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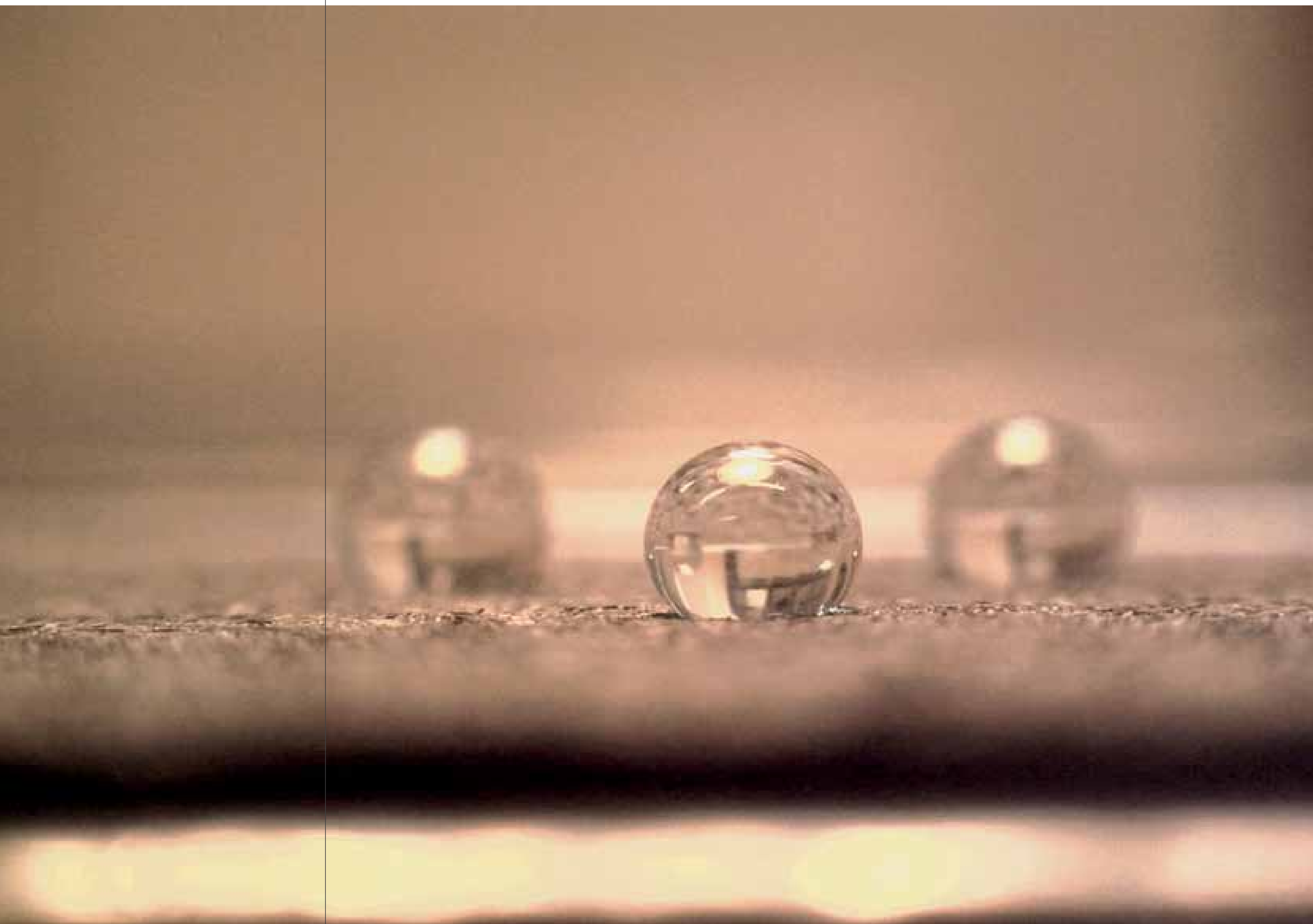
Swiss Federal Office of Energy SFOE

Energy research and innovation
Report 2016



Solar catamaran of the Swiss expedition "Race for Water Odyssey", which was launched in 2017. The boat is a further development of the "PlanetSolar" project: surplus solar energy is converted to hydrogen on board (200 kg at 350 bar). If necessary, this energy can be used again as electric current with fuel cells, which increases the autonomy of the boat by six days. The technology was developed by the Swiss company SwissHydrogen (image source: www.raceforwater.com).

Editorial

Switzerland currently has a reliable and cost-effective supply of energy at its disposal. Economic and technological developments, as well as political decisions both at home and abroad result in fundamental changes to the energy markets. This change in the Swiss energy system brings with it significant challenges. One example is the strongly decentralized organization of the energy supply and the correspondingly increased need for flexibility in the electricity network. At the same time this change has great potential for economic development and innovation. In the context of Switzerland's Energy Strategy 2050, research in the field of energy has thus been greatly expanded in recent years. The Confederation has put aside a significant amount of funds for additional human resources dedicated to research, and at the same time substantially increased the funds available for pilot and demonstration projects and the stimulation of innovation.

For some decades now the programme of the Swiss Federal Office of Energy (SFOE) for the promotion of research and innovation has constituted one of the most important funding institutions in Switzerland in the field of energy. Through its support programmes for applied research and for pilot, demonstration and flagship projects, the SFOE accompanies innovations from the laboratory to the market, and endeavours to integrate the most diverse activities in Switzerland in coordinated fashion. The examples presented in this brochure are representative of a multitude of projects which contribute to the widest range of topics in energy research.

Benoît Revaz
Director SFOE

Cover: Water droplet on the surface of a gas diffusion layer for fuel cells during contact angle measurement (image source: Paul Scherrer Institut).

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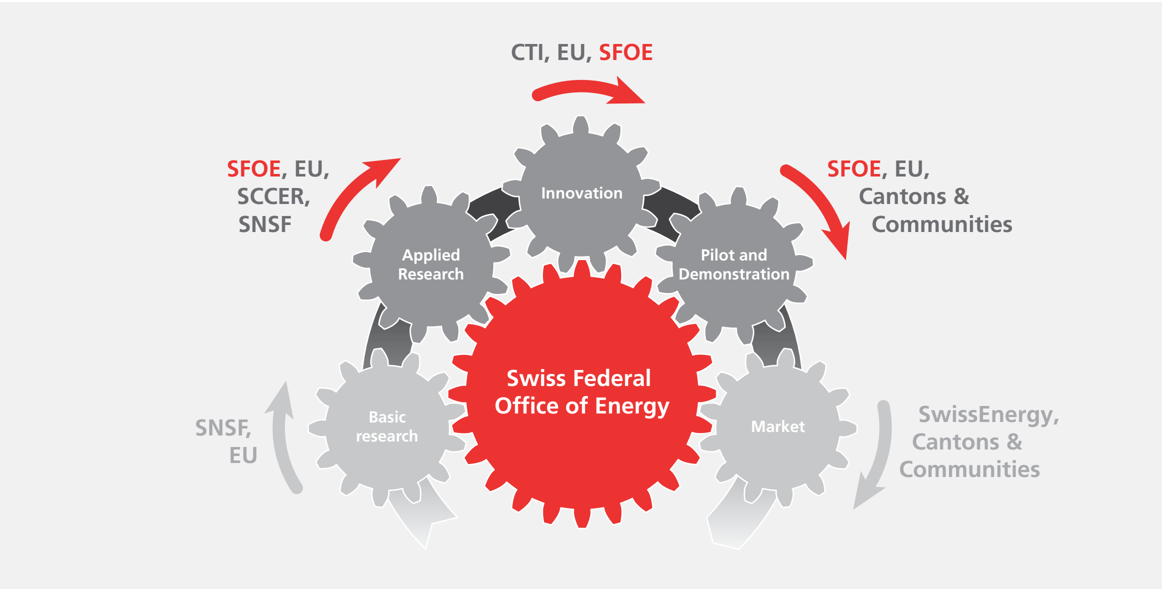
2.3 MW wind turbine in the “Puchapatte” wind farm in the Swiss Jura. The annual production of the wind farm supplies around 10 % of all households in the canton of Jura (image source: www.suisse-eole.ch).

