wind tunnel, samples are taken and analyzed. One of

3 x 13

meters are the outer dimensions of Empa's new wind tunnel for investigating nanoparticles in the air. It consists of standardized ventilation elements and serves, among other things, to develop more efficient air filters.



Agglomerated silicon carbide nanoparticles are trapped in a filter, while air is able to circulate freely through its cylindrical holes. (Scanning electron microscope image)

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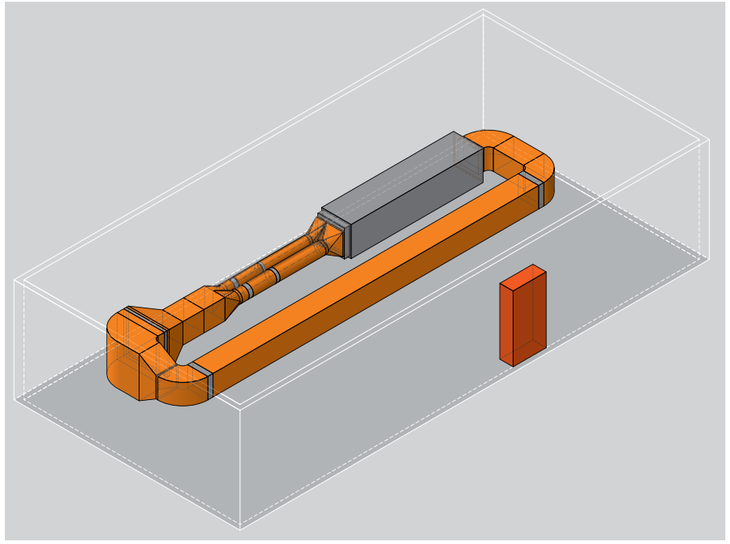

Wind tunnel schematic.

the instruments used for analysis is the newly developed, patent-pending "Universal Nanoparticle Analyzer". It measures size, morphology, surface and volume of the nanoparticles or of agglomerates thereof – and the results are at hand within minutes. Previously, nanoparticles had to be tediously analyzed under a microscope. In the tunnel, the efficiency of air-ventilation filters can also be evaluated. The aim is to address the filtration challenges posed by fast-growing nano-materials for human health and the environment in applications such as face masks or filters installed inside automobiles and aircrafts.

Soot particles from diesel engines are being investigated with Empa's wind tunnel. The findings could lead to better soot filters and catalysts for diesel engines.

Structuring large surfaces with nanometer precision

The heart of Empa's new laser center in Thun, which was inaugurated in 2011, is a new pulsed ultraviolet laser capable of very precisely removing nanometer-thin layers from surfaces with areas up to 3 square meters. Because the new facility allows material surfaces to be micro- (or even nano-)structured, new physico-mechanical effects can be generated. Microstructures can, for example, reduce friction, decrease air resistance or hinder fungal growth. Foils for optical elements with light guiding properties can also be manufactured, for example 3-D screens that do not require the viewer to wear special glasses. Even novel window panes could be developed, which would illuminate indoor areas at night while functioning as solar cells during the day. It is also possible to "germinate" materials for electrochemical processes, so that electrical connections can be "grown" on flexible screens or solar cells.

Operated by Empa in collaboration with the company Crealas GmbH, the new facility – one of only three worldwide – will not only benefit materials science; it also offers completely new opportunities to Empa's industrial partners. The ability to laser-treat large surface areas makes it possible, for example, to manufacture molding tools, which are required for the manufacture of structured foils on an industrial scale. To date, molding tools have to be created from

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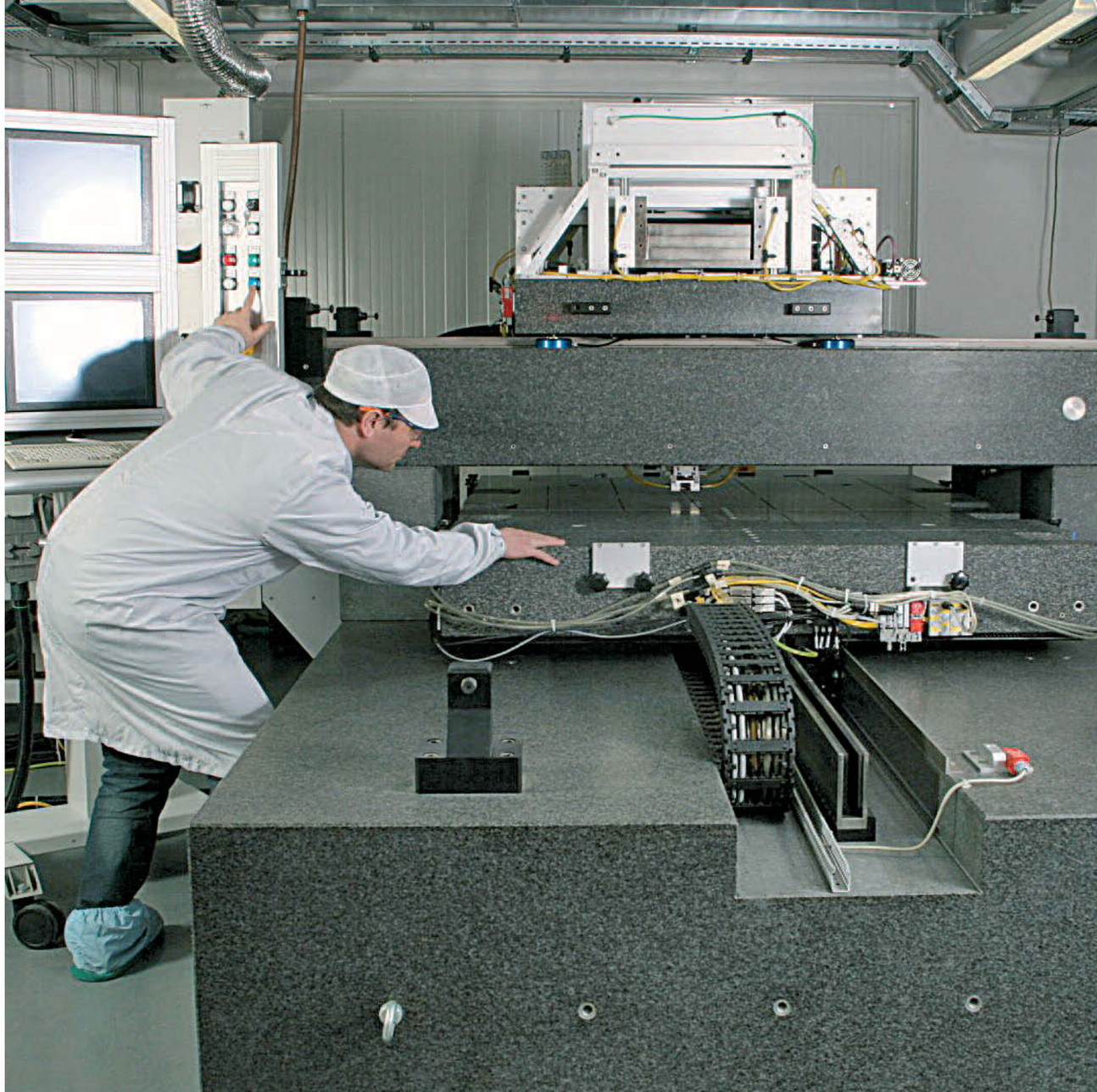
square meter-surfaces can be micro- and nanostructured in the new laser facility. A 19 ton granite table ensures that the film being processed is kept perfectly immobile.



Treatment with the UV laser lends materials new physical and mechanical properties. For example the microstructures reduce friction, have a water-repellent effect and hinder fungal attack.

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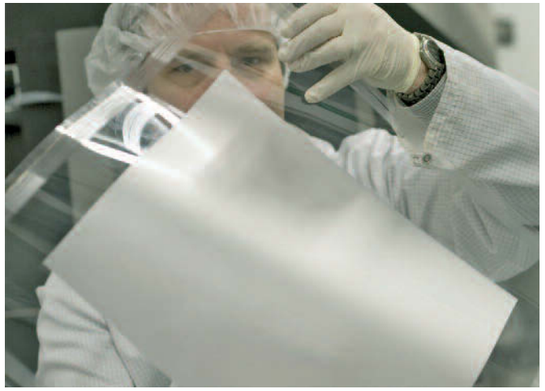
an assemblage of different parts, whereas the new laser center allows them to be manufactured as a single piece. Films bearing optical security features can also be produced at the laser center. A number of countries are already making efforts to replace the holograms on their banknotes with microstructured foils which create 3-D optical effects.



Large area molding tools can be manufactured using the laser system, such as a 350 x 350 square millimeter microlens array on a flexible substrate.

In addition to molding tools, the thinnest layers can be microstructured on films using roll-to-roll techniques.

Greenhouse gases: Self-reporting is good, independent verification even better

Fluorinated hydrocarbons are potent greenhouse gases, the emission of which must be reduced under the terms of the Kyoto Protocol. According to official reports submitted by participating countries, the output of trifluoromethane (HFC-23) in Western Europe is indeed decreasing. Officially, for example, Italy has emitted no significant quantities of HFC-23 since 1996. To ascertain whether this is actually so, Empa researchers made atmospheric measurements using a special gas chromatograph mass spectrometer called MEDUSA, which enables the emission levels of more than 50 halogenated greenhouse gases to be quickly and precisely quantified. Thanks to atmospheric and meteorological computer models researchers are also able to identify and locate emission sources.

15,000

times more efficient than CO_2: HFC-23. And with an atmospheric half-life of about 270 years it is also very long-lived. The substance is created as a byproduct during the manufacture of chlorodifluoromethane (HCFC-22), which is used as a cooling and foaming agent.

The sobering result of the study: Western Europe emits around twice as much HFC-23 as officially reported and countries differed significantly in their "reporting accuracy". Italy, for instance, emits 10 to 20 times more HFC-23 than it officially reports. On the other hand, declarations of many other European countries are more or less in line with their emission estimates.

In order to quantify the amounts of HFC-23 in the atmosphere over Western Europe as precisely as possible, the Empa scientists analyzed atmospheric HFC-23 concentrations at both

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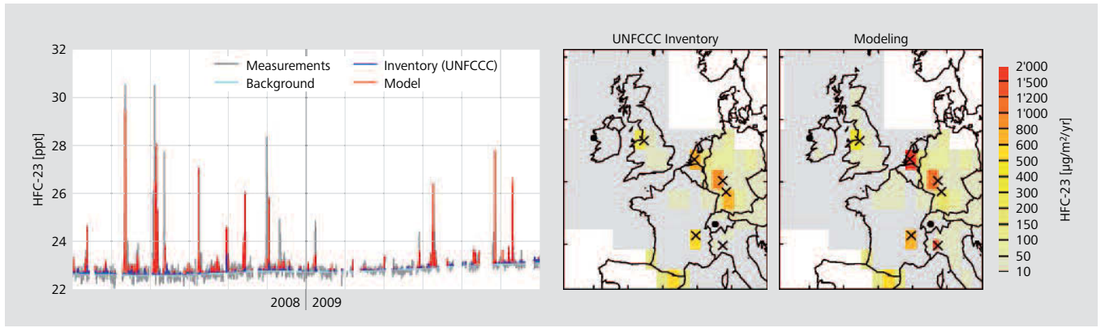
Jungfraujoch and Mace Head, a measurement station on the west coast of Ireland, from July 2008 to July 2010. Time and again they found mysterious peaks, which far exceeded the baseline concentrations. Using atmospheric transport models, the Empa researchers were able to pinpoint the origin – or source region – of the polluted air masses that transported HFC-23 to Jungfraujoch. Six sources of emissions for HFC-23 were identified. First and foremost was a factory west of Milan, which is the sole producer of HFC-23 in Italy (as a by-product of cooling and foaming agent manufacture and PTFE production).

With their results the Empa scientists have shown that these types of measurements really are suitable for monitoring compliance with international agreements on air pollution control. While the Kyoto Protocol does not specify any independent control mechanisms, this could be of central importance in subsequent agreements with binding emission targets.



HFC-23 concentrations at the Jungfraujoch: there is a great discrepancy between actual measurements (grey) and values calculated using data from the official inventory (dark blue). Empa's model data (red) are much more consistent with the measured values. The inventory of the United Nations Framework Convention on Climate Change (UNFCCC) underestimates real HFC-23 emissions, sometimes by a significant amount. Using transport models in combination with measurements made at Jungfraujoch, all six emission sources could be identified and pinpointed.

The pollutants emitted by a factory in the Milan region do not remain localized over Italy.

