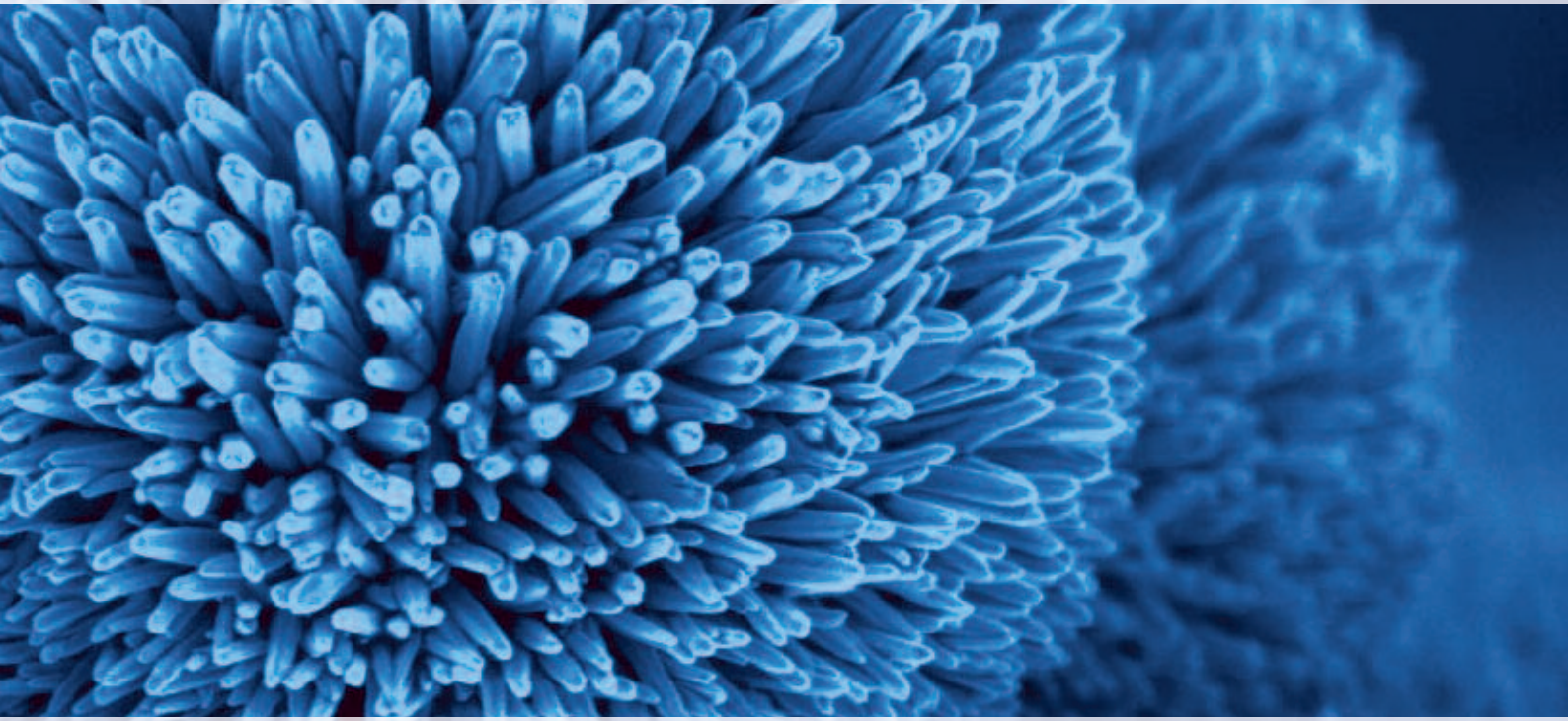
Empa Horizons

# A Glimpse into the Future

## Cutting-edge Materials Science and Technology Development



EMPA

Materials Science & Technology

# Our Vision. Materials and Technologies for a Sustainable Future.

Empa conducts cutting-edge materials and technology research, generating interdisciplinary solutions to help overcome major challenges faced by industry, and creates the necessary scientific basis to ensure that our society develops in a sustainable manner.

In collaboration with partners from industry, Empa turns research results into marketable innovations. In doing so the institution makes a significant contribution to enhancing the international competitiveness of the Swiss economy.

As an institution of the ETH Domain, Empa is committed to excellence in all its activities.

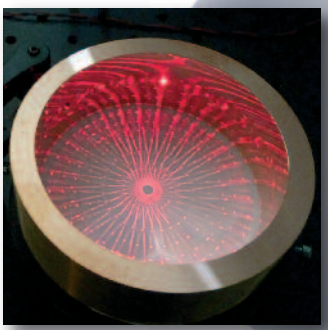
# Tackling Global Challenges.
## Through Innovative Materials and Sustainable Technologies.

What are the big challenges we are facing today and even more so in the coming years? The first one that comes to mind is certainly a sustainable, safe and secure energy supply. 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 without increasing our greenhouse gas emissions and our dependency in import. This is also stressed by the United Nations General Assembly having declared 2012 the "International Year of Sustainable Energy for All" and the resulting new global UN initiative – "Sustainable Energy for All" –, which aims at reaching three major objectives by 2030

- ensuring universal access to modern energy services
- doubling the rate of improvement in energy efficiency
- doubling the share of renewable energy in the global energy mix

At Empa we are very well prepared for the challenges lying ahead in energy research. 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, not only in our dedicated Research Focus Area "Energy", but also in our other focus areas such as "Nanostructured Materials" – our core business, as it were – and "Sustainable Built Environment". In total, around a third 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.

Health and Performance



Natural Resources and Pollutants

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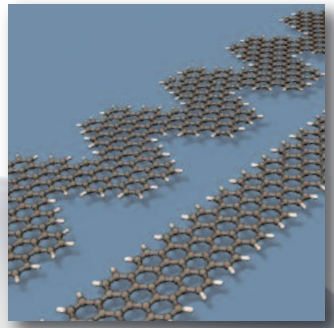

Nanostructured
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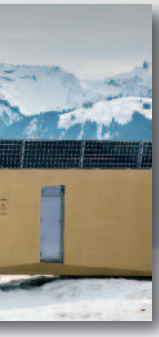


Sustainable
Built Environment

Another one is global climate, the environment and our dwindling natural resources – besides fossil fuels. For instance rare earth metals, found in many (if not all) forward-looking technologies such as ICT "gadgets" and computers, solar cells, batteries, and so on. In our Research Focus Area "Natural Resources and Pollutants", we are looking both into the effects of materials and compounds on our environment as well as into developing novel resource-efficient processes and systems that rely on abundant rather than scarce elements.

And, closer to home, personal health and well-being, an issue that is becoming ever more important in light of our increasing life expectancy. In the med- and biotech sector Empa is building on and expanding its network of academic and industrial partners to design solutions for advanced health care such as drug delivery devices, implant coatings or cell-based therapies.