Promotion of research and innovation by the SFOE

The ability to develop new ideas and bring them onto the market is an important factor for the competitiveness of a country's economy. The key is research, where novel findings and ideas are born that lead to the development of innovative and competitive products. In the context of the new energy policy ("Energy Strategy 2050") proposed by the Federal Council and the landmark decision to withdraw from the use of nuclear energy, this applies in particular to research and development in the energy sector.

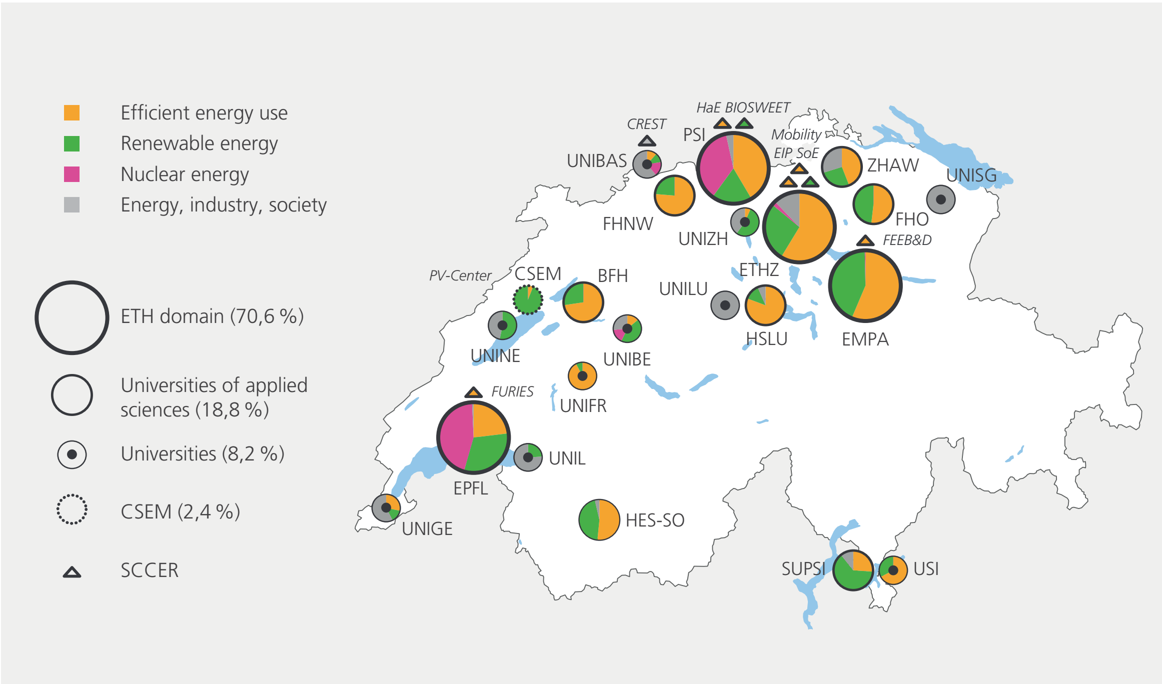
The SFOE promotes and coordinates national energy research, and supports the development of new markets for a sustainable energy supply. To successfully perform its coordination activities, the SFOE allocates its resources within a programmatic framework and in a targeted manner to promote the development of innovative technologies and concepts. It provides subsidiary support wherever there are gaps in Switzerland's research support landscape. Players include the private sector, the Swiss Federal Institute of Technology domain, plus universities and universities of applied sciences. The SFOE closely monitors the projects it supports, and on a case-by-case basis also calls on experts and representatives from other funding agencies.

The SFOE also provides expert reviews and know-how to project proposals that have been submitted to other national, cantonal, city or private funding bodies. In addition, the SFOE contributes to the regular exchange of information among various national research programmes, as well as to measures aimed at knowledge transfer. Thus, the SFOE is tightly networked with all research segments along the entire value chain, and enables continuous development of know-how and its translation into practical applications.



In close cooperation with the most important funding agencies that competitively award grants, the SFOE supports and coordinates research and innovation in the energy sector along a major portion of the value chain. Its activities are based on a programmatic and subsidiary approach that is governed by the Federal Energy Research Masterplan. In addition to national networking, the SFOE's central pillars are active dissemination of knowledge as wells as international exchange and cooperation (CTI = Commission for Technology and Innovation, EU = European Union, SNSF = Swiss National Science Foundation).

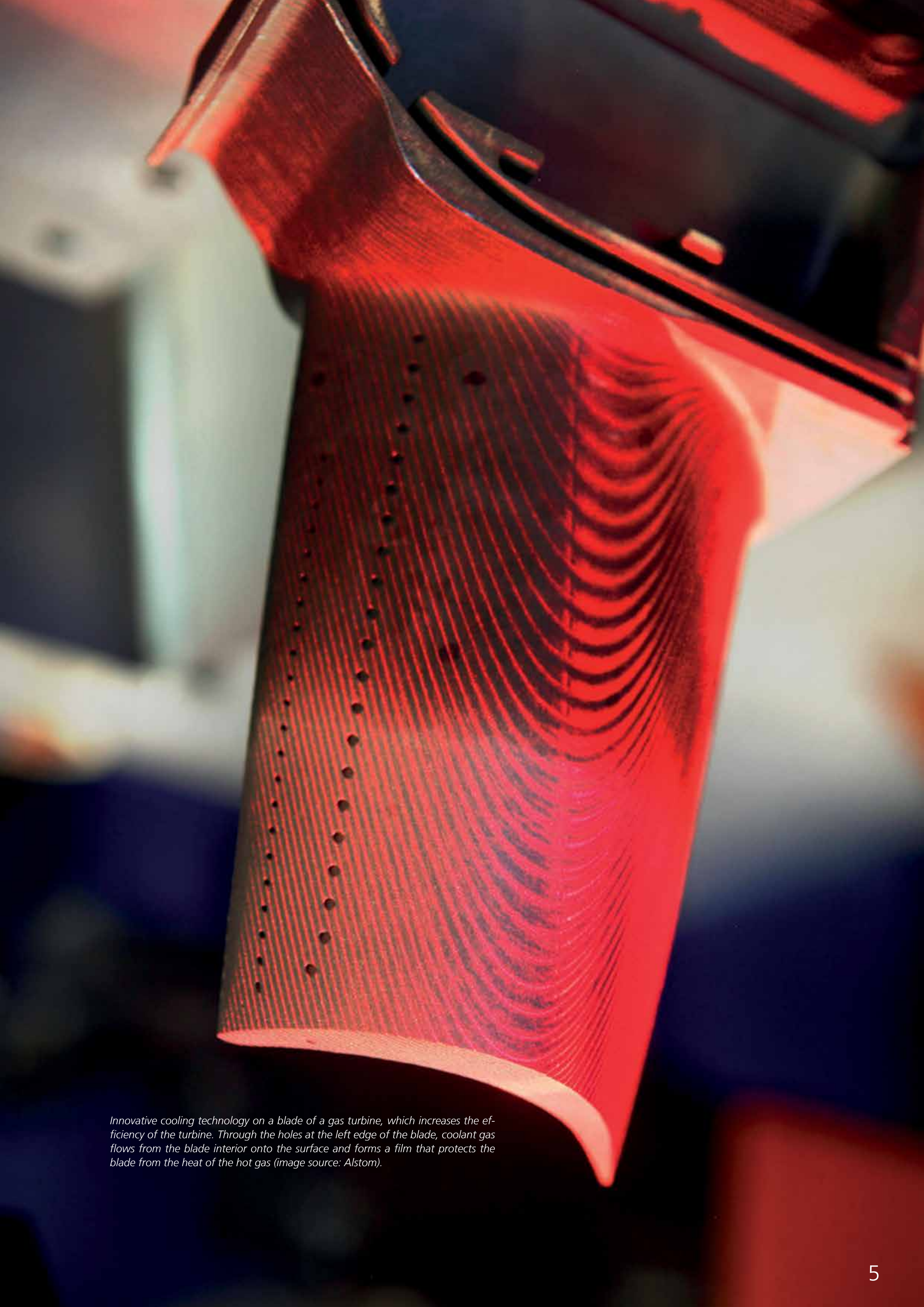
Energy research in Switzerland



Investment in the four fields of research, "efficient energy use", "renewable energy", "nuclear energy" and "energy, economy and society" at various Swiss universities and colleges of technology (figures for 2015). The largest proportion of Swiss energy research activities (71.6 percent) is carried out at the Swiss Federal Institutes of Technology Domain and Empa (Swiss Federal Laboratories for Materials Science and Testing), the Paul Scherrer Institute, Eawag and WSL (Swiss Federal Institute for Forest, Snow and Landscape Research), followed by universities of applied sciences (18.8 percent) and cantonal universities (8.2 percent). (CSEM = Centre Suisse d'Electronique et de Microtechnique, SCCER = Swiss Competence Centre in Energy Research).