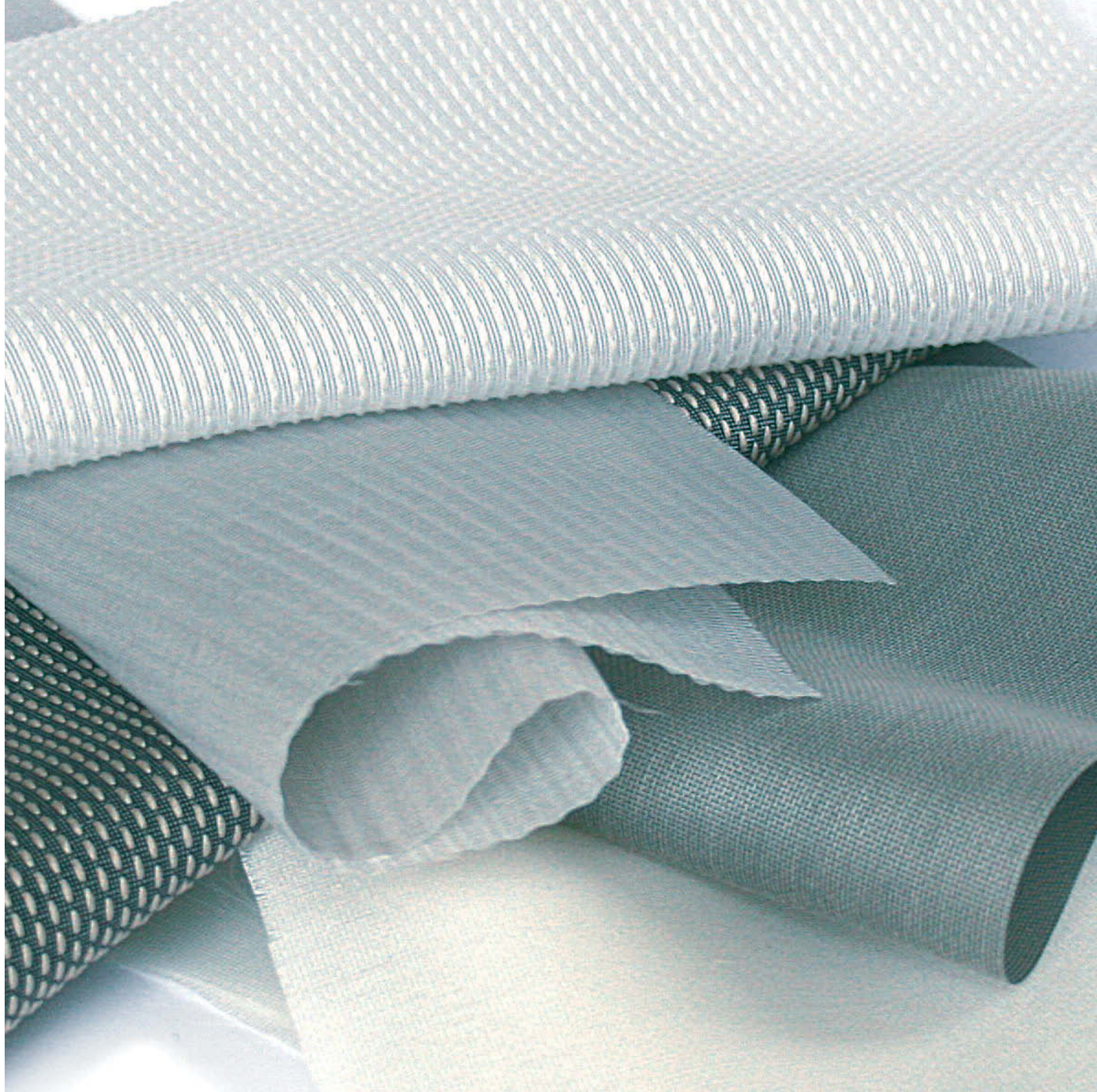
Curtains that “swallow” noise

Researchers at Empa, in cooperation with textile designer Annette Douglas and silk weavers Weisbrod-Zürrer AG, have developed lightweight, translucent curtains, which are excellent at absorbing sound. This is a combination that has been lacking so far in modern interior design. The new noise-quenching curtains have just gone onto the market. The first acoustically optimized lightweight textile came into being on a computer. Empa acoustic specialists wanted to use the characteristics of this virtual textile to prepare a kind of “recipe” for material experts, which would enable them to specifically manufacture a fabric that could absorb sound. In addition, they developed a mathematical model to illustrate both the fabric’s microscopic structure as well as its macroscopic composition. On the basis of numerous measurements made on various samples they were able to gradually optimize the acoustic properties of the fabric until the new material was capable of “swallowing” five times as much sound as conventional translucent curtains.

5

times as much sound energy can be absorbed by the new curtains compared to conventional materials when placed at an optimal distance of 15 centimeters from a wall.

Textile designer Annette Douglas then translated the new findings into weaving techniques. She chose the yarns and developed a special woven structure, which lent the new material the necessary characteristics in terms of flammability, translucence and aesthetics. Weisbrod-Zürrer then adapted its sophisticated manufacturing processes so that the curtains could be made on an industrial scale.



Annette Douglas’ collection is (very aptly) called “Silent Space” and includes a range of different materials.

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Recently, the project team's work was awarded the "Design Preis Schweiz" for innovative solutions in the field of woven materials. The new fabric is a genuine and valuable innovation which is soon expected to establish itself on the market, the jury felt, won over by its understated and unostentatious appearance and the new opportunities it opens in interior design.

The new noise absorbing and yet optically transparent curtains open new opportunities in interior design.

Increasingly attractive: solar energy

Photovoltaics have become an established feature of our everyday life since the first solar module was made over half a century ago to supply power to telephone amplifiers. However, the only thing preventing their wider use is their cost – even though steadily increasing production levels mean that prices are slowly dropping. In fact when the installed capacity doubles, the price for a solar module falls by some twenty per cent. Standard solar modules made of crystalline silicon cells efficiently convert sunlight to electrical energy, but they also have their downsides: They are heavy, rigid and bulky, making installation quite difficult. What's more, the semiconductor silicon, despite being plentiful, is becoming more expensive due to increasing demand. It would be advantageous, therefore, to find an alternative.

18.7

per cent energy conversion efficiency – and thus a new world record – has been reached for flexible solar cells based on copper indium gallium diselenide (CIGS).

This is why, for example, an Empa team has developed flexible thin-film solar cells based on inorganic materials. They are economic to manufacture because the lack of rigid glass plates means that compact production machines can be used to quickly produce large quantities of solar panels using the so-called roll-to-roll process. Delivery and installation are also significantly easier. In addition, thin-film solar modules also offer novel applications, such as usage on building facades, in solar fields or with portable devices.

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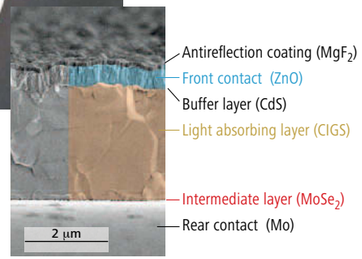
Lightweight, flexible, high-performance solar cells, deposited on polymer or metal films, therefore, have an enormous economic potential. One technique developed at Empa currently holds the world record in energy conversion efficiency, reaching 18.7 per cent. The surface which absorbs sunlight and converts it into an electric current consists of a copper indium gallium diselenide (CIGS) layer. Another active material which can be deposited as a thin film onto a flexible substrate and which has been responsible for a (second) world record at Empa is cadmium telluride (CdTe). A decisive factor is that the manufacturing processes developed at Empa take place at relatively low deposition temperatures (below 450°C), since polymer films are not as heat resistant as glass.

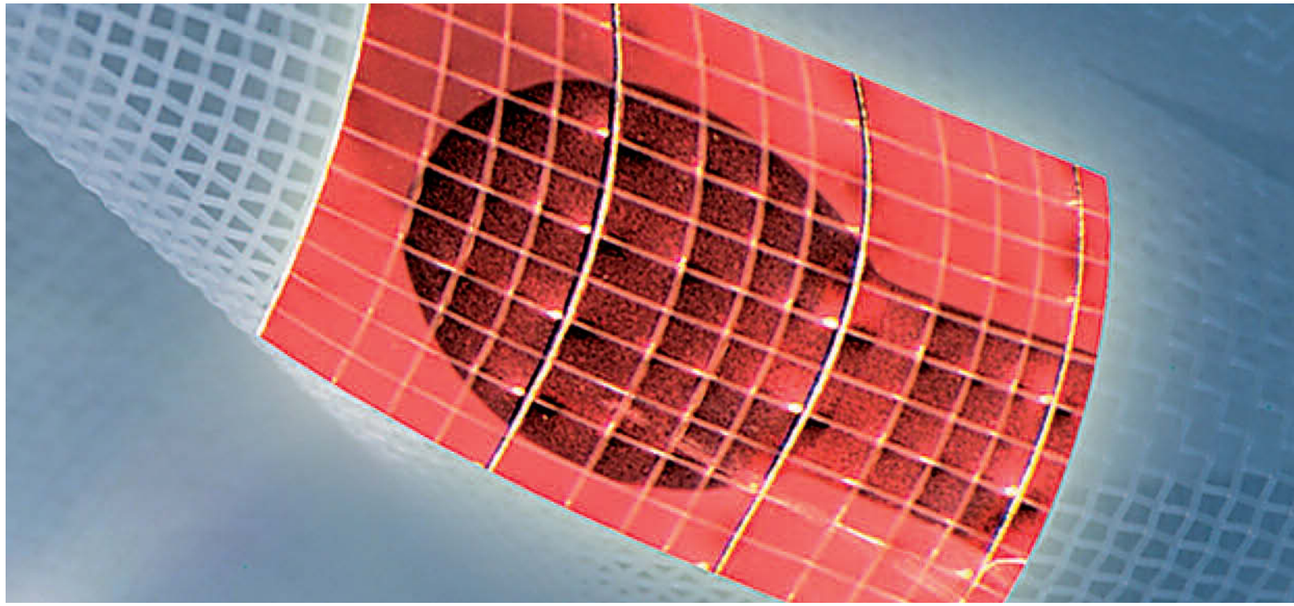
In order to make economic, production-line solar modules a reality as fast as possible, Empa regularly transfers innovations from its laboratories to industrial partners. Empa researchers are, for example, working together with the start-up company "Flisom" to further develop the manufacturing processes and to ramp up production of the high-efficiency cells.

Another Empa research team is using polymers and organic dyes instead of the more "conventional" inorganic semiconductor materials to create the active layers. To cite but one advantage of this technology: it consumes no rare elements such as indium, which is frequently used in conventional photovoltaics.

CIGS-based thin film solar cells developed at Empa are extremely flexible.



Cross-section through the light absorbing layer.



Solar cells made of purely organic materials. The substrate is a flexible, transparent precision-woven polymer. It is electrically conductive because a metal fiber is woven into the polymer. Organic solar cells can be manufactured without using rare elements.
(© Wiley-Blackwell)

KitePower – a power plant takes wing

The development of large kites for harvesting wind energy is currently being pursued vigorously. At higher altitudes the wind blows stronger and more constantly but these heights are out of reach of even the largest wind turbines; 85 per cent of all wind turbines in central Europe operate with a hub height of less than 120 meters. Large kites, on the other hand, can ascend to several hundreds or thousands of meters and are, therefore, capable of exploiting this enormous source of energy.

300

grams per square meter or less is the weight of inflatable kites, based on Tensairity® elements, which will be used to harness wind energy at high altitudes.

To generate power the kite must fly at high speed through a zone of strong wind along a course, which is essentially perpendicular to the wind direction. As it climbs the lift force pulls the kite's tether, causing it to unwind from a drum, which is coupled to an electrical generator, thus producing power. Once the kite has reached a certain altitude its angle of attack is altered to allow it to be pulled down to a lower altitude. Then the kite is trimmed so as to climb again and the power generation phase begins anew.

Tensairity® elements, which are constructed from air-filled membranes combined with struts and cables, have made a name for themselves in the building sector as extremely lightweight support structures capable of bearing heavy loads. The aim is now to adapt this technology to create very light wing structures. The first demonstrator devices with wing areas of up to eleven square meters weighing only of a few kilograms have already demonstrated the

High-tech with altitude! The team completes a successful tow trial with their superlight prototype.

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potential of the Tensairity® technology for wing construction. The next task is to optimize these kites and prove their usefulness under operational conditions.

Testing such large kites can be quite a challenge. Using 3-D image correlation methods the Empa researchers survey the shape of the flexible structure under load. As part of the "SwissKitePower" project, in cooperation with the University of Applied Sciences Northwestern Switzerland, the ETH Zurich and the energy concern Alstom, the Empa kite will be attached to a mobile ground station in order to test its controllability and measure its power output. The behavior of the kite in the wind is also being studied by towing it behind a vehicle the length of a long runway. This allows the scientists to measure the forces acting on the kite's tether, to study the aerodynamic efficiency and to evaluate the deformation of the wings at different wind velocities.

Work on the second generation of the Tensairity® kites, which will have a modified profile and improved aerodynamic properties, is currently underway. Test flights of the new design are planned for fall 2012.

Tensairity® technology put to the test: the load bearing parts of the kite are made of special beams filled with air. In future, kites like this one could be used to generate electric power.

Valuable fuel from a greenhouse gas

Electricity from solar and wind power is expensive to generate, and storing it is still difficult. Problems arise mainly, when there is an excess supply on wind power, which cannot be properly handled by the grid. Yes – one could convert the electrical power into hydrogen right at the power plant. But then you need to store or transport a very volatile gas.

200 – 300

degrees centigrade is the temperature which must be maintained in a mini reactor to convert hydrogen, H_2, and carbon dioxide, CO_2, into valuable methane, CH_4.

To solve that problem, many energy researchers have long been tinkering with an idea that would have made the alchemists of the Middle Ages proud – take a cheap, unwanted gas, e.g the "waste product" CO_2, and with it "transform" hydrogen into a much more manageable energy store. The final product would be valuable synthetic fuel, today called synfuel. The old alchemists' dream – to turn lead into gold – would thus be translated into 21st century terms.

In detail it works like this: A catalyst developed at Empa is intended to bond H_2 and CO_2 into short-chain olefins, such as octane. This hydrocarbon, which is a liquid at room temperature, is best known among car drivers as a constituent of petrol; the "octane rating" is considered a quality characteristic of knock-free petrol. Synthetically produced octane can be used in cars with conventional engines. With it, hydrogen generated with solar or wind power could finally be turned into an easy-to-handle form, and at the same time, the method would bind CO_2.

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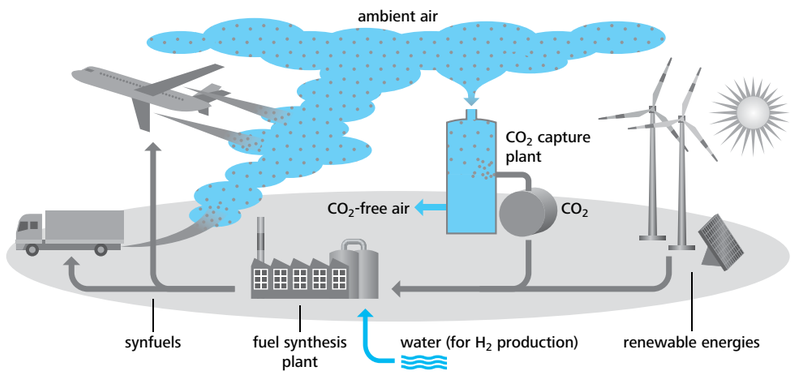
The necessary equipment is now ready for use in a lab at Empa. It's an unimposing, heated metal cylinder about the size of a keg of beer. Mixed with a carrier gas, CO_2 and H_2 flow into the cylinder, where the gaseous mixture comes into contact with a metal hydride, at the moment Mg_2NiH_4.

Although this small reactor has only been in operation since spring 2011, first results are already available. At temperatures between 150 and 350 degrees Celsius, the Empa team was able to produce methane from CO_2 and H_2. They are already postulating about a mechanism. The metal hydride Mg_2NiH_4 gradually decays into magnesium oxide (MgO) and finely dispersed nickel during the cyclic sorption and desorption of hydrogen. CO_2 molecules then accumulate on the nickel particles and, as is desired, are hydrogenated to form CH_4.

Now the team is looking for metal hydrides which are able to build up long-chained olefins like octane. The vision of synthetic fuel made of renewable energies comes closer.



The energy supply of the future? Synthetic fuels are created from environmentally friendly electricity and CO_2 – "synfuels", which can be used to power cars, lorries and aircraft, exactly as is done today. The green-house gas emerging from the exhaust pipe is collected and re-used, thus closing the recycling loop.