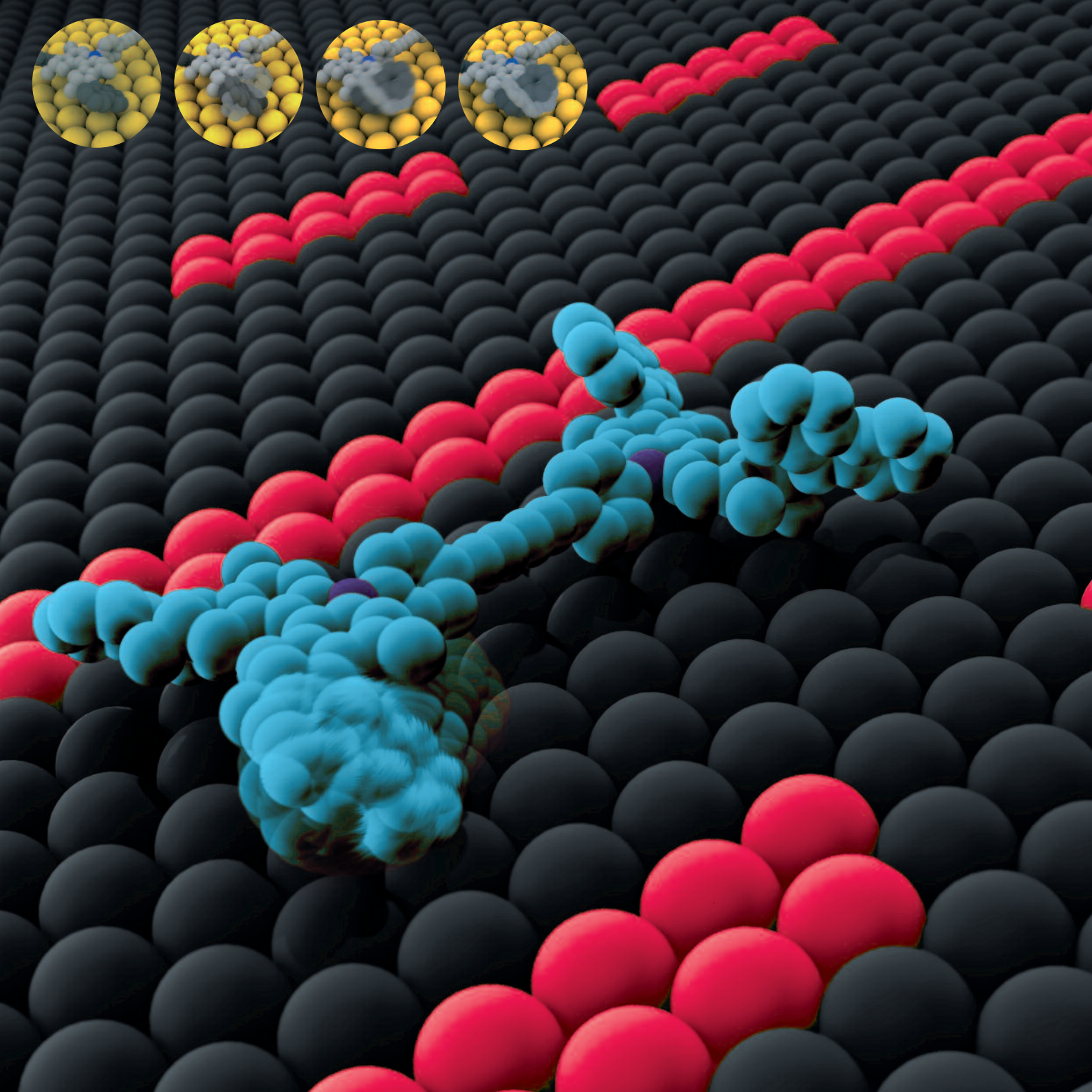
The objectives pursued in Empa's Research Focus Areas should deliver ideas, new impulses, demonstrators and innovative applications within a time horizon of a decade. Hence, the vision for 2020 summarized in the brochure at hand. At the core our goals remain unchanged: materials and technologies for a livable future. Because meeting today's challenges requires, above all, innovative materials and sustainable technologies.

At Empa we are eager to tackle these challenges now to create much needed solutions in the not too distant future.

# Nanostructured Materials

Advanced materials with improved and/or novel properties are a prerequisite for most technological innovations and mandatory to meet the increasing demands of a growing global population in areas such as energy, the environment, personal health and the economy. The most promising approach for the development of novel materials and manufacturing processes is nanotechnology. Nanostructured materials and devices exploit physical phenomena and properties that cannot be derived by simply scaling down the associated macroscopic structures – so "nano" is more than just another step of miniaturization. Tackling nanoscale phenomena in the context of materials science and development means pushing the physical and technological limits. Rationalizing and explaining these effects will yield results and insights, which are essential for the successful development of nanomaterials and -technologies. 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.

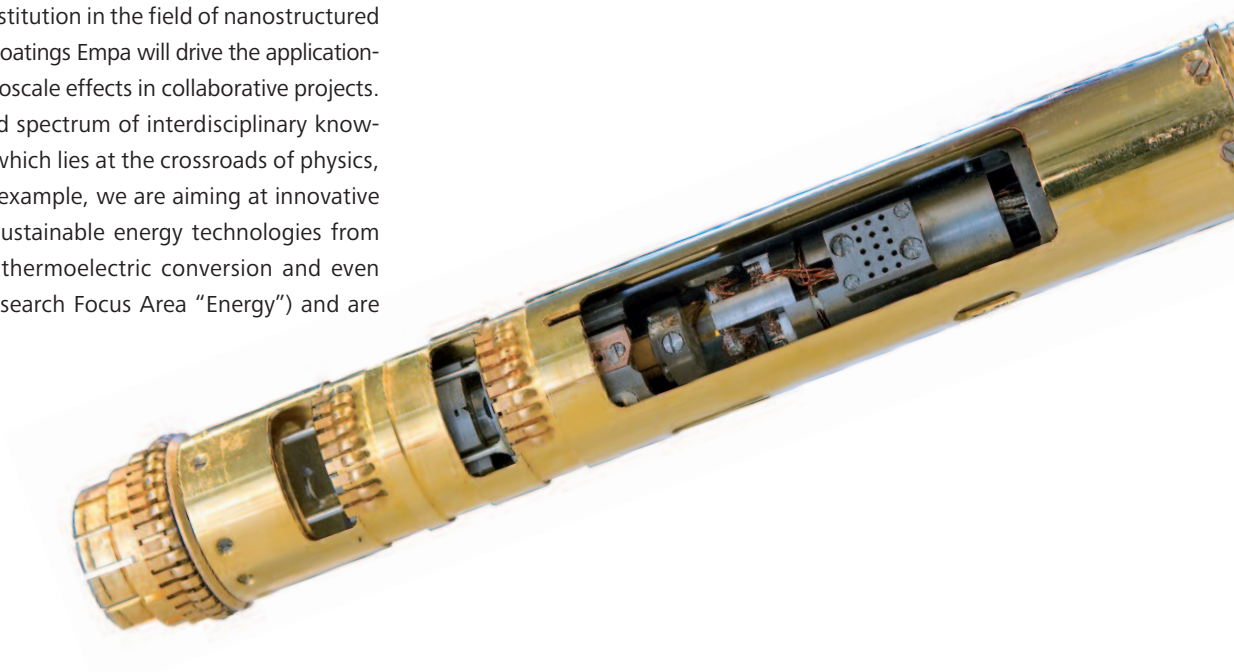
**Function follows architecture – nanostructured materials with novel features are the result of efforts to tailor material properties through rational design on the nanoscale.**