- Energy in buildings
- Transports and accumulators
- Process engineering
- Grids
- Electricity technologies
- Combustion
- Fuel cells
- Heat pump technologies
- Photovoltaics
- Solar heat and heat storage
- High-temperature solar energy
- Hydrogen
- Bioenergy
- Hydropower
- Geothermal energy
- Wind energy
- Dams
- Energy, economy, society
- Radioactive Waste
- Pilot, demonstration and flagship programme

SFOE Research and Pilot, demonstration and flagship programmes.



Innovative cooling technology on a blade of a gas turbine, which increases the efficiency of the turbine. Through the holes at the left edge of the blade, coolant gas flows from the blade interior onto the surface and forms a film that protects the blade from the heat of the hot gas (image source: Alstom).

Efficient energy use

Efficient energy use is a crucial factor for achieving the objectives specified in the Federal Council's "Energy Strategy 2050". Both, the Federal Council and Parliament recognise this. Therefore, the sum of 72 million Swiss francs is being spent on creating eight Swiss competence centers, four of which will specialise in efficient energy use. This will greatly increase the research capacities in the areas of grids, buildings and industry, mobility and storage technologies. In all these areas, potentials exist which to date are still a long way from being fully exploited. It is the task of energy research to identify these potentials and find technically feasible and economically viable solutions for exploiting them.

Fuel cells with “turbos“

Fuel cell technology was discovered in the middle of the 18th century. In spite of the enormous ecological advantages they offer over, among other things, heating systems or combustion engines, a breakthrough still has not been accomplished. In recent decades numerous research projects aimed at performance improvement, optimization of durability and the reduction in cost of fuel cells have been carried out. The technical state of the art has advanced to the extent that it is not the cells themselves which pose the main challenge, but rather the hydrogen infrastructure and the compressed air supply. The latter challenge can be solved by the use of a turbo compressor developed by the Swiss firm Celeroton.

In In fuel cells oxygen and hydrogen are directly converted into electrical and thermal energy; the only “flue gas” is pure water vapour. Hydrogen is provided in pressurized cylinders, but oxygen can be taken directly from the ambient air. If one increases the ambient air pressure, the power density of the fuel cells can be increased considerably. This principle of increased power density is applied in modern combustion engines using turbochargers. In the case of fuel cells, particularly at performance levels in the low two-digit kilowatt range, the exhaust mass flow rate is too small to drive a classic turbo charger. This function has to be taken over by an electrically powered compressor. Conversely, the output needed for the compressor is no longer available for drive power. Therefore, the power consumption of the compressor has to be as low as possible for a maximum output performance level, in other words, the efficiency of the compressor system must be as high as possible.

In addition to high efficiency, turbo compressors have other advantages: as opposed to positive displacement compressors, in which a piston executes a cyclic up-and-down movement, turbo compressors deliver continuous, pulsation-free compressed air. This reduces the mechanical strain on membranes, the place where energy is converted takes place, and this in turn increases the length of their working life. Moreover, an oil-free operation ensures that membranes are not subject to contaminants. Finally, turbo compressors function practically vibration-free and are therefore quiet.

The Swiss firm Celeroton (www.celeroton.com), a spin-off of the Federal Institute of Technology in Zurich (ETH), has in recent years set re-

Impeller of a turbocompressor (image source: Celeroton AG).

Highly compact, electrically powered radial turbo compressors from the Swiss firm Celeroton. These compressors, unique worldwide in their weight and performance class with respect to outlet pressure and efficiency, are particularly well-suited for use in conjunction with fuel cells and have been successfully tested in mobile applications. (image source: Celeroton AG).

cords with an electrical motor of one million revs./min. and thus shown what is technologically feasible in the field of very high speeds of rotation. An important feature here is the sensorless regulation process: dispensing with revolution sensors makes the design of the compressor more compact and also more robust.

The gas bearings design developed by Celeroton is another important feature of this type of compressor development. This design is self-sufficient, i.e. no external compressed air is needed for the bearing. The advantage of this system as opposed to ball bearings is its contact-free operation. While ball bearings quickly fail above one million revs/min., the gas bearings function practically free of any wear.

One last, important aspect of the development of the technology is the actual compressor, the "turbo". This concerns that part of the compressor which drives the pressure increase. This technology in itself is not new and used in, among other things, turbo chargers, aeroplane engines and high performance compressors in industrial plants. Only the use of very high rotational speeds enables the miniaturization of these components, and thus the whole compressor system.

The interaction of these three aspects and an overarching understanding of the entire system enable the fabrication of miniaturized turbo compressors with the very highest degree of system efficiency and sufficiently high working life expectations for fuel cell applications. What at first sounds like the straightforward development of a product is in reality only possible with interdisciplinary know-how in the fields of aerodynamics, gas and magnetic bearings, mechanics, electromagnetics, electronics, control technology and software.

The newly launched turbo compressors with gas bearings have already met with a widespread response on the market. The development of other turbo compressors with even higher performance levels is planned over the next few years. In the context of a European project the development of a 10 kW fuel cell compressor and the requisite electronics was started in January 2017.

Gas bearings and aerodynamics can also be adapted for gaseous media other than air, such as coolants in heat pumps. In such a case the coolant is used for both the cooling of the compressors and for the gas bearings. This allows for a very compact design, a feature which combines equally oil-less functionality and a high degree of efficiency. Oil, in particular, can cause coolants to foam, something which has a negative impact on heat transfer and, consequently, the efficiency of the system.

In hybrid and electrically powered vehicles the energy requirements of the heating and air-conditioning system greatly influence the range. High-rev turbo compressors make it possible to have smaller and more efficient heat pumps which can be used for heating and air-conditioning.

Patrik Fröhlich (Celeroton AG)

125 kV converter and transformer station in Sébeillon (image source: Services industriels de Lausanne).

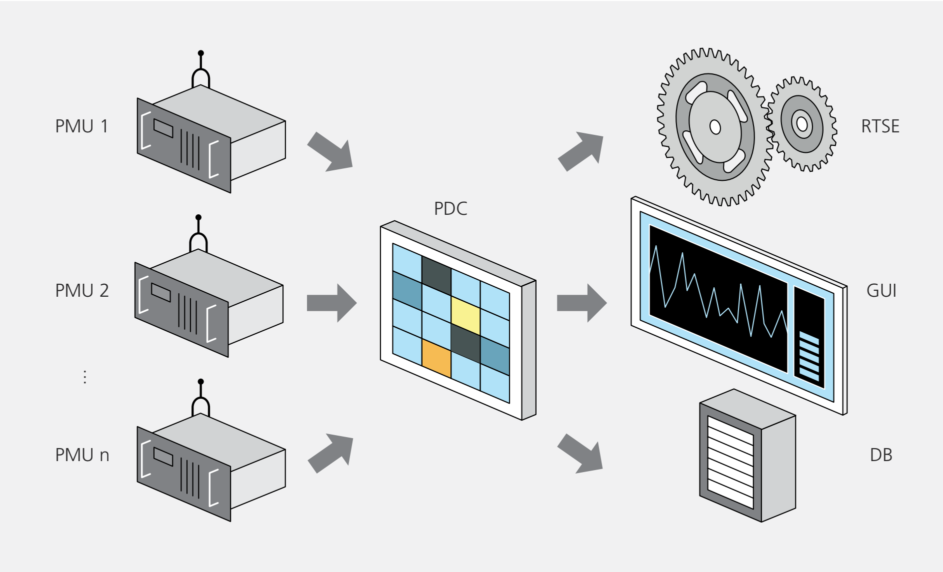
“Phasor measurement units“ in distribution grids

The fluctuating and decentralized feed-in of renewable energy makes higher demands on the running of electricity networks. These networks must be monitored in order to ensure that they are stable and remain within the limits of their operating capacity. For this purpose so-called “Phasor measurements units“ will be used in future also in the distribution grids.