The gas produced by the equipment for converting hydrogen, H_2, and carbon dioxide, CO_2, into methane, CH_4, is tested. If the analyzer detects the odor of petrol, then the sought after reaction has taken place!

Diesel exhaust gases – cleaned up with Empa know-how

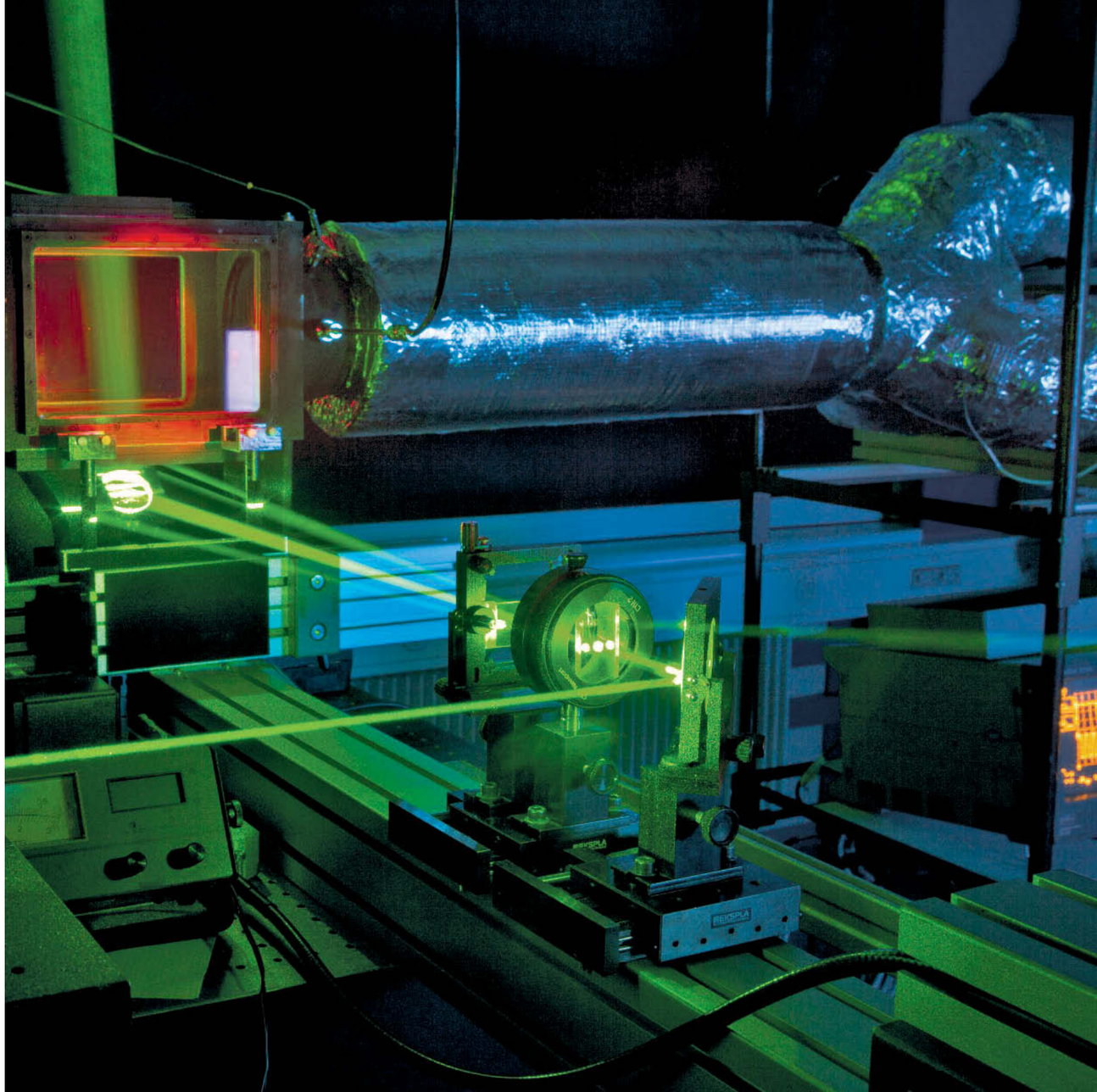
In Empa's "Combustion Engines" laboratory a small team is working on the exhaust gas treatment system of the future for diesel engines, for the benefit of anyone who will take a deep breath at a roadside in 20 years from now. In other words: almost everyone.

500

degrees Celsius is the maximal air temperature in the exhaust gas flow laboratory – the temperature in the tail pipe of a diesel engine operating at full power.

Designed in 2011, the only exhaust gas laboratory in Switzerland of its kind was up and running late last year when it successfully completed a first round of tests. Exhaust gas flow dynamics research will help meet threshold emission values for diesel exhaust, which will become more stringent in the coming years. Primarily medium-sized vehicle manufacturers will benefit from the results, since the complex exhaust aftertreatment processes, which today are only implemented in heavy trucks, have to be fitted in tractors, municipal vehicles and construction machines. Technically and economic efficient solutions are required to be successful on the market. And Empa is helping to deliver.

The new technique is based on urea injection for reducing the emission of nitrogen oxides (NO_x) by modern diesel engines. Urea dissolved in water, commercially available under the trade name "Adblue" in Europe and the US, is injected into the hot exhaust gas. The compound decomposes into CO_2 and ammonia, the latter reducing the nitrogen oxides to nitrogen gas and water vapor. In contrast to the NO_x storage catalytic converters used in diesel passenger cars, the new method does not increase fuel consumption. It does have one



The core of the exhaust gas flow laboratory: air at temperatures of up to 500°C flows into the optical access chamber. A red laser illuminates the spray, while a high speed camera records the trajectories of individual droplets. Simultaneously a green laser measures the droplets' velocities.

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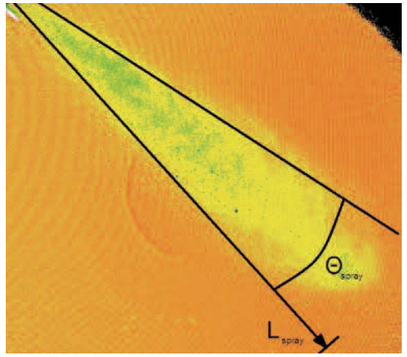
drawback, though: if too little Adblue is injected into the exhaust flow the nitrogen oxides are only partly reduced. Should, on the other hand, the additive dosis be too high, then the excess ammonia (which is toxic) is emitted with the exhaust gas, causing a pungent, unpleasant smell to the ambient. To avoid overdosing, all current exhaust treatment systems are tuned to be on the safe side using only 60 per cent of the required Adblue amount.

This is exactly where Empa's exhaust gas flow laboratory comes into play. Researchers are using the 10 meter-installation in the Engine Building to investigate how the Adblue solution can be mixed with the exhaust gas as efficiently as possible, how much Adblue one would have to add (depending on the engine operating load and speed) and how emissions can be optimized with the least technical effort.

In 2012 the Empa scientists will concentrate primarily on spray and fluid dynamics. Their goal is to establish a systematic scientific method that will allow small and medium-sized vehicle and construction machine manufacturers to design exhaust gas aftertreatment systems "from a recipe book", as it were, to best suit their own engines and requirements. This is the only way to ensure that future emission targets will be met.

A Swiss company, which intends to benefit from the results, already has a joint project with Empa. In the initial phase of the project, measurements will be made using hot air or artificially generated gas mixtures. Later on, however, a commercially available diesel engine will be used to ensure that the novel catalytic converters are tested under real-world conditions.



A spray image as recorded in the flow laboratory: the sizes of the droplets and the length of their trajectories can clearly be seen. The aim is to reduce nitrogen oxides in diesel emissions by adding exactly the "right" amount of Adblue solution.

The laser brings it to light: the "isotopic signature" of CO_2

It is not just the burning of fossil fuels that creates carbon dioxide (CO_2), but also the respiration of humans, animals, plants, bacteria and other living creatures. But one carbon dioxide is not the same as another: CO_2 molecules originating from combustion processes differ from their biological "siblings" in their isotopic signature, their carbon and oxygen atoms having different masses. A quantum cascade laser spectrometer developed by Empa, together with the US company Aerodyne Research, can detect and continuously measure these isotopes. For quite some time now none has been operating on the Jungfraujoch, measuring the CO_2 concentration in the atmosphere and deciphering its isotope signature. A sample of gas is fed into the measurement cell of the spectrometer where it is analyzed based on the absorption of a quantum cascade laser beam. The photons being absorbed by the sample do not reach the detector and are registered as "missing". When the CO_2 isotope measurements are combined with those of other atmospheric pollutants as well as with weather models, the geographical source region of the gases can be identified. The quantum cascade lasers spectrometer is equally suitable for medical applications, since it can detect different isotopes in the breath of a patient, indicating a bacterial infection of the stomach – frequently a precursor to stomach cancer. Moreover, the measurement technique can also be used to analyze numerous trace

10^{-8}

per cent is the fraction of CO_2 with the (rare) ^{13}C isotope, which can be measured in ambient air with Empa's quantum cascade laser spectrometer.

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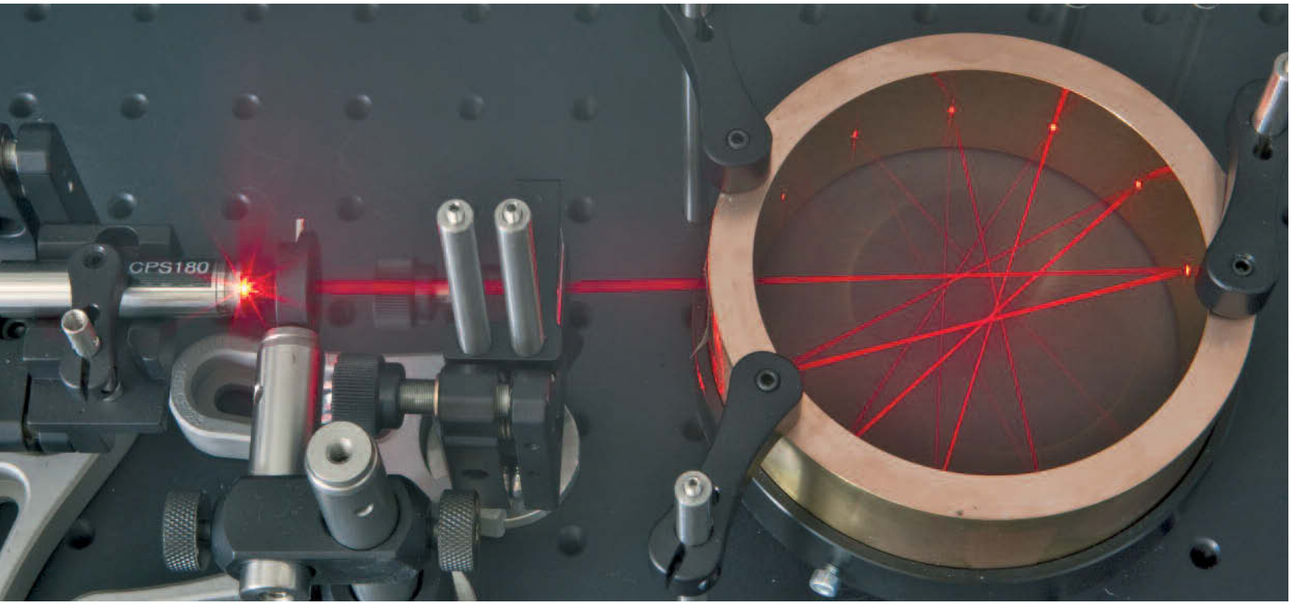
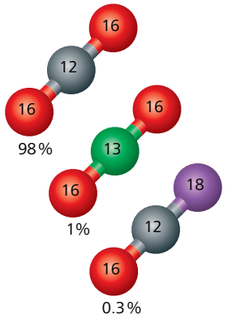


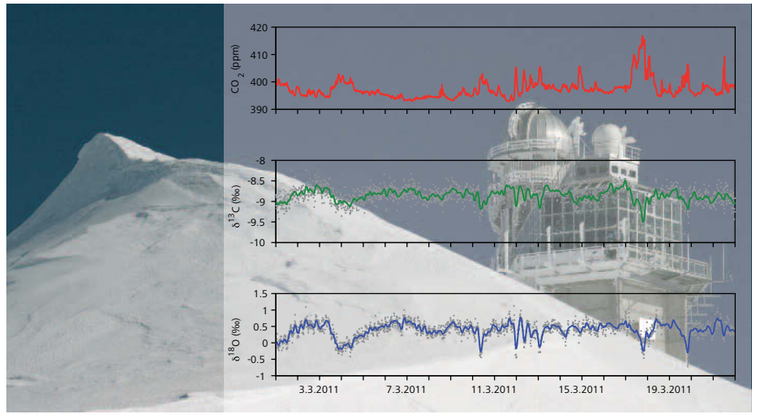
The new instrument, which is based on a quantum cascade laser, allows the user to analyze the isotopic composition of trace gases. The heart of the system is a measurement cell, the walls of which reflect the laser beam back and forth many times, allowing very sensitive measurements to be made.

gases. In the semiconductor industry, for example, it would be useful for process analysis, and the food industry could apply it to determine the ripeness of fruit.

The quantum cascade laser instrument offers a number of advantages: it is more accurate and more economic than today's gas analyzers – and faster. Empa is currently developing, with various partners, a more sensitive instrument, which will quickly and selectively measure numerous trace gases. It will also be small (no bigger than a shoebox), mobile and easy to use. Whilst Empa is responsible for the spectroscopy and the construction of the instrument, EPF Lausanne will supply electronic components, ETH Zürich is responsible for the light source, the University of Neuchâtel for the detector and the University of Applied Sciences of North-West Switzerland for the control and data processing systems.



CO_2 consists of one carbon (C) and two oxygen (O) atoms, which both occur in nature as different isotopes. At 98%, the most common combination of CO_2 is made of ^{12}C carbon and ^{16}O oxygen.



Measurements on the Jungfraujoch: simultaneous changes of the CO_2 concentration and its isotopic signature ($\delta^{13}C$ and $\delta^{18}O$) are due to the exchange of ambient CO_2 with soil surface and fossile fuel burning.

Real smart: protective clothing with built-in A/C

Functional sportswear is taken for granted nowadays. It is quite unexceptional for a sports jacket, for instance, to be both waterproof and breathable. In the case of working clothes, the functionality is mostly restricted to personal protection against fire, sharp objects, chemicals and so on, with wearer comfort (mostly) not being a top priority. Bullet-proof vests made of Kevlar, as their name suggests, hold off bullets but they are also impenetrable for water vapor. Thus police personnel who must wear such gear under their uniforms sweat profusely when the weather is warm. A situation that is merely uncomfortable when working in the office negatively affects the physical performance of police officers on duty.