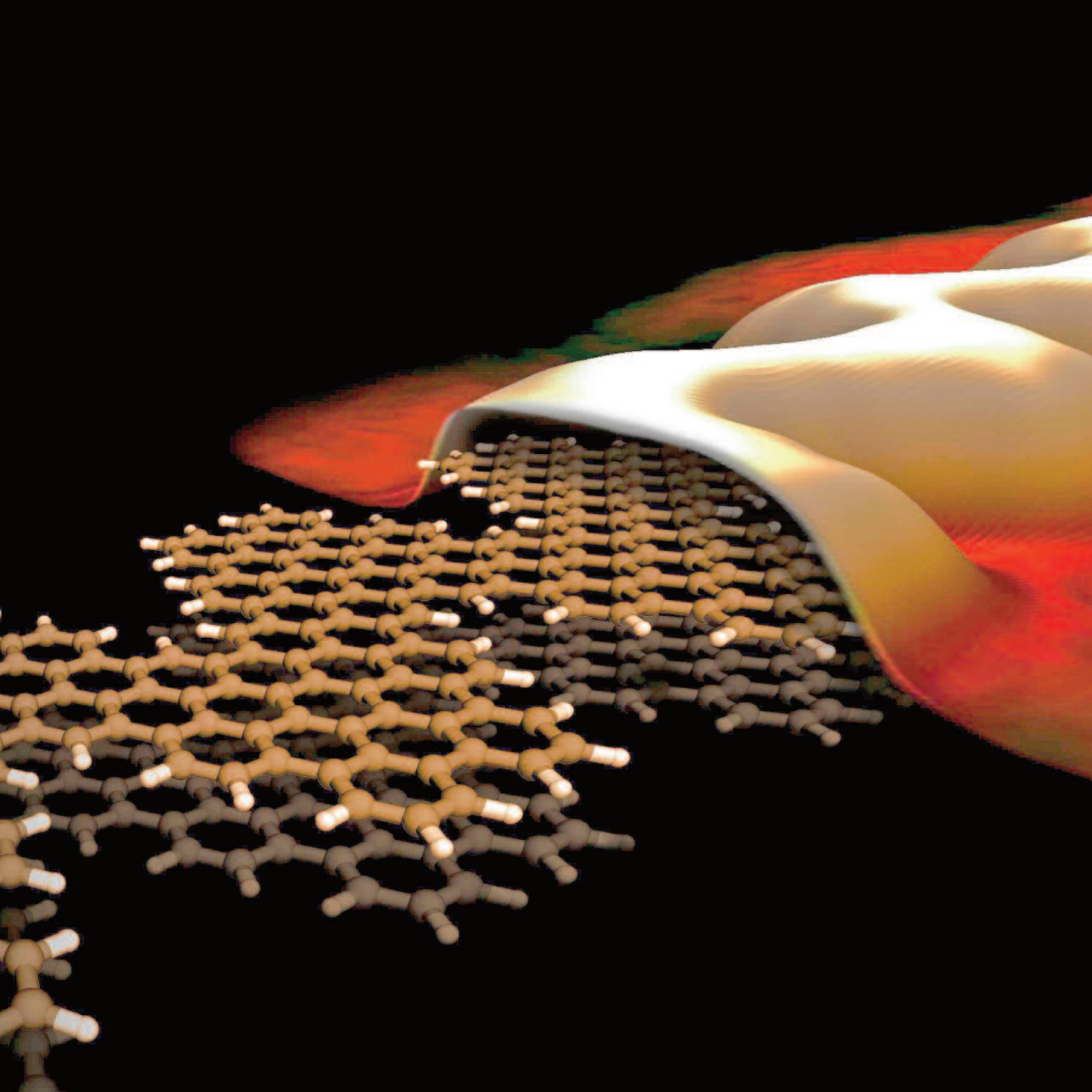


The physical properties of nanostructured materials and coatings are based on complex and subtle interactions of their nanoscale components, in particular at their interfaces. There are limits to the extent, to which experimental methods can be used for investigating and developing such materials. Therefore, computational material science, including modelling, simulation and materials design algorithms, is becoming a mandatory tool for the development and testing of nanostructured materials and devices. This new field of research, in which Empa has been working extensively for a number of years, is of strategic relevance and will thus be further developed.

As the leading Swiss R&D institution in the field of nanostructured materials, its interfaces and coatings Empa will drive the application-oriented exploitation of nanoscale effects in collaborative projects. We can call upon our broad spectrum of interdisciplinary know-how in this scientific field, which lies at the crossroads of physics, chemistry and biology. For example, we are aiming at innovative solutions for problems in sustainable energy technologies from thin film photovoltaics to thermoelectric conversion and even synthetic fuels (see also Research Focus Area "Energy") and are working together with the IT industry on novel materials and concepts like self-assembled graphene structures built out of precursor molecules.

Moreover, Empa is engaged not only in the development of new nanoscale materials but also in research concerning the possible risks for human health and the environment. In its Research Focus Area "Health and Performance", Empa will establish new advanced *in vitro* systems to assess the safety of nanomaterials before they reach the market in substantial amounts.