The electricity system of the future will be characterized by a multitude of decentralized producers that feed electricity directly into the grids from renewable energy sources such as the sun, wind and biomass. As a rule, feed-in from these sources fluctuates considerably as it is primarily determined by local weather conditions. At the same time, however, a balance must be maintained between supply and demand at all times. Whereas previously the energy flow was almost exclusively from higher to lower network levels, this is now increasingly no longer the case. Nevertheless, voltages must at all times and everywhere remain within the tolerance band, and the temperature limits of the power lines must be respected.

In order to be able to detect in a timely fashion, to analyse and rectify deviations in voltage and frequency, as well as vibration phenomena, “Wide Area Monitoring & Control“ (WAMC) systems have now been in use for some years in transmission grids. Here, a so-called “Phasor Measurement Unit“ (PMU) measures in a synchronized manner amplitudes of voltage and current, generally at the rate of 50 times per second. Central to this process is the fact that various PMUs analyse the phase angle based on a common reference, the coordinated universal time (UTC). Time-stamped data are transmitted via a “Phasor Data Concentrator“ to a high speed central computer which determines the network state in quasi real time (RTSE).

In principle, the same process can be used in distribution grids. However, the degree of measuring precision of the PMUs currently available on the market poses a basic problem: because of shorter power lines the smaller phase angles can no longer be measured with sufficient accuracy. To address this problem, the Decentralized Electrical Systems Labo-



The individual "phasor measurement units" (PMUs) in the electrical distribution grid transmit their information to a central location ("Phasor Data Concentrator" PDC) which determines the network state in quasi real time (RTSE), shows the current system situation ("Graphical User Interface") and secures the system status in a data bank (DB).

ratory (DESL) at the Federal Institute of Technology in Lausanne (EPFL) has developed the first prototype for a PMU which meets the new IEEE-Standard "C37.118-2011" and is therefore suitable for use in distribution grids. In the context of a research project the medium voltage grid on the EPFL campus was fitted with five of these new PMUs. The project successfully demonstrated that the network state could be reliably determined in quasi real time by these PMUs.

However, it is not just for monitoring the network state that PMUs can be used. For example, the data obtained make it possible to determine the effective power loss, the reactive power flow and the power line parameters. In addition, missing measurement readings can be estimated and fault locations detected. In order to further develop and verify these applications under real conditions, the power lines of the 125-kV high voltage grid of the Lausanne Industrial Services (SIL) were fitted with a total of 15 PMUs in the context of an SFOE pilot project. The relevant "Phasor Data Concentrator" (PDC) is situated in the control centre Pierre de Plan and is supplied with data readings via the internal fibre optic network.

Analysis has shown that the time lag is less than three milliseconds and that data can be transmitted reliably, i.e. without loss. On the basis of these positive results plans are underway to integrate this system of determining the network state in the next generation of control systems and also to equip sections of the medium voltage grid with PMUs in order to optimize their operation. It is even conceivable that in a few years' time conventional protective devices will be replaced by PMUs.

In order to make this possible the PMUs must, however, be absolutely reliable and supply sufficient data. Harmonics and interharmonics which are caused, for example, by consumer electronic goods or photovoltaic inverters can adversely affect the functionality of PMUs. In the context of a European project the Federal Institute of Metrology (METAS) has, therefore, developed and set up a measuring station for testing and calibration of PMUs in accordance with the new IEEE standard.

Because of the large number of PMUs required in a medium voltage grid, the cost of GPS receivers and telecommunications constitutes a considerable barrier to implementation. The "Competence Center Innovation in Intelligent Multimedia Sensor Networks" at the University of Lucerne is specialized in the field of highly reliable real-time communications via power lines, so-called "Power Line Communication" (PLC). In the context of several research projects funded by the Commission for Technology and Innovation (KTI) and the SFOE, research is currently being carried out to determine how PMUs and PLC can be synchronized with a high degree of precision and to establish whether, if need be, the technology is also suitable for the entire data transmission to the central Phasor Data Concentrator. Such an application of PLC would eliminate another major cost factor.

Michael Moser

A newly developed 26-tonne electric truck prior to the refuse unit being installed. The large storage battery is situated between the wheel axles (image source: Designwerk).

Battery drive systems for utility vehicles and construction machinery

Lorries and construction machines are nowadays almost exclusively driven by powerful diesel engines, the disadvantages of which - noise and waste gas emissions - are well known. What is more, these combustion engines are very inefficient, as in practical use they are mainly used in the partial-load range. The electrification of such vehicles offers advantages in many respects. But, the technical implementation poses great challenges for developers.

These days, pollution in the form of noise and exhaust gases on building sites or in traffic are still omnipresent. In addition to the harmful effects of exhaust gases, noise also increasingly causes problems. Because of the high traffic density in many large cities, waste disposal and road cleaning are only possible during the night. This exacerbates the problem of noise, which leads to the limitation of the use of public service construction machines and utility vehicles. The operation of electrically driven vehicles, however, is quiet and virtually emissions-free, and delivers substantial energy savings because of their efficient drive systems and the regenerative brakes. Consequently, research in the field of the electrification of heavy utility vehicles and heavy machines has increased in recent years.

In these projects the focus is principally on the development of new batteries and the design of control systems in order to comply with the technical specifications of utility vehicles. Batteries must be efficient and also have a high storage capacity. At the same time they must be ever lighter, cheaper and longer-lasting, so that in the future, electrical vehicles and machines can offer a viable commercial alternative to those with combustion engines. Lifespan also continues to be one of the biggest unknowns in this new technol-

Prototype of an electric digger at work on a building site. The battery is situated in the raised structure at the rear, thus replacing part of the counterweight (image source: SUNCAR HK AG).

ogy, and is the object of intensive research in pilot and demonstration projects.

Correspondingly, prototypes of electric excavators have been in use since 2016 on a number of building sites in Switzerland as part of a pilot project. Initial operational experience has shown that a 16-tonne digger with a battery capacity of 170 kWh can function for almost six hours. It is now a matter of increasing the run time through technical optimization. In comparison with a diesel powered digger it uses almost 60 % less energy, and the noise pollution is reduced by up to 10 decibels. At the same time, workmen on site are not exposed to harmful exhaust gases. If, in addition, power from renewable sources were used to drive the digger, several hundred fewer tonnes of CO_2 would also be abated during its lifetime.

Testing of an electric waste disposal vehicle will demonstrate hopefully similar advantages, as well as greater cost effectiveness because of lower maintenance and operating costs. After the positive results obtained with an 18-tonne electrical lorry developed in Switzerland, hopefully the electrification of heavier vehicles will commence. The use as a waste disposal vehicle with its marked "stop-start" mode of operation and the high degree of partial load use, offers ideal conditions for testing a 26-tonne lorry with a range of up to 300 kilometres. Targets are a saving in energy of up to 70 % compared to a conventional vehicle which consumes, depending on use, up to 100 litres of diesel fuel for every 100 kilometres. In addition to the technical aspects, the question of the acceptance of such vehicles by communes, drivers and local residents is also being examined.

With a storage capacity of 270 kWh the battery that has been newly developed for the waste disposal vehicle, is amongst the biggest in Switzerland. Another industrial consortium has already started to develop an even bigger battery system with a capacity of 600 kWh designed to power an electric dumper truck weighing a total of 50 tonnes. The experience gained from these pilot and demonstration projects can be used in the future for countless other applications in the field of vehicles and machinery, thus making an important contribution towards the electrification of transport and industry.

Men Wirz


Measurement campaign on a Empa's roller test bench on a gas powered vehicle fuelled with natural gas enriched with hydrogen (image source: Empa).

Addition of hydrogen for natural gas vehicles

Current research at the Swiss Federal Laboratories for Materials Science and Technology (Empa) addresses the promising potential of adding hydrogen to natural gas (CNG = compressed natural gas) as fuel for vehicles. Various driving cycles were run through on the roller test bench, including acceleration phases and high speed driving. Fuel savings of 2 % was proven compared to running on pure CNG. Hydrocarbon emissions were reduced by around 30–60 %. In particular, the peaks in nitrogen oxide emissions due to load changes can be almost completely eliminated in the catalyst.