544

grams is the weight lost through perspiration by a person wearing the new "smart" protective jacket with integrated air conditioning system during a lab test. In a conventional jacket it would have been 735 grams.

Empa has, therefore, together with its industrial partners, developed a "smart" protective vest with an integrated cooling system based on the Coolpad technology, originally designed for use in cooling garments for medical applications. The Coolpads built into the vest are filled with water, which is allowed to evaporate through the membrane, cooling down its surroundings. A mini fan blows air though a fabric spacer behind the pad, providing further cooling.

The ballistic vest to be worn under the uniform shirt with integrated "air conditioning unit", for use by police personnel, for example.

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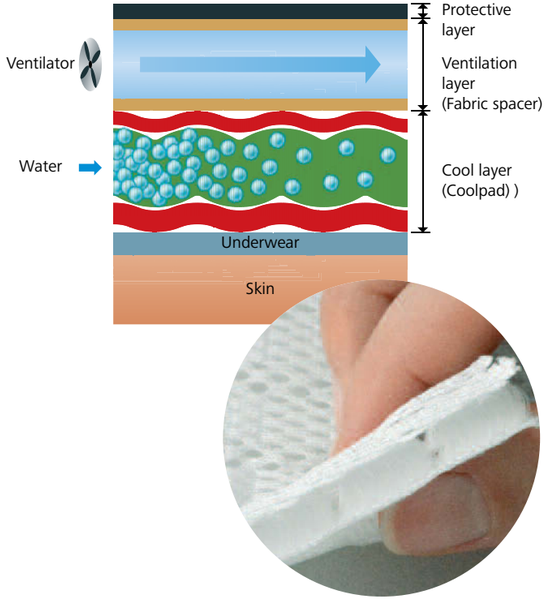
Integrating such an A/C into a garment proved to be quite tricky. It required a novel fabric spacer, which was stable under pressure yet also flexible and soft to the touch, and which offered very little resistance to air flow. A suitable spacer was developed together with Swiss textile manufacturer Eschler. Likewise, there were no fans on the market which were small enough to be built into the vest; so Empa engineers designed a miniaturized version themselves. Two units including batteries and control electronics now provide the cooling air circulation in the vest. Similarly, the cool pads used earlier proved unsatisfactory – since in the protective vest they were mechanically stressed they frequently leaked water. A new technique for welding the ultra-thin pad membranes using diode lasers proved to be much more reliable than the conventional method, with the seam remaining soft and flexible. In addition the Empa specialists were able to increase the evaporation rate and therefore the cooling ability.

But that wasn't all. In order to simplify refilling the cool pads with water they developed a portable filling station that can be attached to the vest with a quick-release fastener. During the same "pit stop", the mini fans can be exchanged for those with freshly charged batteries. Then the vest is ready once again for three to four hours of duty.



A multilayer system provides active cooling, including ventilation through the fabric spacer (round image).

Comparative measurements show that the new vest is significantly lighter and also cools much better than systems currently on the market. And in practical use, too, the vest has proven its worth. Staff of the Zurich City police force tested the vest over several warm summer days and gave the new innovation the thumbs up. The first small series of the novel under-uniform protective vest will be produced in the near future by project partner Unico swiss tex GmbH. The "smart" cooling technology is, however, also suitable for protective suits worn over normal clothing, uniform jackets, camouflage suits and even for rucksacks. Developments along these lines are already in progress.

The bullet-proof vest is cooled by a water-filled Coolpad and a mini fan, which blows air through the ventilation layer – ensuring that the wearer remains comfortable.

The FIB – microscope and workbench, all in one

Imaging techniques are widely used in materials science. Empa, too, has various instruments to visualize objects under investigation, for instance ultrasound, thermography and X-ray systems, electron microscopes, atomic force microscopes and so on. For some 10 years now the institute has also been operating "Focused Ion Beam" (FIB) systems, which function in a similar way to the scanning electron microscope. The difference is that, instead of an electron source in the case of the microscope, the FIB harbors a gun firing gallium ions, which knock electrons and atoms out of the sample. These secondary particles (and also scattered primary particles) are detected, providing information on the topography and material characteristics of the sample surface. As in a TV screen, the beam of ions scans over the sample in a raster pattern, generating an enlarged overall picture, point by point and line by line.

0.35

nanometers is the resolution in images made with the Focused Ion Beam (FIB) system, using helium ions.

The advantage of using gallium ions instead of an electron beam lies in the significantly higher mass of the ions. Researchers can use the FIB not just to image the surface of a sample, but also to remove entire layers from it as well as to assemble nanostructures on it.

In the latest development of FIB technology, a beam of (lighter) helium ions is used rather than gallium. This allows the user to create images with a previously unachievable spatial

Empa's new helium-FIB instrument, commissioned in autumn 2011, opens up new opportunities in the field of nanotechnology.

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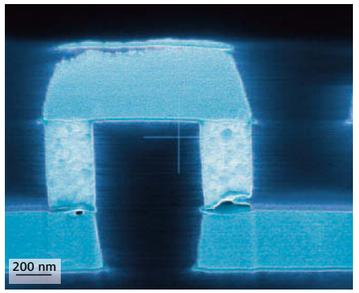
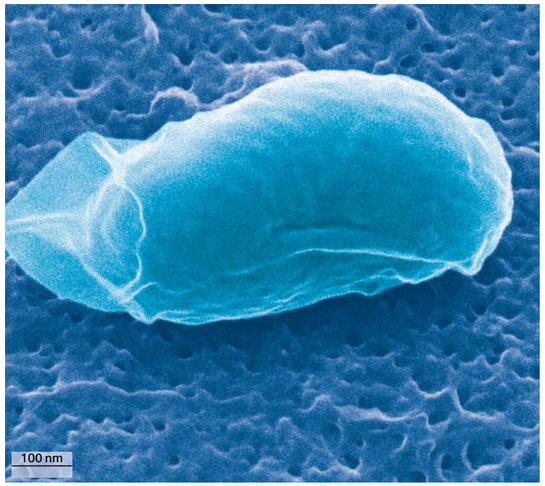
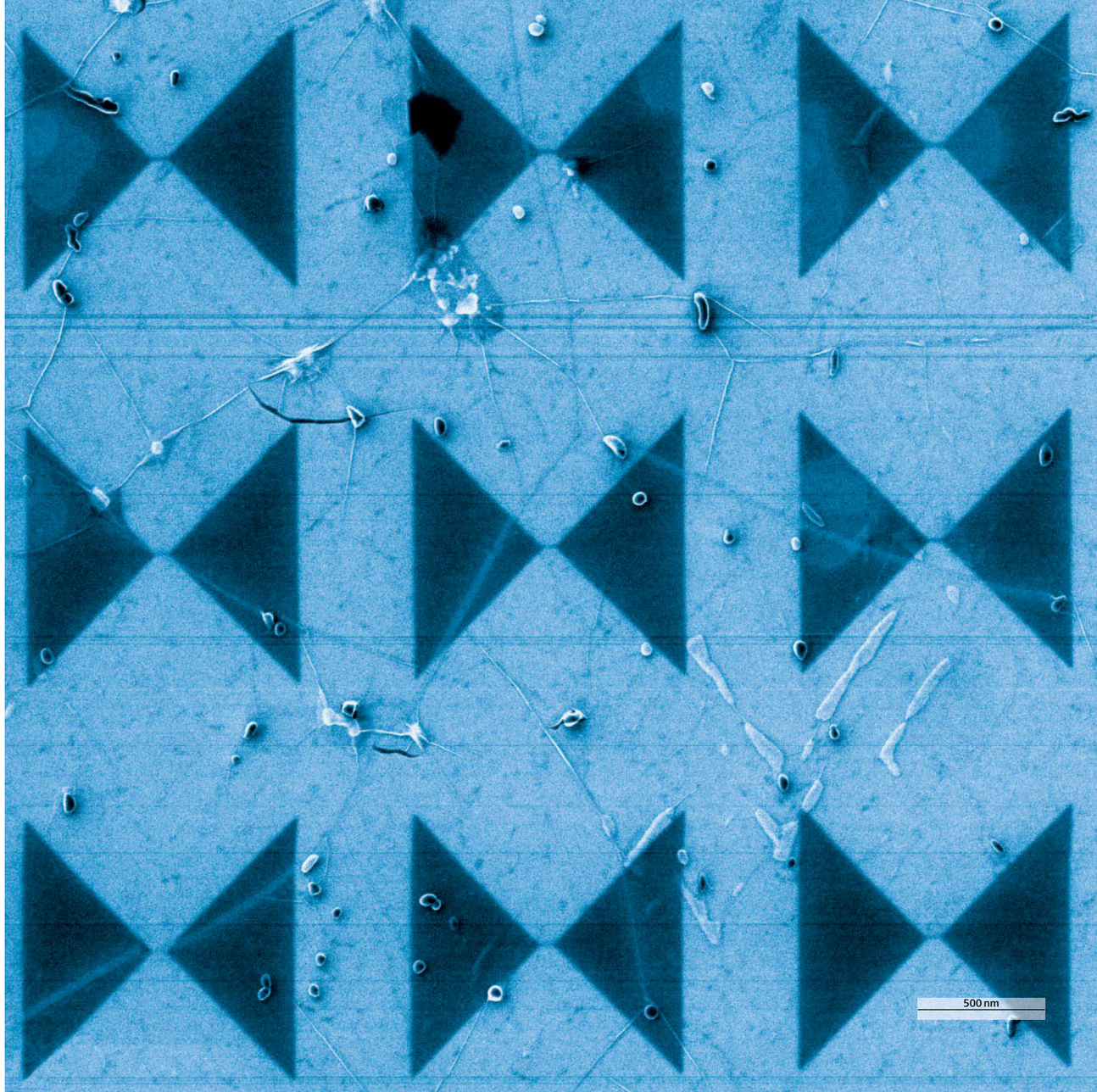
resolution of 0.35 nanometers as well as a significantly improved contrast. By comparison, an FIB using gallium ions achieves a resolution of between 5 and 10 nanometers. An additional benefit is that, for any given acceleration voltage, the helium beam penetrates more deeply into the sample.

Taken together, this represents enormous progress, particularly for nanotechnology applications. The helium-FIB is ideally suited, for example, to investigate ultra-thin layers in microelectronics and materials science. One such material is graphene, made up of single layers of carbon. Because of its unusual electronic properties it is viewed as a possible substitute for silicon in the semiconductor industry. Recently, Empa began operating one of these new helium-FIB instruments – the first (and to date the only one) in Switzerland – thanks to the financial support of the SNSF. It is already being used by several research groups from Empa, the ETH Zurich, the Universities of Zurich and Basel, and the PSI.





High-resolution images taken with the helium-FIB instrumen: **left:** failure analysis in micro- and nanoelectronics; **center:** a bacterium for bioleaching (sample from Brandl/Fabbri, University of Zurich); **right:** graphene structure that had been "shaped" using FIB.



NEST – for the building of the future

It's probably the most ambitious research project in building technologies in Switzerland: NEST. The modular "building laboratory" located in the heart of the Empa campus in Duebendorf will be a demonstrator for the sustainable building technologies, systems and materials of tomorrow. It is here that everything and anything which dare not be attempted elsewhere can be tested: the newest Plusenergy modules, entirely renewable materials, fully automatic building control systems remotely controlled via iPhones, and so on and so forth. Whatever proves its worth will find its way onto the market; the failures will be replaced after one or two years by other modules – "plug and play" in a civil engineering context.

Use-inspired Research
Innovative Developments
Knowledge & Technology Transfer
Services & Expertise
Advanced Training & Education

NEST – constructional high-wire act with a safety net

Doing experiments with buildings? Many building experts would shake their head in dismay. Visionary concepts are not welcome in the industry – after all buildings have to function and to generate income as soon as construction has ended. That is what the owners demand, and it doesn't leave much room for innovative thinking. Which is exactly what the NEST research project, a joint initiative from Empa, Eawag, ETH Zurich and EPF Lausanne, intends to make possible. Modular building compartments will house the experiments, and when an idea doesn't work the module will simply be exchanged for another. This means that visionary concepts can be given a fair trial, while limiting any risks involved.

600
square meters of usable area are available for experiments on each of NEST's five floors.

The design is already being elaborated. A reinforced concrete core built around a central staircase will create the backbone for the "building laboratory". The experimental modules will be "plugged" into this core structure. This is where visionary and pragmatic ideas, modernistic and traditional living concepts will lie cheek by jowl. A fully ecological, self-regulating, passive living module constructed entirely from natural materials might perhaps sit next to a low Minergie-A module with vacuum insulation panels and walls of carbon fiber honeycomb, fitted with the latest heating and ventilation electronics, all controlled via smartphone, and boasting a photovoltaic-based active sun screening system, which provides shade in the middle of the day while at the same time delivering energy.

Virtual image of the NEST staircase with the cafeteria in the background.

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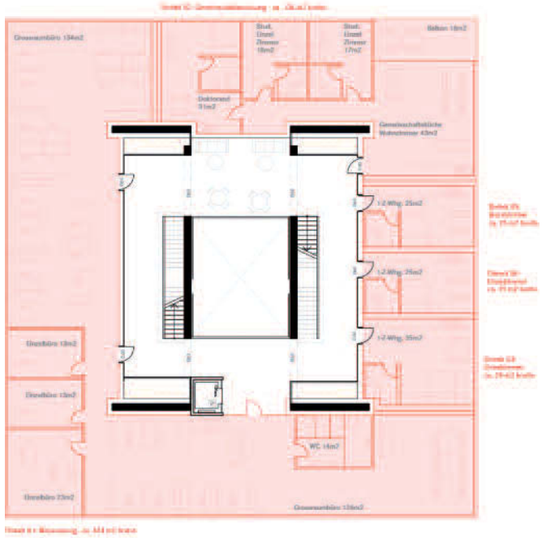


NEST floor plan. Each platform makes available over 600 square meters of usable space. The staircase, lift and service ducts are integrated into the inner core.