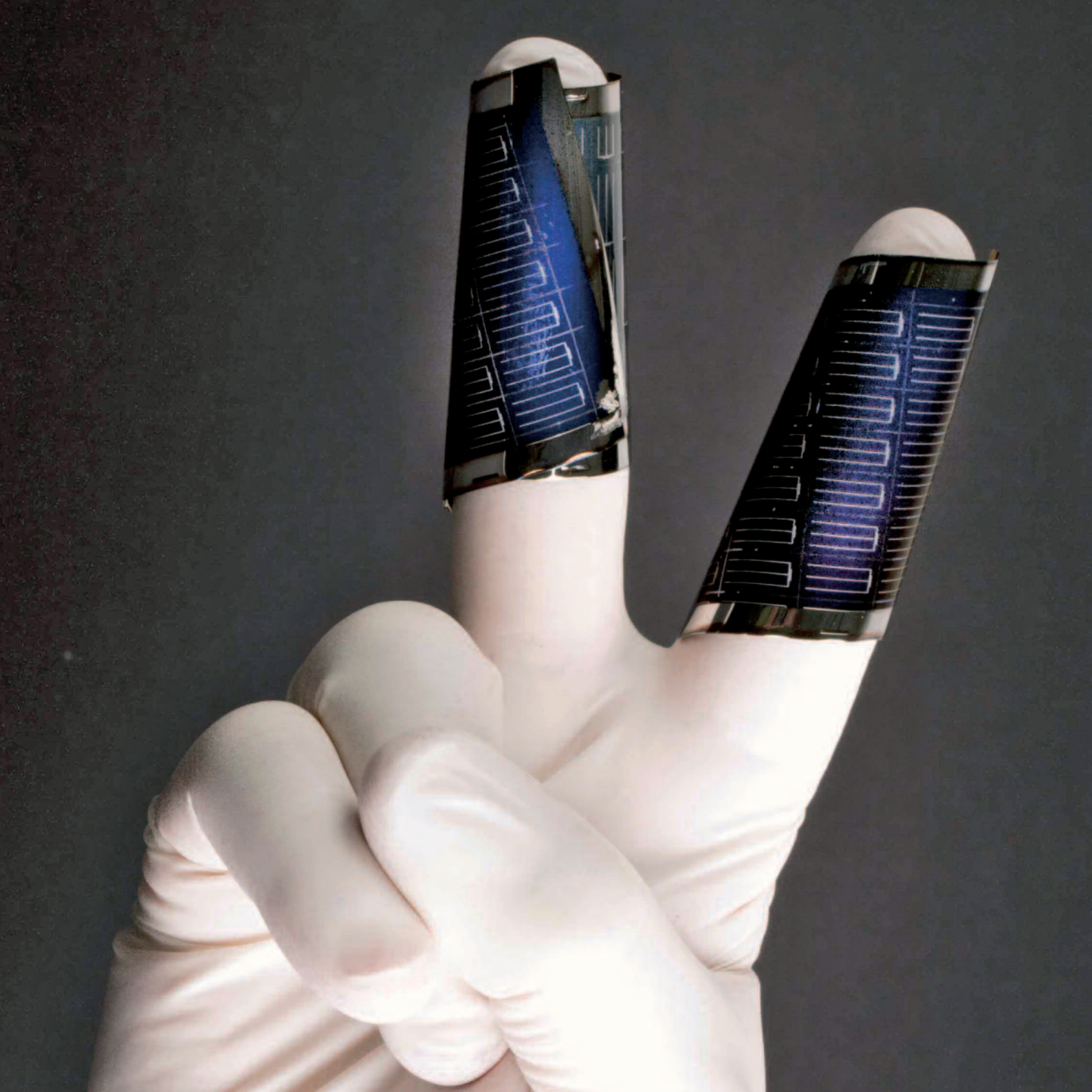


# Energy

**The "energy turnaround" will only be feasible through sustainable solutions based on novel materials and innovative energy technologies that will enable us to drastically reduce our current carbon footprint.**

Increase in global greenhouse gas emissions and the intended phase-out of nuclear energy require concentrated efforts in energy research to achieve the ambitious goals of securing a sustainable and reliable energy supply, reducing energy consumption and achieving $CO_2$ reduction targets. Empa's research is focused on developing materials, systems and technologies for a renewable energy supply – which by and large means "clean" electricity production –, for energy conversion and (mid- to long-term) storage, that is, from batteries to synthetic fuels, and for an increasingly efficient energy use, especially in buildings (see also Research Focus Area "Sustainable Built Environment") and for mobility – both areas of great importance for efficiency increase. In parallel we develop tools for assessing the ecological and societal as well as economic impact of novel energy systems. Besides an excellent industry network, the interdisciplinary know-how of Empa is a strategic strength for advanced engineering of such systems and processes that will contribute to achieving the goals of the Swiss government's Energy Strategy 2050 but will even yield substantial results until 2020, for instance in the following areas:

- **Pushing solar cell efficiency to new levels (energy supply)**
  Building on Empa's 2011 world records in energy conversion efficiency for flexible inorganic thin film solar cells based on both copper indium gallium diselenide (CIGS) and cadmium



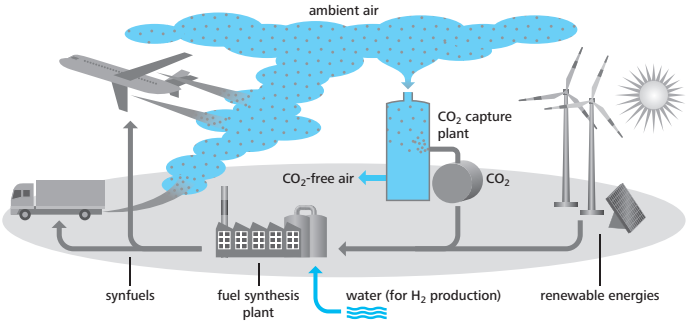
telluride (CdTe). Empa researchers will develop highly efficient thin film solar cells with new materials that are both non-hazardous and abundant (such as organic dyes) and that can be manufactured in a cost-effective way, for instance by roll-to-rollproduction.