Stephan Renz

Performance Gap in building renovations

Building renovation projects are motivated by planners on the grounds of, among other things, energy savings. In practice, however, it has been determined that expected savings can only partially be achieved. In a current research project of the University of Geneva the thermal energy consumption in buildings both before and after renovation has been systematically investigated during the past few years. The project focused on ten very large apartment buildings in the Geneva region and established that only 30–70 % of the promised saving in energy were achieved. The reasons for this performance gap are diverse and currently the object of a more detailed analysis.

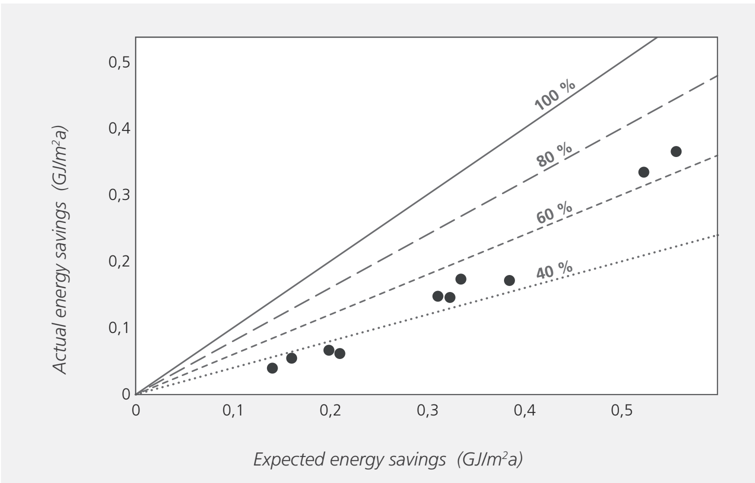
Rolf Moser

"Internet of Things" – efficient networking

Internet-based management and control systems invade everyday life. So-called "Internet of Things" (IoT) technologies provide comfort and often contribute to sustainable energy consumption. But, there are the energy requirements of the IoT-devices themselves which counter the latter. According to forecasts made by the University of Lucerne the annual energy demand worldwide owed to running IoT appliances in stand-by mode will amount to 46 TWh by 2025. "Home automation" is the largest contributor as energy demand is driven particularly by the communications technology used and its mode of operation. A significant amount of energy can be saved by making the right choice for a particular application.

Roland Brüniger

Actual thermal energy savings realized in ten large apartment buildings in Geneva, compared to the theoretical forecast. The performance gap amounts to between 30–70 % (Data source: University of Geneva).



Renewable energy

The proportion of renewable energy in the overall energy supply is constantly increasing throughout the world, especially in the electricity sector, where the annual percentage increase is in the double-digit range for certain technologies, e.g. wind power (27 percent) and photovoltaics (42 percent). The use of other technologies such as hydropower, biomass and geothermal energy is also on the rise, with hundreds of gigawatts of additional capacity now being installed throughout the world. However, the proportion of renewable energy in relation to total global primary energy demand has remained constant in the past 10 years at around 13 percent. In the area of renewable energy, the SFOE promotes research and development activities relating to technologies that can be directly applied in order to maintain a sustainable energy supply in Switzerland, as well as in other fields that have the potential to create industrial value-added in the country.

Money does not grow on trees in Davos: thermal energy from underground for the WEF

Davos, well-known both as a ski resort and for its annual World Economic Forum (WEF), is less known as a pioneer in the field of geothermal energy. In fact, project "GNAMA" (fundamentals of geothermal utilisation of alpine aquifers* at intermediate depths) has been running since 2012. The project aims to show that geothermal resources can be integrated into an energy system even in high alpine valleys. More specifically, waste heat from the skating rink is used in the Kongresshaus and its leisure centre, which is complemented with heat from a geothermal aquifer.

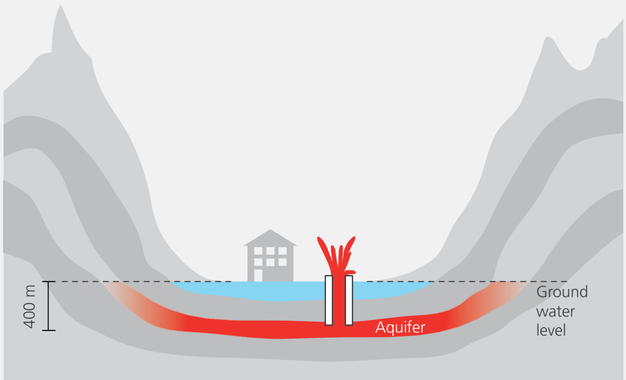
As an "energy city"**, Davos strives to find new solutions to consume less gas and oil for heating its buildings. Various studies demonstrate that, from the energy point of view, this alpine city has a valuable subsurface. So it made sense to use these resources as well, and plans were prepared to supply the Kongresshaus and the indoor pool with a mixture of waste heat generated from the ice production for the skating rink and heat from a geothermal aquifer. The corresponding geothermal project "GNAMA" (fundamentals of geothermal utilisation of alpine aquifers at intermediate depths) started already in 2012. The aim was to use the water-bearing rock horizon in the Arosa Dolomite, some 400 meters below the surface. The water in this layer is under 'artesian pressure', so that it spontaneously flows tosurface as soon as the horizon is drilled.

As an exploration well revealed a water temperature of the aquifer of only about 11–12°C. In order to be able to supply the Kongresshaus

* Aquifer = underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials

** The "Energiestadt" label is a proof of achievement for municipalities that implement a sustainable municipal energy policy (www.energiestadt.ch).

Congress center in Davos (image source: World Economic Forum/Photo by Andy Mettler).



A near surface aquifer can be used as a geothermal heat source in Davos (left). View of the head of the 400 m-deep well (right) (image source: Municipality of Davos).

and indoor pool with heat at the desired temperature, the heat content in the geothermal aquifer had to be utilized via the existing heat pump for waste heat at the skating rink,. At present, the energy from the geothermal aquifer is only used if the skating rink's refrigeration compressors do not produce waste heat, i.e. are not in operation.

The aquifer's natural flow of 1 240 l/min was used up to September 2016. The artesian pressure is too weak to push the water through the 260 m-long pipe and a groundwater heat exchanger. So, in autumn 2016 a groundwater pump was installed in the exploration well. This has been in operation since then, with short interruptions, providing both heat and interesting data as part of the "GNAMA" project.

The installation of the pump was both technically and scientifically challenging. For instance, it was necessary to determine the subsurface installation depth of the pump. On the one hand, the pump must always be in the water-bearing layer and on the other hand, it is advantageous for the pump not to be inserted too deep below the surface. Furthermore, it was not clear what the optimum flow rate needed to be to obtain useful data for the "GNAMA" work programme, which would enable an assessment of the aquifer for more intensive use later on. Finally, there was a risk to create a so-called short-circuit or mixing between adjacent aquifers.

It was possible to obtain initialanswers to these questions through numerous measurements acquired by the Davos city administration supported by the service company Geotest, as well as by numerical modelling efforts of the University of Basel. Thus, an ideal flow rate of 2 000 l/min was identified.

Owing to these optimization measures, the artificially lifted flow rate can provide about 24 % of the total heating requirements of the Kongresshaus and the indoor pool through a combination of waste heat and geothermal energy. Further studies will show whether this volume can be further increased, and what influence an even higher flow rate could have on the aquifer and the substrate.