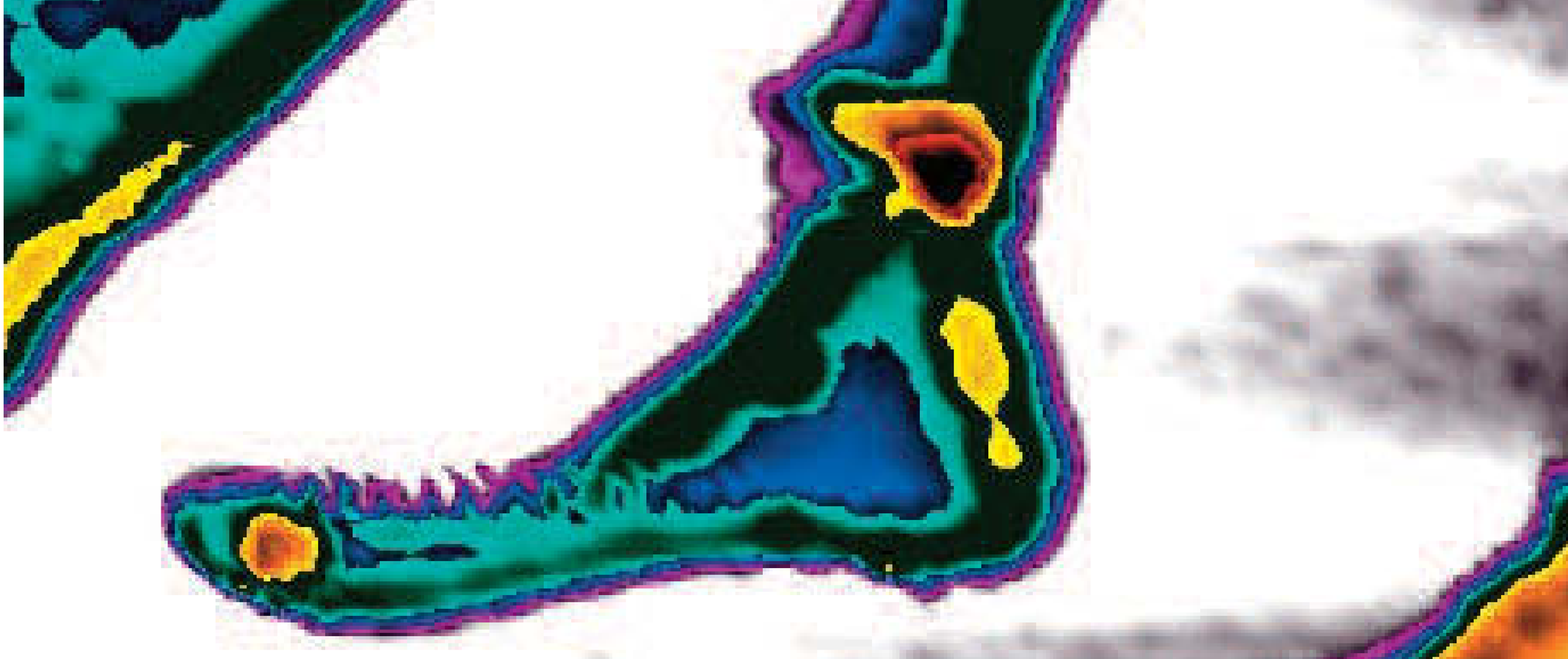
Of course, a selection of purely showcase modules would have little scientific significance. That's why the intention is for people to actually move into NEST and report on their experiences. Plans call for mixed usage, with large open-plan offices, conference rooms and apartments, for example studios for doctoral students and maisonette apartments, built using lightweight techniques, for guest scientists and their families. NEST tenants will thus have the chance to experience how the buildings of the future will affect the people who live and work in them.
In contrast to "normal" buildings, mistakes are allowed in NEST. Researchers can dare to try out what is not possible anywhere else, since the modules will be replaced after some time. This enables constructional experiments with a manageable level of risk.

The central core of reinforced concrete, which provides services and media to the temporary modules, is a long-term investment in building research and will be usable for decades to come.
Empa intends to hold competitions to encourage innovative ideas for the various project phases. Topics such as "building automation vs. passive climate conditioning" are conceivable; variations on the theme of renovating older buildings could be studied. And because each module is connected to the core structure with a type of umbilical cord, it will be possible to record and accurately compare the flow of thermal energy, the need for chilled air in summer, and power and water consumption. NEST should also attract international research projects because – quite simply – there is currently no other "building laboratory" like it in the world. It will be globally unique.
At the moment what is probably the most ambitious civil engineering project in Switzerland exists only on paper. Currently, detailed construction plans are being finalized for the backbone, which will be submitted for approval by mid-2013 if everything runs on schedule. At the same time, the search is on for industrial partners in Switzerland and abroad who wish to be part of the first round of experiments.

NEST at various configuration stages. The research modules can be installed and removed independently of one another.

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, Materials for Energy Technologies, Sustainable Built Environment, Nanostructured Materials – Empa combines the interdisciplinary know-how of its 29 research laboratories to create practical solutions for industry and society.



Use-inspired Research
Innovative Developments
Knowledge & Technology Transfer
Services & Expertise
Advanced Training & Education

Innovative materials for a healthy future

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The influence humans exert on their environment, and on themselves, is reaching ever greater levels. Climate change and ozone depletion are two examples of the more serious consequences, increasing life expectancy is another. As a result, in its Research Focus Area "Health and Performance", Empa is developing solutions to environmental problems and for the health care sector: innovative materials and technologies that contribute to providing a high quality of life and to maintaining good physical health for as long as possible.

Mannequins" modeled after the human body are used for such purposes as studying humidity and heat transport through fabrics.

High-tech models for the human body

More and more people are exposed to extreme conditions, both professionally and in their leisure time. It is not just the practitioners of extreme sports who expect their clothing to be "functional" – in particular firefighters, members of the police department and the rescue services depend on garments, which simultaneously offer protection (for instance against fire or projectiles, see p. 46) as well as comfort, either by virtue of their light weight or through advanced humidity and temperature management capabilities. In this context Empa is developing cutting-edge physiological measurement systems and a range of sensor-studded "mannequins" – models of the human body, which are unique worldwide.

"Conveying" novel functions to textiles and fibers

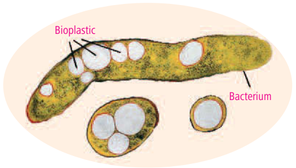
Whatever material we wear on our skin, it must perform various functions. Frequently clothing is made of fabric fitted with different polymers and composite membranes, woven from composite fibers and designed to produce certain desirable characteristics by creating new structures, for instance with nanoparticles. Empa is, for example, working on a system for the controlled dosage of medication via textiles, as well as on light transmitting or electrically conducting fibers, which can be exploited for therapeutic purposes or for monitoring bodily functions.

Fibers and fabrics can also be lent new properties by the use of additives, such as flame retardants for clothing and home textiles. Empa has developed completely new, environmentally friendly flame retardants, which are suitable both for polymers as well as for other materials. Based on a combination of phosphorous, silicon and nitrogen compounds, the new flame retardants should in future replace older substances, which are damaging our environment.

Environmentally friendly flame retardants: sought worldwide, developed at Empa.

Biocatalysis – a perfect example of GreenTech

In the framework of the Swiss Cleantech master plan, biological methods (amongst others), which simplify synthetic processes, require less energy and do not use toxic solvents, will be of great importance. Empa is investigating how to best use and further develop biocatalysis, a method that uses enzymes to perform chemical reactions. Biocatalysis is a "green" technology, since enzymes are produced from renewable resources – generally bacteria or other single-cell organisms – and are themselves biodegradable. Moreover, these "manufacturing tools" can be optimized in the lab by "protein engineering". The advantages are obvious: what chemists can only achieve with a high expenditure of materials and energy can now be performed by enzymes at room temperature, without solvents, often with higher yields – and without unwanted by-products. As an example, Empa is using biocatalysis to improve wood treatment processes.



Bacteria and other biological systems can be used to produce large quantities of certain polymers, so-called biopolymers.

New building technologies thanks to research with practical relevance

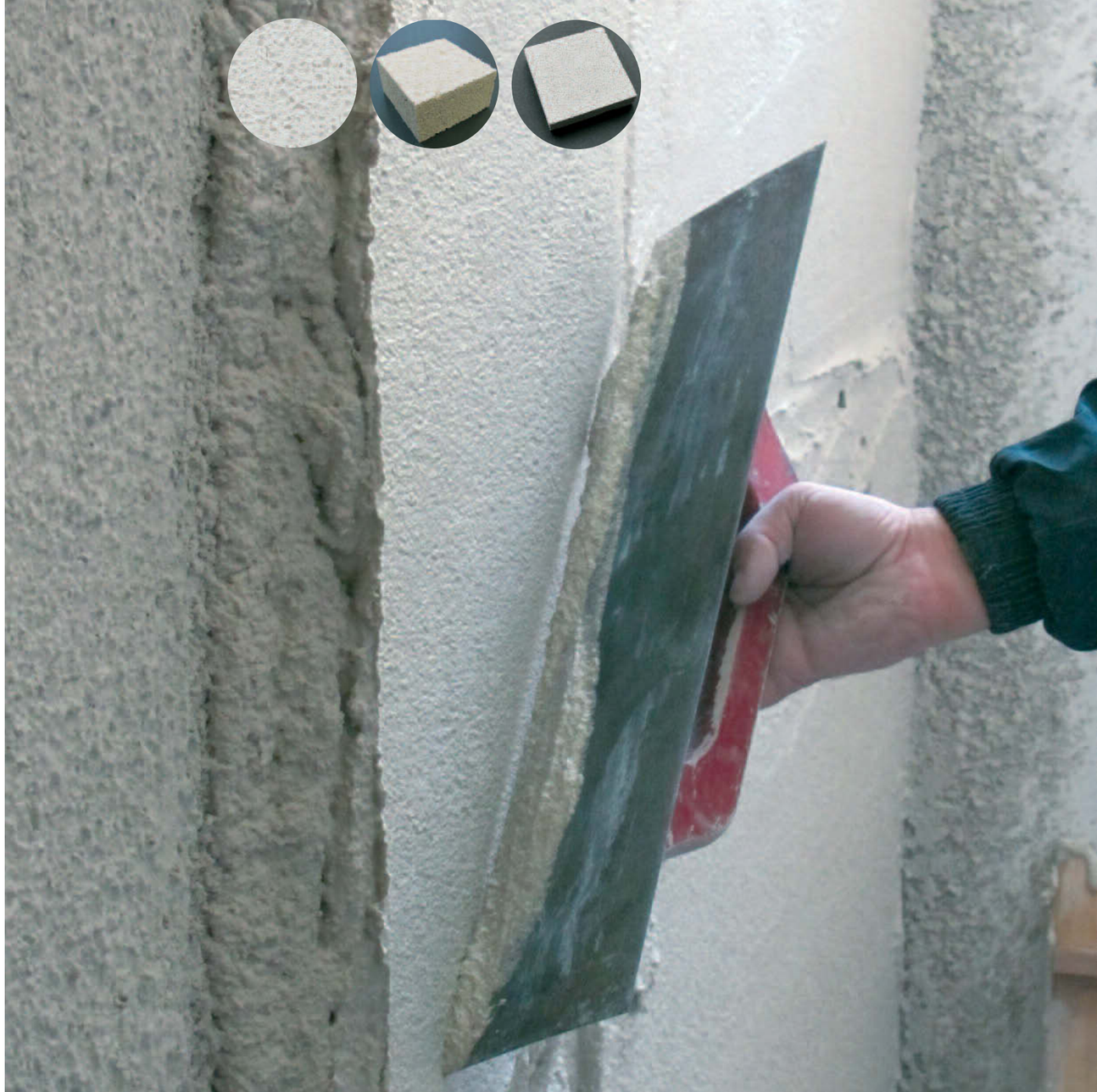
In the wake of the earthquake catastrophe in Japan discussions about a safe and sustainable energy supply have further emphasized the significance of the built environment for the development of our society. Performance, efficiency and security are key terms by which the quality of our built environment is measured. Empa’s Research Focus Area “Sustainable Built Environment” treats this topic in an interdisciplinary fashion at the interface between scientific research and engineering.

The future development of civil engineering in Switzerland and in other industrialized countries faces a range of challenges, including among others:

- reshaping and optimizing the existing building stock in order to reduce energy consumption and greenhouse gas emissions,
- adding value to existing buildings by taking constructional measures to ensure that they meet current and future requirements in terms of comfort and design, and
- maintaining the infrastructure required for mobility, energy and water supply by appropriate maintenance and renewal.

Air is an insulator – in historical buildings too!

Together with industry, Empa has developed a novel Aerogel-based insulating plaster, which shows great potential in the renovation of the thermal insulation in traditional build - ings. In these historic buildings it is often important that the appearance of the facade remains unchanged. However, this also means that fitting a layer of thermal insulation to the external walls is not an option. On the other hand the existing plaster can be replaced by



Made possible by nanomaterials – Aerogel-based insulating plaster. Its thermal conductivity of less than 30 mW/(m K) lies below that of any other conventional insulating material. Plaster enriched with nanoporous Aerogel granulate is spray-applied and then levelled.

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an innovative Aerogel material, which boasts a significantly lower thermal conductivity than conventional insulation materials. In addition to being permeable to water vapor (i.e. it "breathes"), it is of mineral origin and therefore also suitable for indoor use (see p. 88).

Noise absorbing and transparent

Besides architectural design, critical factors for human comfort in our living and working environment are air quality, temperature, relative humidity, illumination and acoustic properties. The latter two points in particular are often neglected. Daylight is essential for our metabolism and rooms with long reverberation times make conversations very difficult when several people try to speak at the same time. Through a clever combination of computer simulation coupled with special textile knowledge and acoustic measurements, an interdisciplinary project has succeeded in creating sound-absorbing curtains, which are also transparent (see p. 28).

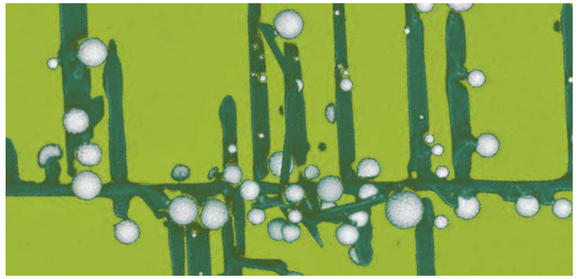
One of Empa's meeting rooms has already been fitted with the new sound-absorbing curtains.

International conference on the Persian Gulf

One of Empa's traditionally strong fields of research is the monitoring and reinforcing of existing structures. The institute has earned an outstanding international reputation in this area, so it was very appropriate that it organized SMAR 2011, the First Middle East Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, together with the American University in Dubai (AUD). The conference attracted more than 300 participants from 30 countries (see p. 94), and plans are already being made for the next event in the series to be held in Istanbul.