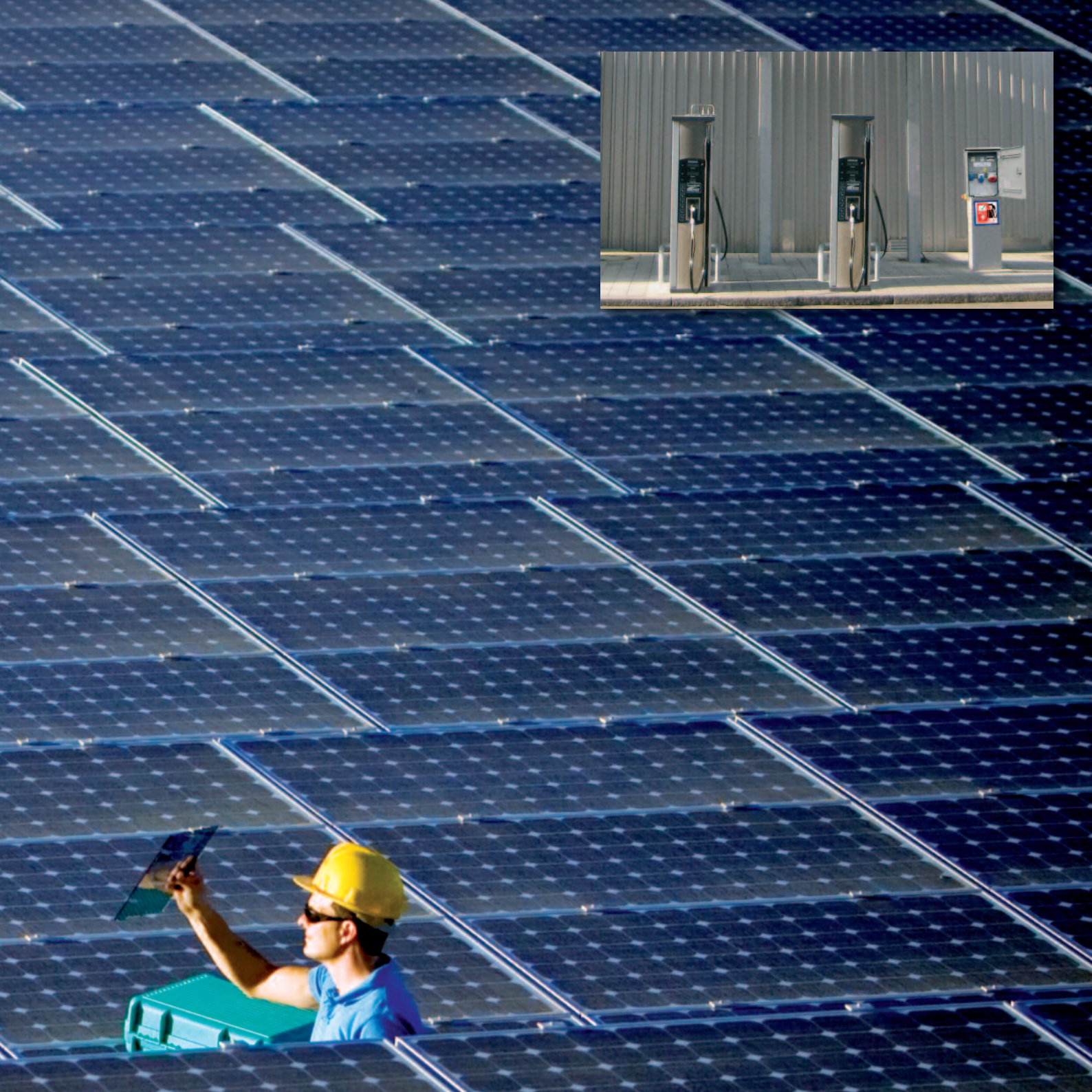
- **Harvesting waste heat (energy supply/conversion)**
  Thermoelectric generators can directly convert (waste) heat to electricity, for instance in/on car engines and industrial production facilIties, and thus recuperate a substantial amount of energy that would otherwise go to waste. Empa develops perovskite-type and other novel materials that can serve as energy harvesters.

- **Synthetic fuels from sunlight (energy supply/conversion/storage)**
  Hydrogen produced by electricity from photovoltaic cells and $CO_2$ (as, for instance, captured from the atmosphere) can chemically react to form methane, that is, natural gas, and other hydrocarbons, even liquid ones. Empa is developing the required catalysts and elucidating efficient synthesis routes.

- **Nanomaterials for new battery concepts (energy storage)**
  Storing electricity in non-chemical form for short to intermediate use will be a prime requisite for the transition to an all-electric society. Empa is designing novel types of highly efficient batteries based on abundant materials.

- **Showcasing the mobility of the future (energy efficiency)**
  A demonstrator for the versatility of tomorrow's mobility: solar cells will generate electricity, which will be used to directly charge electric cars and scooters and to produce hydrogen – which in turn can either be used to propel fuel cell-driven cars (such as Empa's municipal cleaning vehicle) or as an admixture to gas to fuel natural-/biogas-driven hybrid cars (a concept also developed at Empa).





# Sustainable Built Environment

The quality of the built environment is a key factor for a truly sustainable society. Research at Empa is carried out at different levels, from the development of new materials to the design of advanced systems and their integration into buildings and structures. Finally, we also look at entire cities and their interaction with the environment. Key issues at all levels are the minimization of the environmental footprint and the enhancement of comfort and safety to its users.

**Energy consumption and greenhouse gas emissions by tomorrow's built environment will be marginal, while comfort in buildings and the performance of our transport networks will be of the highest standard thanks to today's research in materials science and technology.**

Current advancements in novel construction materials are driven by new insights into the fundamental nature of materials such as concrete, asphalt or wood, which, in turn, is enabled by new characterization techniques down to the molecular and/or atomic level. A common issue with all construction materials is porosity and the resulting transport of gases and fluids through the material. This is a major factor determining the material's mechanical performance and durability, for which Empa is developing new experimental techniques. Combining experimental results and computer modelling will eventually lead to a better understanding of the strengths and weaknesses of various materials. Based on profound knowledge about construction materials and the needs of industry, Empa develops new materials and processes. A recent example is the aerogel plaster, which has superior thermal insulation properties than conventional foam-type insulation materials.

Heating and cooling of buildings is responsible for up to 50% of Switzerland's energy consumption. The vast majority of this is consumed by buildings erected before 1990. In cooperation with partners from academia and industry, Empa is developing concepts for the holistic renewal – retrofitting – of existing buildings. The combination of new materials, prefabrication methods, highly efficient vacuum insulation and renewable energy systems turn outdated and energy-consuming buildings into highly attractive and efficient buildings. At an urban scale, research is directed towards understanding and mitigating the heat island effect, increase wind comfort and reduce the accumulation of air pollutants. Furthermore, the potential of creating integrated energy systems in already existing communities is investigated.

Transforming research results into true innovations is a challenge in every field but most notably in the construction sector. Large-scale demonstration projects are an efficient tool to foster technology transfer and thus bridge the gap between the lab and the real world. Furthermore, the final judgment of a new solution will only be feasible after all components have been integrated. Typical examples are "self", a living and working unit for two persons, which is autonomous with respect to both energy and water, the "EmpaWindow", which combines knowledge from vacuum technology, photovoltaics and surface-coating technologies, and new concepts for chemically storing seasonal heat in a widely available concrete variant. All these new elements (and many more) can be experienced in real life in "Nest", a holistic, dynamic and flexible research and technology transfer platform for sustainable construction to be built on our campus in close collaboration with academic and industrial partners.