Céline Weber, Gunter Siddiqi and Gian-Paul Calonder (Municipality of Davos)

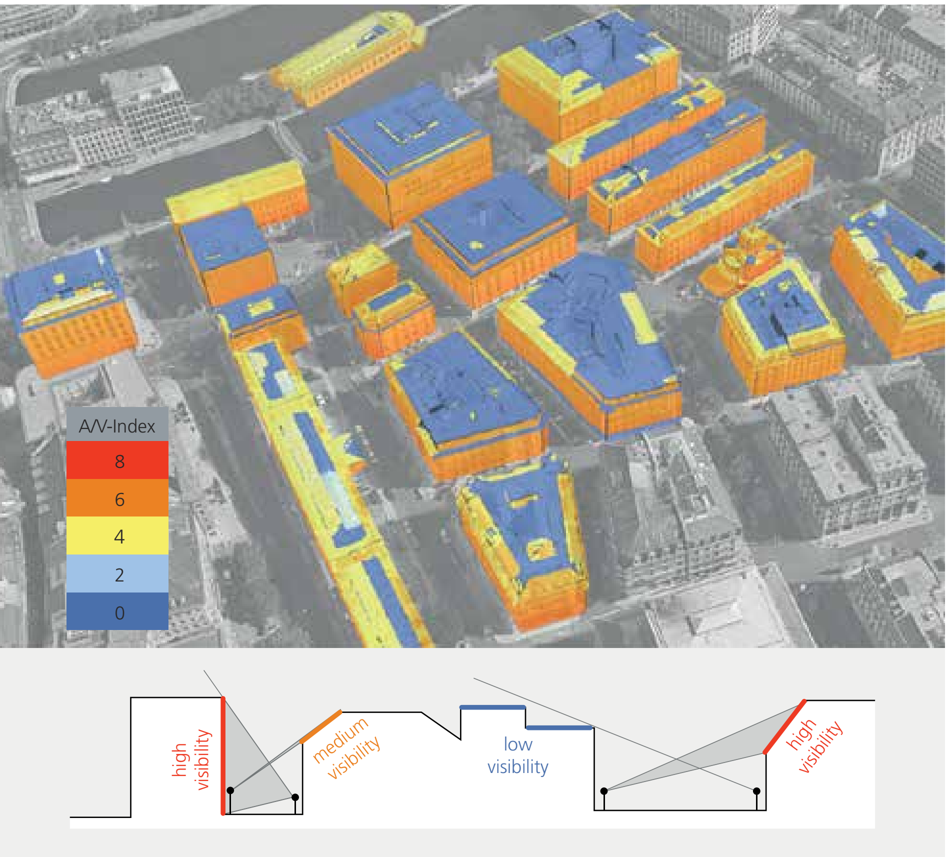
Integrated solar system in the energy self-sufficient house in Brütten (Source: Schweizer Solarpreis 2016, www.solaragentur.ch).

Architectural Integration of solar panel systems

When it comes to aesthetics, opinions tend to differ sharply on the subject of solar panels systems. An objective assessment tool has attracted international attention. Solar panels on buildings are particularly important in Switzerland, compared to other countries. However, such installations are often caught between the concerns of preserving the architectural culture (historic preservation and monument protection) and an increased use of renewable energy.

The revised Swiss urban and territorial planning legislation contains the necessary provisions aimed at ensuring that "sufficiently adapted" solar panel systems can be built on roofs without a building permit. The solar panels must be "carefully integrated" and not affect "cultural and natural monuments". There is still a certain degree of uncertainty as to the way in which such legal requirements are to be implemented.

Architectural quality can be generally described in terms of utility, stability and beauty. In the case of buildings that integrate solar systems, utility is no longer limited to the environmental protection function but also includes energy production. In contrast to building requirements, the question of aesthetics is not always easy to grasp for many experts - but neither is it for the authorities.



Representation of the assessment of building surfaces for solar use with the "QSV cross-mapping" tool by the Swiss Federal Institute of Technology Lausanne. A/V Index (Ambient/Visibility index) from 0= low visibility in an insensitive environment (e.g., industrial areas) to 8= high visibility in a sensitive environment (e.g., historical town centres) (image source: EPFL).

A catalogue of objectively assessable criteria for solar systems and their integration into architecture was developed at the Swiss Federal Institute of Technology in Lausanne (EPFL). Through a three-stage systematic process, the so-called "QSV method" (QSV = quality, location, visibility) makes it possible to verify whether a photovoltaic or thermal solar system is perfectly integrated into the architecture.

Based on this approach, the EPFL developed a software tool which allows authorities, builders and architects to apply the method with ease. This consists of three components: "QSV-Acceptability" helps municipalities to define and evaluate requirements in a socio-political context. "QSV-Grid" visualises the impact of different decisions on the urban environment. Lastly, with the component "QSV-Cross-mapping'' the architectural sensitivity of settlement areas can be mapped for proactive solar planning and compared with solar irradiation maps.

Within the framework of the International Energy Agency, the current project "Solar Energy in Urban Planning" (IEA-SHC, Task 51) addresses the same issue. The purpose of the project is to support urban planners, authorities and architects in the architectural integration of solar energy systems into the built-up environment, thus providing cities with a high proportion of renewable energy. The "QSV method" was introduced as a Swiss contribution to the international project and serves as a common tool for all participating countries. In addition, the tool has been included in various universities' curricula as well as in vocational training. In November 2016, the Swiss researchers involved were awarded Sweden's "Innovator of the Year Award" for their work.

Andreas Eckmanns

Strong inflow of suspended matter at the hydro power station in Fieschertal (image source: ETH Zurich).

Adaptation measures to climate-related increase of sedimentation

Due to the retreat of glaciers and upward migration of the permafrost boundary in alpine catchment areas, the amount of deposition of easily erodible sediments into the water bodies, water reservoirs and reservoirs increases. This leads, on the one hand, to a reduction in the storage volume that is important for flexible operation and, on the other, to more suspended particles entering the water which drives the turbines. As a result, structures and machine components are exposed to increased wear. Geologically speaking, the Alps are relatively stable and although the sedimentation rates increase, the latter remain at a low level compared to the rest of the world. Worldwide, more storage space is lost due to sedimentation than is gained by building new facilities, although the construction of new hydropower plants continues worldwide at an intensive pace.

In a research project ETH (Swiss Federal Institute of Technology) Zurich and the Lucerne University of Applied Sciences are investigating, together with hydropower plant operators, the origin of, and possibilities for avoiding, storage sedimentation, as well as a mitigation of its negative effects.

There are various ways to slow down storage sedimentation or to discharge already stored deposits. Sediment diversion tunnels, such as at the Solis reservoir in the Grisons and commissioned in 2012, are opened in the event of heavy sediment wash at high water. They divert the sedi-

Geophone plate series at the outflow of the diversion tunnel at Solis: Metal plates, equipped with acoustic sensors which detect vibrations from impacting particles, serve to quantify the transport of solid materials (image source: ETH Zurich).

ment-laden high water from the reservoir and dump water, debris and suspended particles directly into the riverbed below the dam. As a result, sediment-diverting tunnels also contribute to the bed-load transport, the restoration of which is a medium-term requirement set out in the revised Water Protection Act. In several ongoing research projects, the performance and effectiveness of such tunnels are currently being investigated using Solis as an example. The actual transported quantities of solid materials are measured with geophones and with metal plates at the bottom of tunnels fitted with sensors that measure vibrations from the impacting particles. In order to quantify the relationship between signal and transport of solid materials, comparative laboratory and natural calibrations are necessary. In another project, airplane-mounted laser scanners are used to analyse how the morphology of the waterbed below the dam changes as a result of the moving masses, and again approaches a more natural state.