"Borderline experience" on the nanoscale

Targeted and controlled exploitation of nanoscale effects and phenomena is today the basis for developing materials, coatings and surfaces with improved, tailor-made or novel properties. Critical factors for success are scientific excellence in physics and chemistry, necessary to understand and master events occurring on a molecular and atomic level, combined with engineering "magic" required to create the desired materials using appropriate manufacturing techniques. In its Research Focus Area "Nanostructured Materials", Empa pools these essential competences, thereby strengthening its innovative capabilities in the development of new materials and technologies.



Golf-ball like droplets of the metal catalyst form on ceramic fibers, which grow during the manufacture of aluminium oxide composite materials via fusion infiltration.

The last frontier of materials science

Tackling nanoscale phenomena in the context of materials science and development means pushing up hard against physical and technological limits. Rationalizing and explaining these effects will yield results and insights, which are essential for the successful development of nanotech materials and technologies. The smallest "electromobile" in the world, a molecule which can be set in motion through electron injection (see p. 12), or the first complete 3-D reconstruction of the atomic structure of a nanoparticle with a transmission electron microscope (TEM, see p. 15) are exemplary for pushing the final frontier in materials science, with which Empa scientists have attracted a great deal of international attention over the past year.

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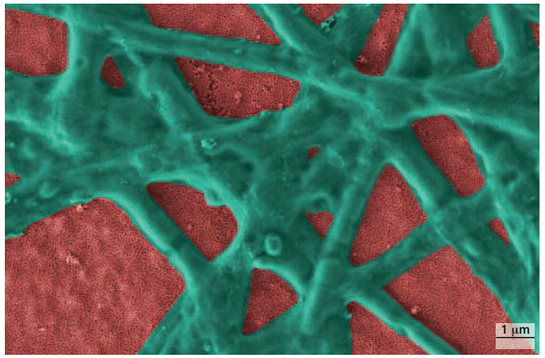
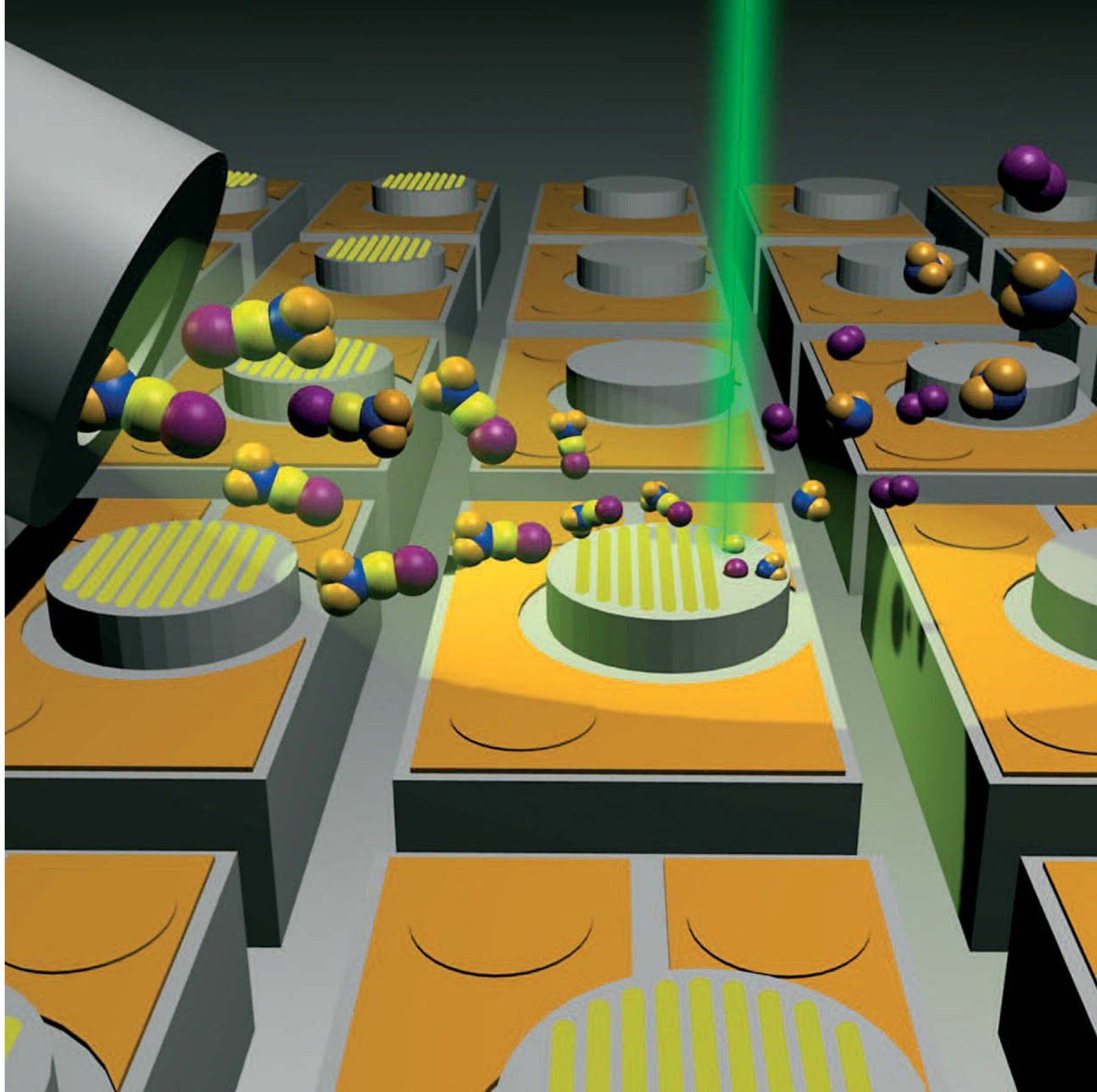
Applications in sight

One of Empa's great strengths is its ability to swiftly convert newly gained competencies and results from fundamental research into application-oriented projects of use to industry. For example Empa researchers have, together with colleagues from the EPF Lausanne, utilized the "Focused Electron Beam Induced Processing" (FEBIP) method to create fine polarization gratings on the surface of VCSELs (Vertical Cavity Surface Emitting Laser), a type of semiconductor laser. These gratings improve the stability of the polarization of the emitted laser light, hitherto a weakness of these devices, which are frequently used for data transmission.



Surface coating of hematite nanoparticles (red) with a network of phycocyanin proteins (green). (E. Vitol, Argonne National Laboratory)

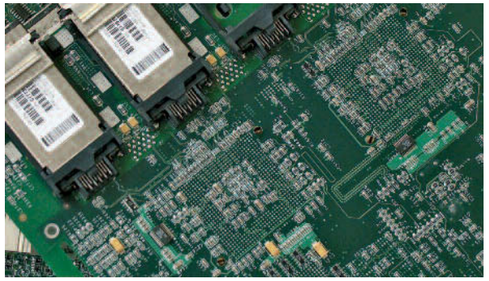
Another very promising application for nanomaterials are electrodes for photo-electrochemical cells (PECs). These devices are used to split water directly into hydrogen through an electrochemical process powered by solar energy. In collaboration with colleagues from the University of Basel and the Argonne National Laboratory (US), Empa specialists succeeded in developing a completely novel "nano-bio" electrode with twice the efficiency of conventional iron oxide types. The new electrodes consist of iron oxide nanoparticles (hematite, alpha-Fe_2O_3) rendered functional by a layer of phycocyanin, a protein obtained from blue algae, which serves as a sun collector for the cells' photosynthetic machinery. The new electrodes have proven to be extremely stable even under harsh alkaline operating conditions.



Electron beam-induced local deposition process to create polarization gratings on semiconductor lasers: metal-organic gas molecules are decomposed in the highly focused electron beam, which leads to the deposition of the resulting nonvolatile compounds on the target surface.

Metals, motors, measurements – in the cross-hairs for the environment

The Research Focus Area “Natural Resources and Pollutants” makes a significant contribution to achieving environmental targets, including the reduction of both the usage of resources and the emission of pollutants. This is a question of using materials and energy more efficiently, finding substitutes for critical raw materials and effectively treating exhaust air and waste water before releasing it into the environment.



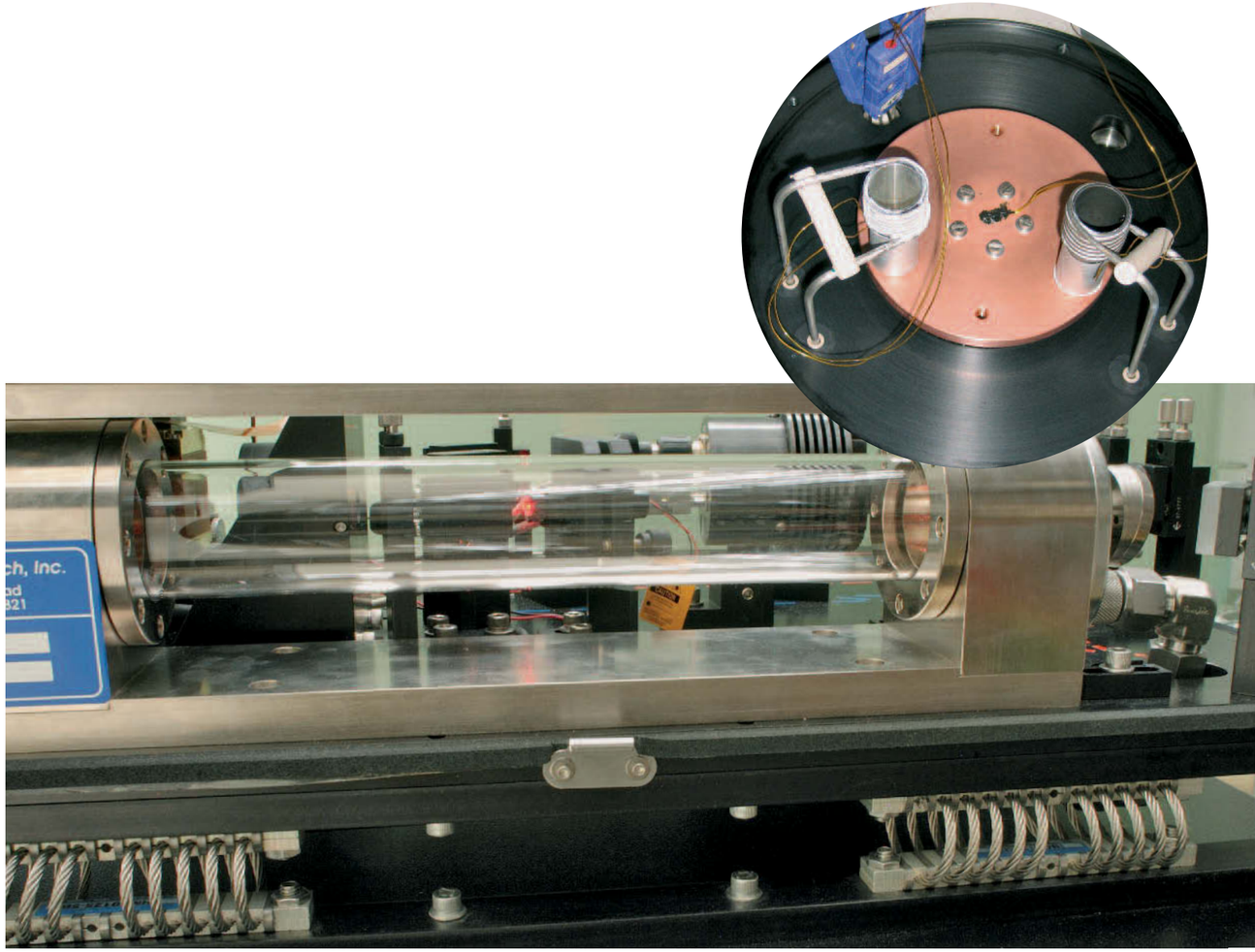
Scarce metals are being recovered from waste electrical and electronic equipment (WEEE), among other sources.

The rarer the metal, the more important its recycling

Metallurgical reactors play an important role in the primary and secondary production of rare metals, and therefore also in the closing material cycles. Umicore Precious Metals Refining (UPMR) operates one of the world's largest plants for recovering rare metals from inter alia electrical and electronic appliances in Hoboken, Belgium. In a cooperative project with Empa, the environmental impacts associated with the processes involved have been quantified, and important questions about the modeling of complex, strongly interlinked metal flows in a metal refinery could be clarified.

Efficient vehicle engines

The efficiency of petrol and gas engines falls drastically when operated at low loads, a situation that occurs frequently under normal driving conditions. One reason for this is that



N_2O is adsorbed at low temperatures (–160°C) and concentrated (small picture) before the individual isotopes in the sample are analyzed by a laser spectrometer.

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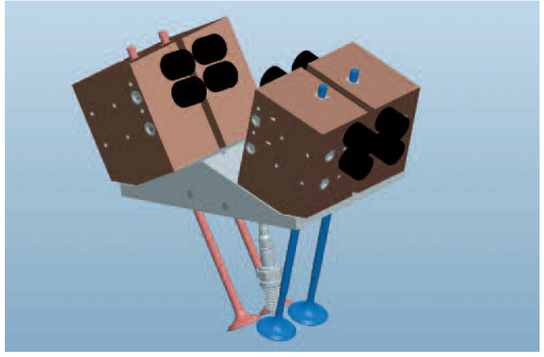
the motor load is controlled by throttling the intake air flow to influence the amount of air going to the engine. This results in a dissipating pumping loop in the gas exchange phase of the engine cycle. Empa is currently developing a new fully flexible electrohydraulic gas exchange valve actuation system, which needs no more energy than a conventional mechanical valve train. This is done by hydraulically recovering the kinetic energy of the valve during the valve braking phase. A fully flexible gas exchange valve actuation makes it possible to control the engine load individually for each cylinder by setting the valve closing time instead of throttling the airflow to the entire engine.



Empa has developed a particularly efficient electrohydraulic valve control system, which recovers the kinetic energy of the valve and stores it temporarily in a hydraulic reservoir. The fully variable valve control replaces the conventional butterfly valve in the engine air inlet. That saves fuel.

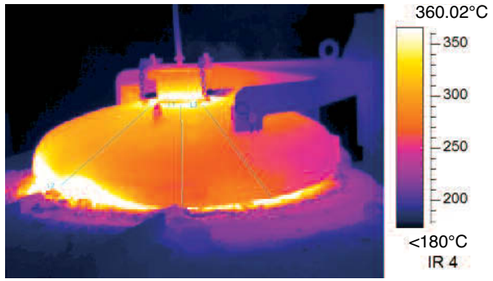
Lower greenhouse gas emissions due to a novel measurement technique

The successful coupling of quantum cascade laser spectroscopy with an automated concentration unit for trace gases has led to the world's first quasi-continuous analysis system for measuring the various N_2O isotopes in the atmosphere. One source of this greenhouse gas is, for example, wastewater treatment where microbial processes generate N_2O with specific isotope patterns – or molecular signatures. In a project with Eawag, the water research institute of the ETH Domain, the new measurement technique is being used to optimize the nitrification and denitrification processes used in wastewater treatment so as to minimize greenhouse gas emissions.