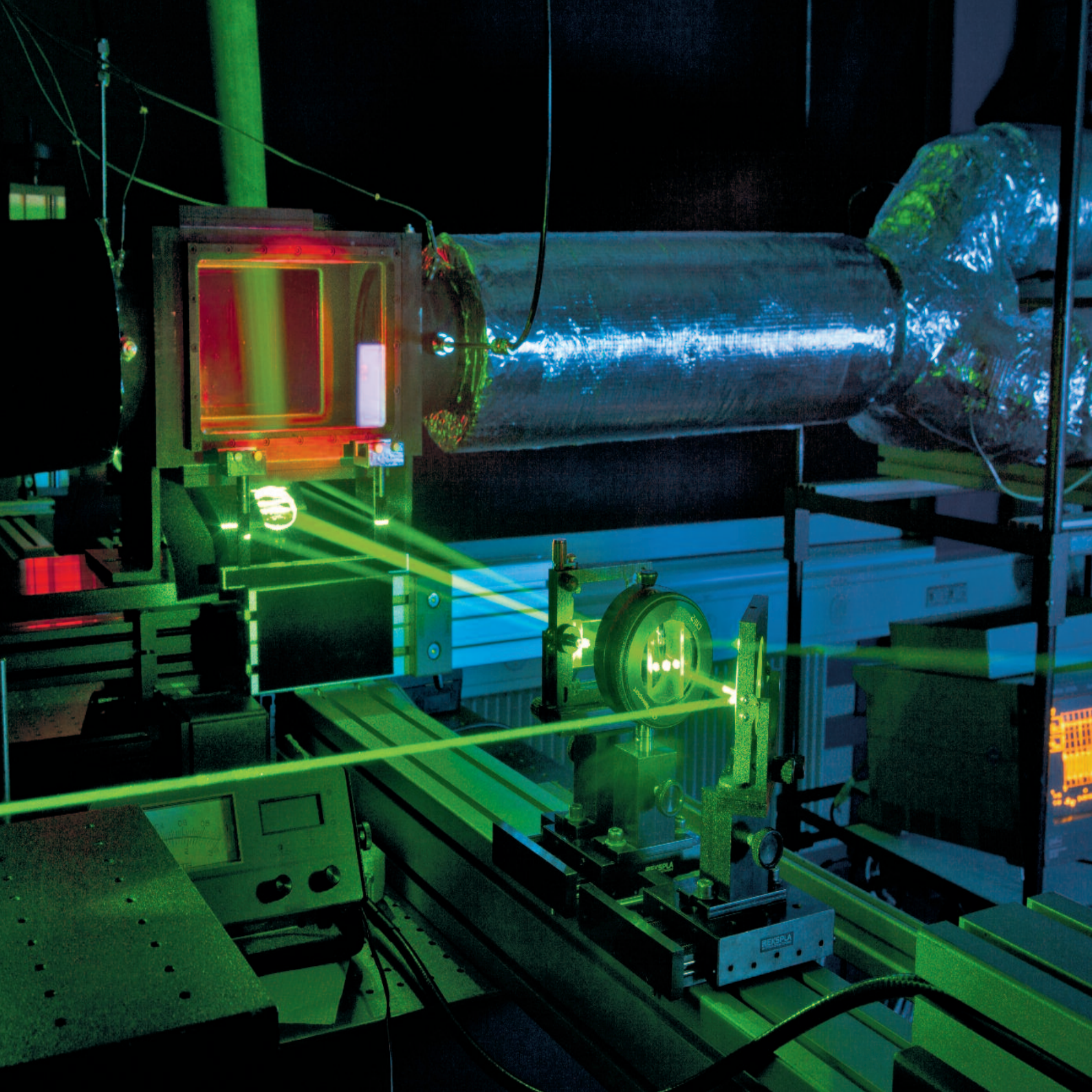
# Natural Resources and Pollutants (NAREP)

Every society requires materials and energy to cover its needs such as heated or cooled buildings, mobility and transport, food and goods for daily life. These activities are accompanied by the release of numerous pollutants: greenhouse gases, volatile organic chemicals (VOC), particles and many more. Empa promotes a society that uses fewer natural resources and produces fewer pollutants based on an in-depth understanding of the underlying physical and chemical processes and the development of innovative technical solutions.

**A truly sustainable society of tomorrow will enjoy the same comfort and living standard – while consuming far fewer resources and emitting less pollutants through the use of innovative materials and technologies.**

Based on these guiding ideas we aim at the following goals within the NAREP Research Focus Area:

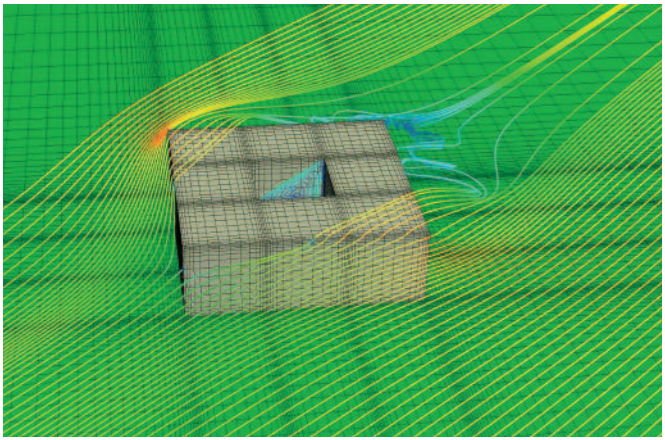
- an increase in the material and energy efficiency of technical processes and systems
- an in-depth understanding of the formation of pollutants in technical processes
- a characterization of the flow of pollutants from the technosphere into the environment
- modelling of the transport of pollutants on different scales, from the dispersion around buildings to the long-range dimension to trace them back to technical sources and processes
- the development of techniques and means to lower emissions into the atmosphere and to decrease the burden on our environment