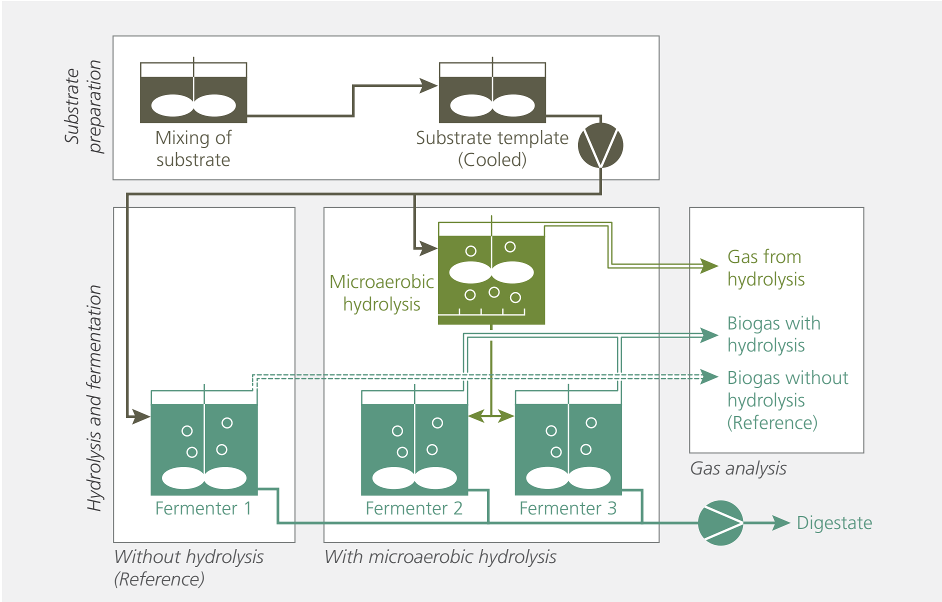
Given that there are only a few sediment diversion tunnels worldwide, in many cases reservoir flushes are carried out instead, and in the future dredging will also need to be considered. Since most of the deposits consist of very fine particles, the possibility of draining off these suspended particles with the drive water through the turbines before they settle is also being considered. In the case of high-pressure systems without storage, some of the suspended particles are separated by means of a sand trap or a so-called "Coanda" rake. Remaining particles are also discharged at this stage through the turbines. However, they can cause considerable abrasion damage. This damage, particularly to the Pelton runners, results in a reduction of the turbines` efficiency and requires regular, very cost-intensive repair measures, while power stations are partially at a standstill. For several years now, various studies have been carried out to investigate the relationship between particle concentration, particle size and the increase in abrasion damage. The damage increases disproportionately above certain particle concentrations; so the particle concentrations as well as the particle sizes have to be measured in real time and compared with the damage and efficiency losses occurring at the turbines. Through real-time measurements and correlation of the two processes, it is possible for the first time to define strategies to determine when it is economically advantageous to switch off the turbines because the financial losses due to the abrasion damage are greater than the costs of the production loss. For real-time measurement of suspended particles in water, five different measuring methods are currently being used in parallel at the Fieschertal power station.

Klaus Jorde

Methane from "complex" biomass

A significant increase in methane production (over 20 %) from fibre-rich biomass, that is difficult to degrade (e.g. manure, harvest residues etc.), is set as target of a two-stage fermentation process at pilot scale at ZHAW. In the biological pre-treatment process of micro-aerobic hydrolysis, small amounts of oxygen are added in an upstream hydrolysis stage to fractionate organic substances (cellulose, hemicellulose, lignocellulose), which are difficult for the anaerobic microflora to access, and form readily degradable intermediate products (organic acids, low alcohols and esters).

Sandra Hermle



Pilot production plant at ZHAW for the use of fibre-rich, persistent biomass.

Biogas reactors with better efficiencies

Excess carbon dioxide (CO_2) formed during the anaerobic digestion with 25–45 % by volume can be converted into methane ("biogas upgrade"). By adding hydrogen the carbon dioxide is completely transformed into 100 % pure methane. A nickel catalyst absorbs the water formed during the methanation stage, thereby suppressing the formation of unwanted by-products. At the same time, the catalyst is self-regenerating from sulfur impurities which if adsorbed would poison the catalyst.

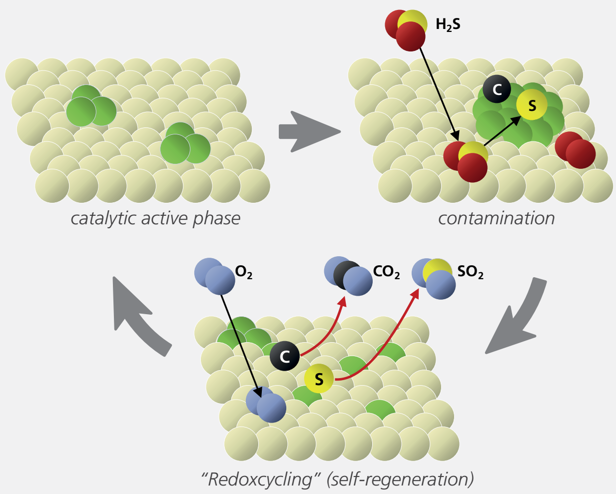
Sandra Hermle

Pilot line for solar foils

In 2015 the Swiss company Flisom put into operation a pilot production line for flexible CIGS thin-film photovoltaic modules. Currently the technology is being scaled up at this facility which has a production capacity of 15 megawatts on to an industrial level, with the aim of producing the first IEC-qualified solar modules and thus expediting the market introduction of this technology..

Stefan Oberholzer

Smart Materials: Catalytic phase can be exsoluted and reintegrated into a oxide host matrix and regenerate the catalytic phase & microstructure (image source: ZHAW).



Pilot production line for CIGS thin-film photovoltaic modules, which are produced in a roll-to-roll process on flexible substrates (image source: Flisom AG).

Socioeconomic aspects of energy technology and systems

The comprehensive "Energy / Economy / Society" research programme focuses on economic, sociological, psychological and political issues along the entire energy value chain. Its purpose is to foster the development of new energy policy instruments and review existing ones.

In 2014 a broad range of research projects have been supported that focus on topics as diverse as behaviour of energy consumers, electricity market structure, potential of demand-side management and the potential impacts of energy policy instruments on the national economy.

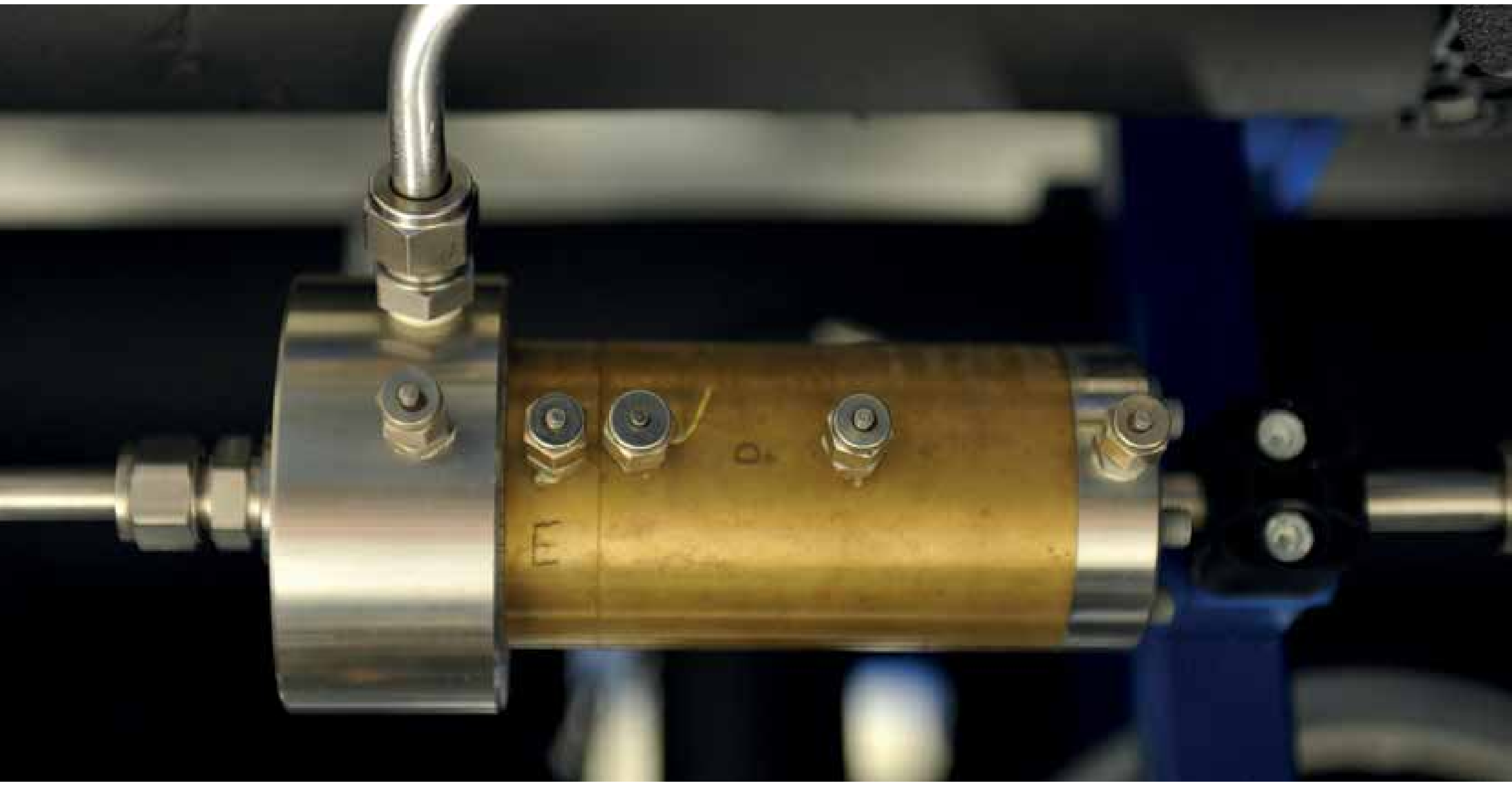
Understanding and influencing individual energy behaviour

The landmark decision of the Federal Council and the Parliament to gradually phase out nuclear power requires the successive conversion of the Swiss energy system. The implementation of the "Energy Strategy 2050" is accompanied by an improvement in energy efficiency, as well as a change in the behaviour of the stakeholders. Various studies undertaken in the context of the EEC's Research Programme examine the question of how unutilized potential can be made available to reduce individual energy consumption.