In the area of exhaust air treatment Empa commissioned two new research facilities in 2011: a wind tunnel to investigate the behavior and removal of nanoparticles from air streams (see p. 18) and a flow laboratory to study two phase flows at temperatures of up to 500 degrees Celsius (see p. 40).

New energy policy – intelligent approaches are called for

The Swiss government's new energy policy, which foresees the gradual phasing out of nuclear energy, calls for new concepts and ideas in the fields of mobility and construction, two core areas of Empa's energy research. New materials and innovative technologies will make an essential contribution to this task.



Demonstrator project to evaluate the conversion of waste heat to electricity at the vonRoll casting plant: as is the case with internal combustion engines, in foundries and casting plants too, more than two thirds of the input energy goes to waste. A project supported by the Swiss Federal Office of Energy (SFOE) aims to recuperate this energy (at least partially) and use it to directly generate electricity. This is accomplished by thermoelectric converters, which are installed on hot surfaces such as the lid of the furnace and along the length of the production line.

From (waste) heat to electricity – thermoelectric generators

Empa has developed stable and environmentally friendly thermoelectric materials, which are based on widely available (and therefore economically priced) raw materials such as zinc, titanium and manganese oxides. They are used to create high-performance, high-temperature converters, for instance for the recovery of waste heat in industrial processes, in automobiles and in solar-thermal converters.

New world record in efficiency for solar cells

Empa's "Thin Films and Photovoltaics" laboratory specializes in the development of highly efficient yet affordable thin-film solar cells. The team has managed to develop and optimize a process for manufacturing highly efficient CdTe cells using low deposition temperatures (i.e. below 450°C). With glass as a carrier material the devices had an efficiency of 15.6 per cent, and when flexible polymer film was used as a substrate this reached a record

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value of 13.8 per cent. Flexible solar cells based on copper indium gallium diselenide (CIGS in short) likewise showed a record-breaking efficiency of 18.7 per cent (see p. 31).

Synthetic fuels "from the sun"

The hydrogenation of CO_2 on metal hydrides is a research project coordinated by Empa with partners including the Paul Scherrer Institute (PSI), the EPF Lausanne and Stanford University. The research team is looking for new, more efficient methods of manufacturing a synthetic fuel ("Synfuel") from renewable energy and CO_2, the prototypical greenhouse gas. The new fuel could be used in conventional motors and aircraft engines (see p. 37). In addition a research project into the direct photo-electro-catalytic splitting of water using solar energy has just started.

Energy of the future? Chemically bound carbon dioxide, CO_2, and hydrogen, H_2, as, some day, "conveniently" stored liquid fuels.

Less pollution thanks to electric two-wheelers

E-mobility is currently on everyone's lips as an alternative, environmentally friendly method of transport, but it pays to take a closer look. Life cycle analyses (LCAs) performed by Empa show that in comparison to their petrol-fuelled equivalents, electric motorcycles ("e-scooters") do cause less pollution – but only when their batteries are charged using electricity generated within Switzerland. This is true both with respect to greenhouse gas emissions and total environmental impact, measured using various evaluation systems. In the case of e-scooters the extra costs associated with the electronic and electrical components – which besides copper and steel also contain rare and critical metals such as lithium and neodymium – pay off. In the case of the currently booming electric bicycles (e-bikes), in contrast, the extra consumption of materials is the dominating factor for their eco-balance.

Life cycle analyses (LCA) conducted at Empa show that e-scooters have a smaller environmental impact than their petrol-fuelled equivalents – so long as the batteries are charged using electric power generated within Switzerland.

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 800-odd highly qualified scientists and its first-class technical infrastructure, is the right address.

Use-inspired Research
Innovative Developments
Knowledge & Technology Transfer
Services & Expertise
Advanced Training & Education

Innovation – essential for economic growth

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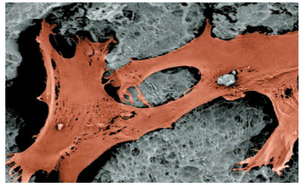
Creating innovation is a dynamic, iterative and highly interactive process. Therefore, Empa is intensely exchanging new ideas based on the latest scientific results with its partners from industry, and in doing so provides vital impulses for cooperative research projects. The aim is to jointly tackle pressing problems, thus generating the basis for innovative solutions, which enable the economy to enter new markets.



Empa and the Cantonal Hospital of St Gallen have strengthened their collaboration in the area of implant development. Image: Bone cells adhere to implant surfaces. Bone precursor cells (stem cells) for the in vitro test were isolated from human bone marrow.

Special measures from CTI to counter the strong Swiss franc

To transfer research results as fast as possible into marketable innovations has always been one of Empa's main goals. Innovations are also key to the long-term success of Swiss industry, particularly in export markets. When the Swiss parliament decided, in October 2011, to take action against the strong Swiss franc, Empa immediately supported the idea. By means of various events and a special information brochure Empa spread the word to its industrial partners on how rapid, short-term forms of collaboration could be initiated to deliver immediate impact. As a result within two months more than 100 projects were submitted to the CTI, of which 27 were granted financial support totaling more than CHF 12 million.

Medicine meets materials research

Empa and the Cantonal Hospital of St Gallen have reinforced their research cooperation in medical technology. In addition to previous partnerships involving the exploitation of adult human stem cells, last year's agreement saw the addition of cooperative projects in areas such as nanosafety, immunology and implant development. The new joint venture supplements existing partnerships with other research institutions, universities and companies in the bio-medtech area.

Inauguration of the IBM "Binnig and Rohrer Nanotechnology Center" in Rüschlikon where Empa as "Junior Partner" will also conduct research.
Mid-left: Nobel Award winner Heinrich Rohrer, mid-right: Federal Councilor Didier Burkhalter. (© IBM Research Zürich)

Junior partner in the new IBM-ETH Nanocenter

In May the new "Binnig and Rohrer Nanotechnology Center" was opened on the site of the IBM Research Laboratory in Rueschlikon near Zurich. This is the very place where the two scientists after whom the new center has been named developed the scanning tunneling microscope (STM) 30 years ago, ushering in the nano era. The center, which cost about CHF 90 million and is run jointly by IBM and the ETH Zurich, represents another milestone emphasizing Switzerland's strength in nanotechnology. Empa, as a "Junior Partner", will also conduct research there. The center offers a total of about 1000 square meters of clean room facilities as well as six so-called noise-free labs.

Empa innovations push onto the market

Empa's Technology Transfer Office is an important link between the research laboratories at Empa and external partners. The office deals with legal questions pertaining to all aspects of collaboration with industry, other research organizations and public bodies. Together with the research staff involved, it drafts and negotiates the necessary contracts and looks after the protection and exploitation of the institute's intellectual property. In 2011, despite the economic crisis, the number of research collaborations with private and public partners for the first time crossed the 100 mark. Moreover, twelve new patent applications were filed and, in terms of the commercial exploitation of research results, 15 new license and technology transfer agreements were signed.

New artificial turf with upstanding qualities

Artificial turf is an economic and practical alternative to a natural grass playing field. However the first generation of these products frequently burned and scraped players because they were made of very robust fibers, which also tended not to spring back upright when trodden down. Researchers from Empa and the ETH Zürich have, in a project financed by the CTI, together with the Swiss artificial turf manufacturer TISCA TIARA and the German fiber manufacturer Schramm, developed a novel fiber for artificial turfs. This has optimal sliding properties and also returns upright after being bent. These artificial blades of grass, which have an optimal cross-section, are spun as a two-component fiber and then worked into a carpet of artificial turf. The product is already in use on a number of football fields.

Cross-section of the fiber: It consists of five thin cores of polyamide and a sheath of polyethylene.

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High-performance insulating plaster for historic buildings
Effectively renovating historic buildings whilst retaining their elegant structure and appearance is a challenge frequently encountered by architects and engineers. In another CTI-funded project, together with two leading plaster manufacturers, Empa researchers have developed a new insulating plaster suitable for both indoor and outdoor use. The secret ingredient in the novel plaster is an Aerogel, a material containing minute air-filled pores which ensure that the new insulating material has a thermal conductivity 2 to 3 times lower than that of conventional plasters. A further advantage of the new material is that it is permeable to water vapor, yet at the same time water-repellent. The high-performance insulating plaster is already undergoing field trials and is expected to be commercially available in 2013.

Biodegradable flip-flops
The worldwide success of flip-flops is impressive. The mass-produced footwear is worn all over the world, be it in nations of the northern hemisphere or in the south, on all continents. However, as a mass-produced consumer item, flip-flops also create a serious waste problem. In collaboration with the company Bioapply Sarl in Gland (VD) and with financial support from the CTI, Empa scientists have developed a new formulation for the popular footwear, for which they have applied for a patent. The new flip-flops are made of biodegradable polymer material and meet the EU's composting standards. A market launch is currently being evaluated.

Aerogels provide an elegant way to renovate historically important buildings without changing their external appearance. They consist of more than 90 per cent air, which is enclosed in pores with sizes in the nanometer range.

Start-ups in glaTec among the best in Switzerland

Acting on behalf of the "Institut für Jungunternehmen" (IFJ) in St Gallen, 100 experts have voted the glaTec-start-up Optotune the best Swiss star-up of the year. Two other glaTec firms, QualySense and Compliant Concept, also made it into the Top 100, ranked 26th and 73rd respectively. This is a proud moment for Empa's technology center on its Duebendorf campus, which, since its foundation in 2009, has provided a home for six start-ups and spin-offs. The first one, Optotune, left the business incubator's premises in the summer of 2011 as planned, moving to a new location to enable it to ramp up production of its novel optical lenses.

Start-ups, which meet the stringent conditions of the selection process, may remain in glaTec for up to three years, during which they benefit from low rental fees and Empa's first-class infrastructure. After this period the new companies are expected to have acquired enough capital – e.g. through third-party investors, business angels and the like – to move elsewhere, making room for new start-ups.

glaTec is housing not just Empa spin-offs, but also other high-tech start-ups with such intriguing names as Decentlab, Compliant Concept, QualySense, Monolitix, Optotune and Micos Engineering, who over the past years have developed a range of very different products and processes. These include optical instruments for the space industry, a measurement system for the wireless monitoring of buildings, an intelligent bed system for bedridden patients, a process to analyse and sort cereals by the ton, compliant components for the mechanical engineering industry and optical lenses with continuously adjustable focusing.

Optotune, the first start-up in Empa's "glaTec" technology center, has been voted the best Swiss start-up in 2011.
(Ben Huggler)

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STARTFELD gets start-ups to take off

In early 2011 "Startfeld", the platform for promoting innovation and encouraging the foundation of start-ups in Eastern Switzerland, established its second pillar. The STARTFELD foundation provides seed money to finance outstanding start-up projects, the main donor being the Cantonal Bank of St Gallen, which contributed CHF 5 million in funding. Ways and means of increasing the foundation capital are currently being sought, and an expert committee drawn from the research, technology and economic sectors evaluates proposals submitted by young entrepreneurs. Applicants who get the go-ahead are provided with an interest-free loan of up to CHF 300,000. The first start-up company to receive financing was Weibel CDS AG from Waldstatt. Together with its manufacturing partners, the company develops and produces user-friendly, application-oriented pharmaceutical primary packaging and products, which allow injectable therapeutics to be administered more easily.

With the construction of a building on the site of the Empa campus in St Gallen "Startfeld" is already planning to move to the next level. The edifice is based on plans by St Gallen-based Eigen GmbH, Architecture and Design. Their conceptual design, entitled "connect", won the planning competition held in 2011. According to the jury of civil engineers and architects, "connect" not only provides functional premises for up to 70 start-ups but also generates a creative atmosphere, presenting itself as simple and as eye-catchy as a hangar.

The first start-up company to receive financing by STARTFELD was Weibel CDS AG. The novel products designed by the company assist in handling and using injectable therapeutics safely, intuitively and easily. (Weibel CDS AG)

In times of the strong Swiss franc

In 2011 the strength of the Swiss franc also influenced the activities of the Empa Academy. A good 2 500 specialists from industry, professional associations and public authorities attended 36 professional seminars, which were specifically intended to strengthen innovation in Switzerland. The events thus attracted some 50 per cent more compared to 2010. In addition, during the past year about 2 200 researchers came together at 11 scientific seminars, 10 scientific courses and 30 specialist lectures to discuss the latest research results in their respective fields.

Events organized at the Empa Academy always attract large audiences.

"Technology Briefings" – showcases for the latest Empa innovations

Three "Technology Briefings" held in the course of 2011 were attended by more than 250 business professionals. The measures authorized by the Swiss parliament to counter the strong Swiss franc were the main topic at the "Smart Textiles" event in late autumn. The Swiss textile industry, which is heavily dependent on exports, is suffering particularly badly under the current exchange rate. A well-established means of countering cheap competition from abroad is to concentrate on innovative products such as textiles with integrated sensors, or fibers with special surface coatings. In the second Technology Briefing, participants discussed the future of fuel cell technologies. In the third event of the series, attendees from the fields of architecture and civil engineering were brought up to date on the latest developments in lightweight construction techniques. In addition to wood and plaster board, other materials and techniques were discussed – some unusual, such as lightweight assemblies based on concrete or air.

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Specialist courses fully booked

As ever, specialist courses, which the Empa Academy offered in collaboration with its partners, enjoyed great demand. A new addition to the program was the course entitled "Fleet Management viewed Holistically", organized together with the Swiss Vehicle Fleet Owners Association (SFFV) and Sanu (Education for Sustainable Development). In addition to the technical side of vehicle park management it focused on the financial and strategic aspects. Together with the FRSM (Swiss Foundation for Research in Microtechnics), the Academy also organized courses on such themes as "Next Generation Lithography", "Electrochemical Characterization and Corrosion" and "Soldering". Interest in the events was keen and some of the courses were overbooked.

The first event in the "Photovoltaics in Focus" series, entitled "Solar Power for Switzerland – a Future Vision", offered some 200 professionals and interested laypersons a glimpse into the future of solar power, with Empa specialists updating the audience on the various solar cell technologies currently under development. The take-home message was that, as a result of economies of scale and the continuously increasing production levels, further drops in the price of solar cells can be expected. Past experience shows that whenever the installed capacity doubles the price for solar modules drops by some 20 per cent. Empa's R&D efforts are also contributing to this effect.