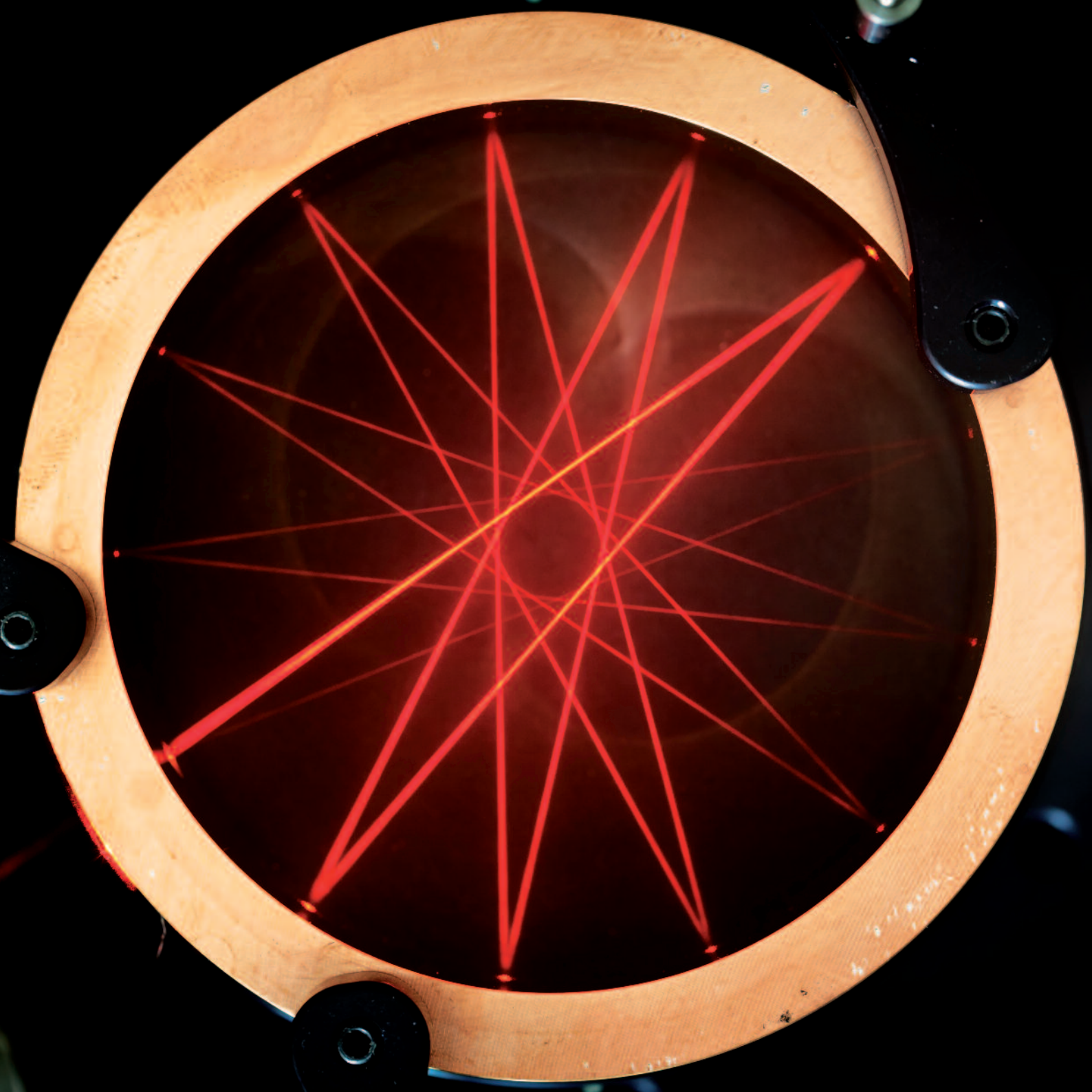


One of our strengths is, for instance, the design of high-precision measurement systems for atmospheric pollutants and the development of atmospheric transport models that allow the interpretation of the acquired data. This includes spectroscopic techniques that distinguish between different isotopes in trace gases, creating new possibilities for their source attribution, for instance for an independent monitoring of compliance with international agreements such as the Montreal or Kyoto Protocols.

We develop new catalysts on a ceramic foam structure, which require significantly less noble metals than conventional catalytic converters. In a newly established high-temperature flow lab we optimize the $NO_x$ reduction performance of diesel catalysts by multiphase flow investigations.

Concerning the scarceness of some critical materials we develop a methodological framework, which allows to assess and to validate the efficiency, effectiveness and sustainability of recovery processes for secondary material resources, such as for instance in "urban mining". In cooperation with the ETH Zurich we extend classic life cycle assessment approaches by including key economic figures.





# Health and Performance

Promoting and restoring good health in a sustainable manner, protecting people, maintaining and improving our quality of life and our physical capacity – these are ever more important topics, especially in light of a continuously increasing life expectancy. Empa takes on this challenge with an interdisciplinary approach combining know-how and experience from textile and material sciences, from biology and nanotechnology. We break new ground in the synthesis of biopolymers and important precursor molecules for chemical synthesis via biocatalysis, and we focus on materials for medical applications within the human body and on materials and systems that protect and assist us in our daily lives. Moreover, we investigate the safety of new materials by developing innovative testing methods and advising the governments of numerous European countries.

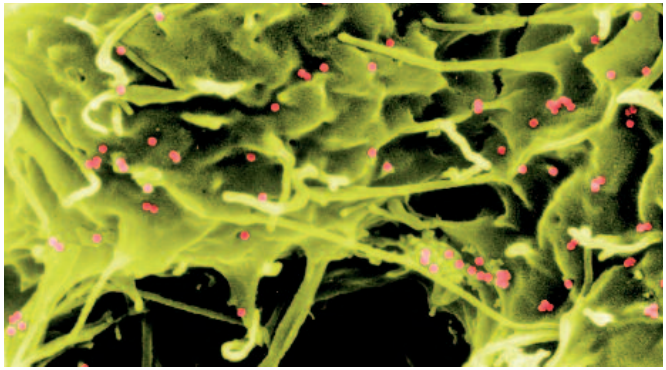
**To preserve good health as long as possible future medical technologies will rely on "smart" devices to monitor physiological parameters and, if necessary, initiate therapeutic measures – a first step towards preventive and thus more affordable health care.**

Crucial tasks we will have to deal with on the subject of health and performance in the coming decade are:

- To develop new materials that can contribute to maintaining human health or even restoring it: In the field of medical implants we optimize materials and surfaces for a longer lifetime of artificial joints, and we develop novel optical and electro-conductive fibers for a new generation of sensors in textiles.