The flexible polymer solar cells, jointly developed by Empa and Flisom AG, a spin-off of ETH Zurich, were also a topic of discussion in the "Photovoltaics in Focus" seminar. (Flisom)

Successful innovation through global partnerships

In the age of globalization, R&D institutions must more than ever orient themselves internationally in order to be successful against worldwide competition. Global challenges can only be tackled through multilateral partnerships to find scientific solutions and to exploit the resulting innovations. Empa is, therefore, further expanding its international network of contacts and collaborators.

iStockphoto

This is exemplified by the Swiss-Chinese partnership in the field of climate and environmental protection, which is being coordinated by the Swiss Agency for Development and Cooperation (SDC). Empa's contribution to the project is its know-how in combining pollutant measurements with emission inventories and source identification. In May, China was also the host nation for the 4th World Materials Research Institutes Forum, in which Empa, as a partner institute, also participated. In fact Empa has now been entrusted with the organization of the next event in 2013. The institute has also signed contracts with South Korea's INHA University and the Korea Research Institute of Standards and Science, which should pave the way for future exchanges of students and staff. The collaborative work with the US National Institute of Standards and Technology (NIST) on the standardization of methods for the toxicological testing of nanomaterials has also been extended.

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International construction conference in Dubai "hosted by Empa"

A more appropriate location for the first international conference on smart monitoring, assessment and rehabilitation of buildings is likely difficult to find: Dubai, the country with the world's highest building – the 162 storied Burj Khalifa. 828 meters high, the tower is exposed to extreme winds and must thus be permanently monitored. Around 300 participants from all over the world came to learn about the newest trends in the field at the invitation of Empa and the American University in Dubai (AUD). They discussed such novelties as wireless sensor networks for monitoring buildings and the retrofitting of strengthening elements containing carbon fiber reinforced polymers to weakened structures. And on the sidelines of the conference, Empa and the AUD came to an agreement to significantly extend common research projects.

In civil engineering Empa has over the past two years or so increased its engagement and collaboration with RILEM, an international association of researchers and experts from academia and economy in the field of construction materials and structures. In fact since 2009 Peter Richner, a member of Empa's Board of Directors, has held the post of President of RILEM.

Tapping the global talent pool

In a worldwide competition to find the brightest minds Empa has, amongst other things, launched a new post-doc program. 22 talented young scientists from around the world have received a two-year scholarship as part of the COFUND Project, co-financed by the EU as part of its Marie Curie program for young scientists. In early 2013 the institute will be able to grant another 22 scholarships.

Moreover, the international master program "MNT Micro- and Nanotechnology" achieved first place in the category of Technical University programs, as ranked by the Austrian business magazine "Format". Although only in its fourth year, the course already enjoys an outstanding reputation. Over 120 heads of HR of leading companies ranked Austrian universities with regard to the capabilities of their alumni in the job market. Crucial criteria in the evaluation were the quality of the teaching staff and the program's "internationality". Empa is one of the founders of the two-year part-time program, which is currently under the scientific leadership of Empa Director Gian-Luca Bona. Other participating organizations are the University of Applied Sciences Vorarlberg, the NTB Interstate University of Applied Sciences (Switzerland) and the Zurich University of Applied Sciences.

Nano, cleantech and energy in public focus

Nanotechnology, cleantech and energy were last year's hot topics from a communications point of view, too. Empa features all three of these areas in some of its "Research Focus Areas", widely publicizing results and raising awareness in public dialogue. In mid-May more than 250 participants attended the first Swiss NanoConvention, which was organized by Empa together with the Paul Scherrer Institute (PSI) and the ETH Zürich. Leading figures from research and industry, entrepreneurs, investors and representatives from the worlds of administration and politics discussed ideas and opportunities as well as potential risks. Among the speakers was Nobel Prize laureate Heinrich Rohrer (one of the founding fathers of nanotechnology), John Kelly (Head of Global Research at IBM) and Mauro Dell'Ambrogio (Secretary of State for Education and Research). In future the Swiss NanoConvention will take place every year in different regions of the country, hosted in turn by the main players on the Swiss nano scene. In 2012 it will be held in Lausanne, and will be organized by the EPF Lausanne and the Swiss Center for Electronics and Microtechnology (CSEM).

More than 400 attendees from 40 countries participated in the 2nd World Resources Forum, which Empa organized once again in Davos.

Live blogs from the World Resources Forum
Discussions and societal impulses were also at the center of the 2nd World Resources Forum, which Empa organized once again in Davos. In excess of 400 attendees drawn from 40 countries – including such personalities as Janez Potočnik, the EU Commissar for the Environment – exchanged ideas and information on the topic of global resource usage and how to reduce it. Student reporters and bloggers reported live and online from the WRF. Next year the event moves to Asia, taking place in Peking for the first time in October 2012.

In addition, Empa was co-publisher of the "Swiss Cleantech Report 2011", an account of the current state of play in the Swiss Cleantech field. The conclusion: environmentally friendly technologies play an ever more important role in economic and research-based activities in the country. Project partners in drafting the report were other research and technological institutions. Among other things, Cleantech deals with energy efficiency and the use of sustainable sources of energy. Topics like these took center stage in last year's series of Science Apéros held at the Empa Academy which are open to the public; the events addressed questions such as "What potential do photovoltaics have here in Switzerland and which technologies hold the greatest future promise?" Or: "Are electro-mobiles the solution to the mobility challenges of the future?" In the latter case, to link the theory of e-mobility to practice a number of e-bikes and e-scooters were available for a test ride.

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michael.hagmann@empa.ch

Empa – an attractive destination for visitors
Last year for the first time more than 2 000 visitors took the opportunity to peer over the shoulders of Empa's researchers during some 80-odd guided tours of the institute. Visiting groups included staff from federal institutions such as the State Secretariat for Education and Research (SER), the Federal Office for Professional Education and Technology (OPET), the Swiss National Science Foundation (SNSF), the Federal Office of Police (Fedpol) and the directors of the Swiss Academy of Engineering Sciences (SATW), the Swiss Accident Insurance Fund (SUVA), the cantonal authorities and the Christian Democratic Party of St Gallen. Federal Councilor Johann Schneider-Ammann praised Empa as "the centerpiece of the Swiss knowledge and technology transfer network and a key to successful innovation."
Empa also communicated intensively with the "rest of the world", of course, by means of some 3 000 articles and about 50 television appearances on its research activities, which appeared in national and international media in a total of 32 languages. Not to mention the institute's new electronic newsletter, which was launched last year, and which currently targets around 3 000 actual and potential partners from industry.

Organizational Chart 2012

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 Peter Hofer

Energy
Dr Xaver Edelmann

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

GENERAL MANAGEMENT

Director General	Deputy	Members
Prof. Dr Gian-Luca Bona	Dr Peter Hofer	Dr Pierangelo Gröning | Dr Peter Richner | Prof. Dr Harald Krug | Dr Xaver Edelmann | Roland Knechtle

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

Functional Polymers
Prof. Dr Frank Nüesch

Thin Films and Photovoltaics
Prof. Dr Ayodhya N. Tiwari

nanotech@surfaces
Prof. Dr Roman Fasel

Nanoscale Materials Science
Prof. Dr Hans Josef Hug

Mechanics of Materials and Nanostructures
Dr Johann Michler

Advanced Materials Processing
Prof. Dr Patrik Hoffmann

Joining Technology and Corrosion
Dr Lars Jeurgens

Civil and Mechanical Engineering
Dr Peter Richner

Mechanical Systems Engineering
Dr Giovanni Terrasi

Mechanics for Modelling and Simulation
Prof. Dr Edoardo Mazza

Structural Engineering
Prof. Dr Masoud Motavalli

Applied Wood Materials
Dr Tanja Zimmermann

Building Science and Technology
Prof. Dr Jan Carmeliet

Concrete/Construction Chemistry
Prof. Dr Pietro Lura

Road Engineering/Sealing Components
Prof. Dr Manfred Partl

Acoustics/Noise Control
Kurt Eggenschwiler

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

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

Mobility, Energy and Environment
Dr Peter Hofer

Internal Combustion Engines
Christian Bach

Air Pollution/Environmental Technology
Dr Brigitte Buchmann

Analytical Chemistry
Dr Heinz Vonmont

Solid State Chemistry and Catalysis
Prof. Dr Anke Weidenkaff

Hydrogen and Energy
Prof. Dr Andreas Züttel

Technology and Society
Heinz Böni a.i.

Support
Roland Knechtle

Library (Lib4RI)
Dr Lothar Nunnenmacher

Marketing, Knowledge and Technology Transfer
Gabriele Dobenecker

Communication
Dr Michael Hagmann

Human Resources
André Schmid

Informatics
Dr Christoph Bucher

Finances/Controlling/Purchasing
Heidi Leutwyler

Mechanical Engineering/Workshop
Stefan Hösli

Logistics and Infrastructure
Paul-André Dupuis

Construction 3 Research Institutes
Daniel Beerle

Portal

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Empa in form & function

ETH Council

The ETH Council 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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Beth Krasna Dipl. Ing. ETH, EPF Lausanne
Joël Mesot Prof. Dr, PSI, Villingen
Jasmin Staiblin Dipl. El.-Ing., Manager ABB Switzerland, Baden
Markus Stauffacher Dr, ETH Zurich
Olivier Steimer lic. iur., Banque Cantonale Vaudoise (BCV), Lausanne

Advisory Commission

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

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Rita Hoffmann Dr, Ilford, Marly
Jan-Anders Manson Prof. Dr, EPF Lausanne
Markus Oldani Dr, ALSTOM, Baden
Andreas Schreiner Dr, Novartis, Basel
Eugen Voit Dr, Leica Geosystems, Heerbrugg
Rolf Wohlgemuth Dr, Siemens, Zug

Research Commission

The Commission advises Empa's Board of Directors on questions of research, the choice of R&D spectrum and the evaluation of internal R&D projects. In addition to selected Empa senior staff, it consists of the following persons:

David Grainger Prof. Dr, University of Utah, USA
Bengt Kasemo Prof. Dr, Chalmers University of Technology, Sweden
Erkki Leppävuori Prof. Dr, VTT, Finnland
Jacques Marchand Prof. Dr, Laval University, Canada
Claudia Stürmer Prof. Dr, Universität Konstanz, Germany
Eberhard Umbach Prof. Dr, KIT, Germany
Sukekatsu Ushioda Prof. Dr, NIMS, Japan

Alex Dommann Dr, CSEM, Zurich
Thomas Egli Prof. Dr, Eawag, Dübendorf
Karl Knop Dr, Zurich
Dimos Poulikakos Prof. Dr, ETH Zurich
Marcus Textor Prof. Dr, ETH Zurich
Alexander Wokaun Prof. Dr, PSI, Villigen

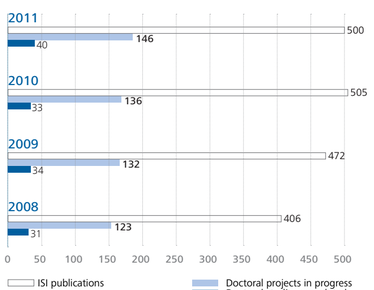
Facts & figures

Empa's positive development over the year is reflected in the relevant indicators (and elsewhere too). For example, the number of ISI publications stabilized at a high level, with 500 contributions. The teaching effort has risen about 10 per cent on the previous year to over 3600 hours annually. The number of professorships rose from 24 to 27, while that of PhD students went from 136 to 146. A rising tendency was also seen in Knowledge and Technology Transfer, with, as an example, patent applications rising from 8 to 12 over the year. In addition, two new spin-offs were established. The upward trend in second and third-party funding also continued unabated, amounting in total to CHF 51.7 million in 2011, CHF 2.7 million more than in 2010.

SCIENTIFIC OUTPUT

	2010	2011
ISI publications	**505**	**500**
Conference contributions	**1036**	**1094**
Doctoral studies completed	**33**	**40**
Teaching activities (in hours)	**3269**	**3637**
Prizes and awards	**30**	**27**
Empa Academy events	**85**	**91**
Participants	4300	5000
Scientific conferences	12	11
Specialist events for the economy	23	38

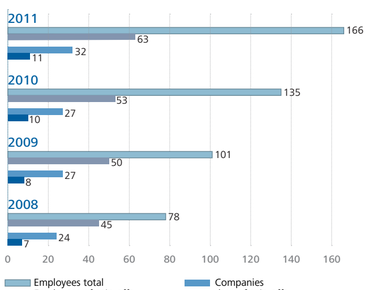
DOCTORATES & ISI PUBLICATIONS



KNOWLEDGE DISSEMINATION & TECHNOLOGY TRANSFER

Classes	2010	2011
New licensing agreements signed or being negotiated	**340**	**434**
Active exploitation contracts	59	67
New exploitation contracts	18	15
New patent applications	8	12
Subsequent patent applications	11	7
Current projects		
Swiss National Science Foundation (SNSF)	91	94
Commission for Technology and Innovation (CTI)	78	80
EU Projects (5/6/7 FP and others)	52	51

SPIN–OFFS UND START–UPS



STAFF (AS OF 31.12.2011)

Classes	2010	2011
Scientific staff	**513**	**523**
of which professors	24	27
of which Ph.D. students	111	115
of which sci. staff excl. profs. & Ph.D. students	378	381
Technical & administrative staff	**424**	**436**
of which apprentices	39	41
Total	**937**	**959**

MEDIA EXPOSURE

	2010	2011	Change
Radio & TV	94	118	+26%
Print	893	1095	+23%
Online	827	1777	+115%
Total	1814	2990	+65%
Languages	15	33	+120%

PROFIT AND LOSS ACCOUNT (IN MILLIONS OF SWISS FRANCS)

	2010	2011
Revenue		
Federal funding contribution	96.9	96.9
Measures "Strong Swiss Franc"	–	2.5
Third-party funding	36.6	38.6
Income from services	12.4	13.1
Miscellaneous income	0.5	5.0
Financial income	–0.2	0.0
Total Revenues	**146.2**	**156.1**
Expenditure		
Personnel costs	100.6	103.1
Material costs	5.2	5.6
Operating expenses	40.7	39.0
Changes in performance bond	–2.0	3.2
Reserve increase for projects	1.3	2.2
Total Expenditure for current activities	**145.8**	**153.1**
Balance	**0.4**	**3.0**
Investment		
Fixed assets	7.5	2.9
Movable assets	6.4	10.1
Information Technology	0.6	1.0
Total Investment	**14.5**	**14.0**

Use-inspired Research
Innovative Developments
Knowledge & Technology Transfer
Services & Expertise
Advanced Training & Education

Empa. Materials Science and Technology.

EMPA
Materials Science & Technology

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