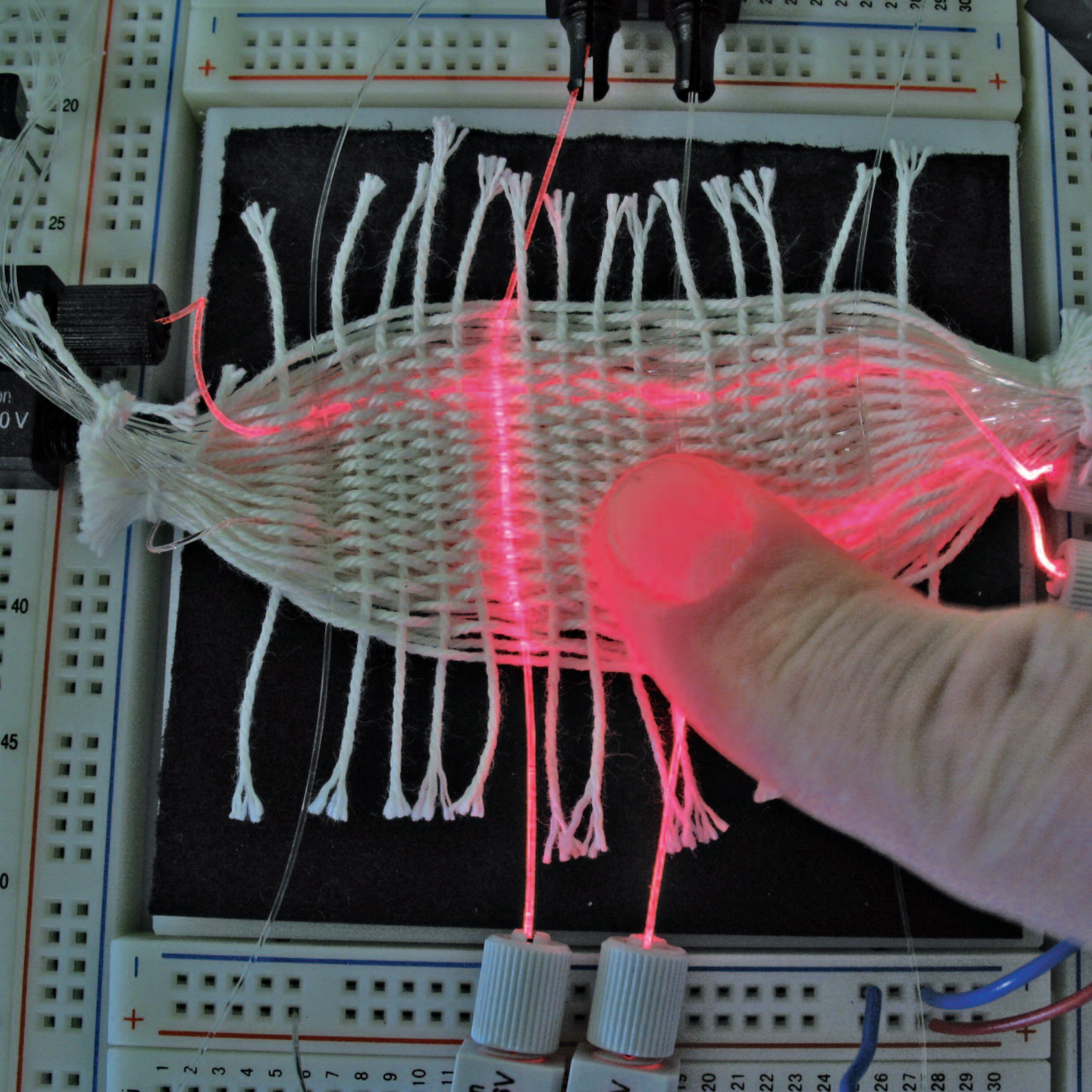
- The implementation of innovative processes such as plasma technology to establish the basis for new products, for instance for textile sensors but also for applications in areas such as food packaging or electronic devices.

- The development of new and specialized fabrics, garments and textiles to support sports activities as well as to restore the quality of life for the disabled: One of the most pressing challenges in this area is an in-depth understanding of the heat and water transfer from and to the body through membranes and fabrics and a quantitative description of such systems using newly developed computer models.



- The design of new additives, for instance flame retardants, which both outperform existing products and, at the same time, do not harm the environment: The vision is to synthesize a set of new chemicals, which fulfill criteria of environmental and health safety with high-performing properties as composite additives in various technical fields.

- Last but not least, to understand the biological effects of new materials such as nanomaterials and to set up an international network of research centers in order to establish reliable biological models as alternatives for animal testing: Implementing a qualified test strategy for nanomaterials into the OECD process is at the core of our activities in this context for the next ten years.



# Creating Innovation. Boosting Competitiveness.

A fundamental element of Empa's mission is to promote innovation through close cooperation with industry, the commercialization of inventions developed at Empa and the continuing education of both industry and the public about the latest research findings. The highly interdisciplinary environment at Empa represents an unparalleled opportunity for transferring research results onto the market. Thanks to its long-term experience in the field, Empa is able to offer its industrial partners solutions tailored to meet their specific needs. In doing so Empa makes a significant contribution to creating marketable products from innovative developments, thus strengthening the international competitiveness of its partners.

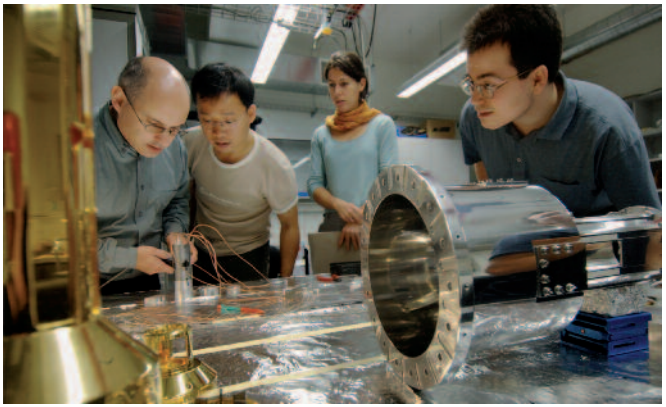
To initiate and support contact between Empa's labs and researchers with potential partners from industry, Empa's "Portal" offers a single point of contact for those interested in cooperating with Empa and in its broad offering in use-inspired research and sophisticated services. Empa has always enjoyed close interactions with industry and has, over the years, carried out innumerable joint R&D projects. For enterprises, Empa plays an important role in the invention phase of the process generating innovation. Such collaboration allows a company to gain access to new ideas and to test them in "real life". These collaborations may result in a first functional prototype, a novel material or a new process.

Developing strategic partnerships with key national and international players is becoming ever more important for Empa. In order to uniformly and transparently frame its collaborations with industry, Empa has defined flexible forms of cooperation and an overall framework of conditions and pricing models.

A number of Empa's research projects result in intellectual property, including patentable inventions or copyrightable materials. Empa seeks protection of its intellectual property and makes these results available to the public by seeking business partners, collaborators and licensees. The commercialization of technologies invented at Empa is a crucial cornerstone of the institute's long-term strategy.

Another route of commercializing inventions, i.e., through spin-offs, likewise plays an increasing role for Empa. Through its business incubators glaTec and tebo Empa actively fosters entrepreneurship and offers a supportive environment for companies in their start-up phase, some of which are showing impressive success by winning prestigious business awards as well as financial funding year after year.

With its Academy, Empa is addressing yet another crucial aspect of technology transfer: the transfer of knowledge through continuing education and a broad variety of seminars, courses and lectures. Last but not least: with over 50% of its researchers working on fixed-term contracts, each year a sizeable, highly skilled workforce leaves Empa towards industry – and thereby helps to fulfil its mission: to turn research results into marketable innovations.



# Empa. Materials and Technologies for a Sustainable Future.

As an interdisciplinary research and service institution within the ETH Domain, Empa, the Swiss Federal Laboratories for Materials Science and Technology, conducts cutting-edge materials and technology research. Empa's R&D activities focus on meeting the requirements of industry and the needs of society, and thus link applications-oriented research to the practical implementation of new ideas in the areas of nanostructured, "smart" materials and surfaces, environmental, energy and sustainable building technologies – that is, Cleantech applications – as well as biotechnology and medical technology. As a result, Empa is capable of providing its partners with customized services and solutions that not only enhance their innovative edge and competitiveness, but also help to improve the quality of life for the public at large. Through an efficient technology transfer Empa is turning research results into marketable innovations. As part of the ETH Domain, Empa is committed to excellence in all its activities. For further information please visit www.empa.ch

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