In improving energy efficiency in the household, information plays an important role when purchasing new equipment. The goal is to enable the consumer to make a rational and informed purchasing decision, based on information. It is particularly important to reduce the energy efficiency gap. This arises when the consumer, in choosing between equivalent devices, does not select the most energy-efficient, although the latter comes with the lowest cost over the entire lifetime. A research team at the Swiss Federal Institute of Technology (ETH) Zurich has investigated the type of information consumers need when making a purchase and the knowledge required to understand this information correctly. The researchers were able to show that the probability of choosing the cost-efficient device increases if the annual energy costs are expressed in Swiss francs, rather than the annual energy consumption in kWh. Likewise, the probability of making the "right" choice among consumers who are able to work out the value of the investment is higher. This not only highlights the importance of the buyer's prior knowledge, but also of a carefully selected presentation of the energy consumption information.

Consumers currently receive information on energy efficiency primarily through energy labels. In a further field study at ETH Zurich, the influence of two different energy labels on on-line purchases of household

Photovoltaic façade at CSEM in Neuchâtel with bifacial solar cells (copyright: CSEM/David Marchon).



Refrigerated shelves and deep-freezers often operate with CO_2 refrigeration plants which use an environmentally friendly refrigerant but operate at very high pressures. The energy losses through the expansion valve in the refrigerant circuit are correspondingly large. A very promising approach to avoid such losses lies in the incorporation of an "ejector" (figure), a relatively simple component that creates a vacuum through a constriction in the pipes cross-section followed by a conical widening. This component acts as a pump, but without moving parts (image source: Frigo-Consulting AG).

appliances and televisions was investigated. It emerged that the established European Union (EU) energy label, as well as a new energy label with monetary and lifecycle related information on electricity consumption, can under certain conditions reduce the annual electricity consumption of purchased equipment. For devices with high annual electricity costs, monetary and lifecycle related information on energy labels seems particularly promising.

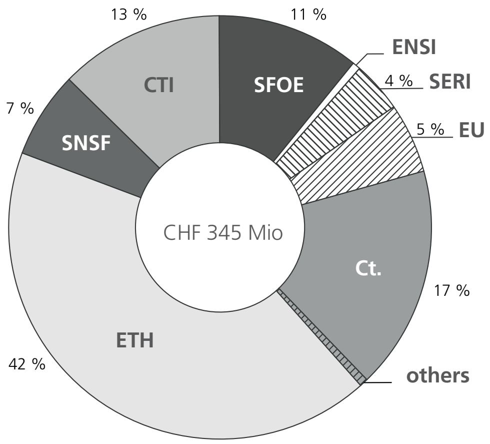
Despite the benefits of EU energy labels, misunderstandings still exist: many consumers assess the energy-friendliness of electrical appliances based on energy efficiency and neglect the effective electricity consumption. They assume that energy efficiency is equated with electricity consumption and thus high efficiency automatically implies lower power consumption. This erroneous conclusion on energy efficiency is problematic since it can lead to a larger device being selected or a device being used more frequently because of the good efficiency rating. In addition, it has been shown that many consumers have trouble interpreting energy information correctly. Hence it is difficult to identify the most energy-efficient device from a selection. The authors of corresponding studies therefore recommend that energy information be better adapted to the abilities of consumers, especially with regard to the numerical information on annual consumption. In addition, the use of an absolute scale for energy efficiency rating is to be recommended, as this would reduce the problem of false interpretations on energy efficiency.

Anne-Kathrin Faust

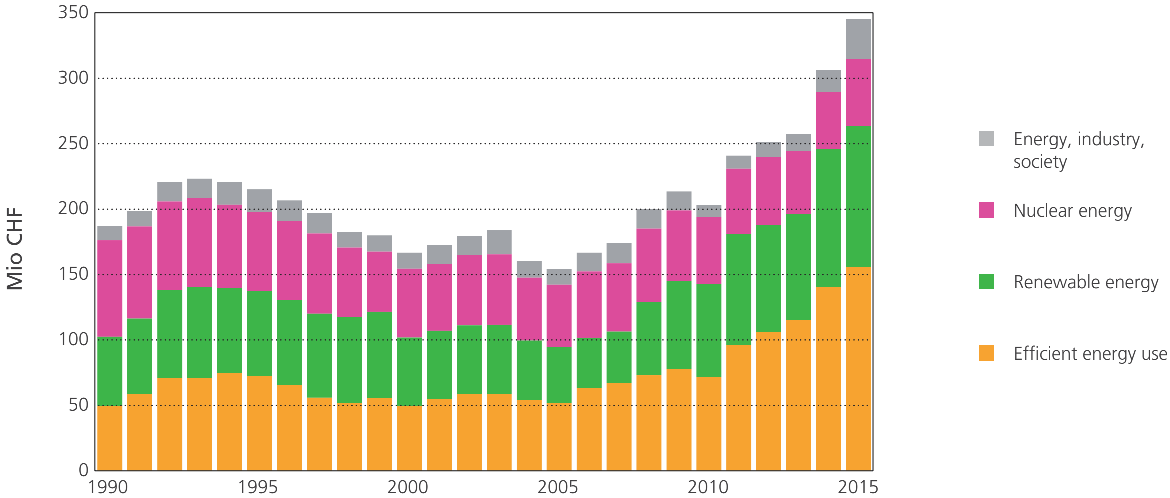
Up-to-date logistical data and yield forecasts for photovoltaic plants make it possible to control the electricity demand of a deep-freeze warehouse. The aggregation of several plants of different characteristics with the necessary granularity and dynamics makes the provision of secondary control performance possible for the network operator (image source: Migros distribution company Neuendorf AG).

Facts and figures

Since 1977, the Swiss Federal Office of Energy (SFOE) is collecting data on research, development and demonstration projects in the energy sector in Switzerland. The survey is carried out by means of inquiries from the databases of the Swiss Federal Government, the Swiss National Science Foundation and the European Comission, the analysis of annual reports, as well as a self-declaration of the research officers of the research centers. The thematic classification and final examination of the projects is carried out by the SFOE. Each year, around 1 400 projects are recorded, tested and statistically evaluated. An overview of the data collection is published at www.energy-research.ch.



Sources of public funding for research, development and pilot and demonstration projects in 2015 (ETH = Federal Institutes of Technology and associated entities: Federal Institute of Technology, Zurich; Federal Institute of Technology, Lausanne; Empa [Swiss Federal Laboratories for Materials Science and Technology]; Paul Scherrer Institute [PSI]; Eawag; Swiss Federal Institute for Forest, Snow and Landscape Research [WSL] / SNF = Swiss National Science Foundation / CTI = Commission for Technology and Innovation / SFOE = Swiss Federal Office of Energy / ENSI = Swiss Federal Nuclear Safety Inspectorate / SERI = State Secretariat for Education, Research and Innovation / EU = European Union / Ct. = cantons).



Long-term overview of public expenditure on energy research. Figures are shown as real data, i.e. after adjustment for inflation for 2012, and vary between 0.03 and 0.065 percent of GDP.

Public expenditure on applied energy research, including pilot and demonstration projects, in million Swiss francs in 2015 (nominal amounts). In the area of nuclear fusion it is primarily basic research that is carried out, but in accordance with international practice, research activities are nonetheless included in energy research. Interdisciplinary projects are allocated to the respective overlying research area.

1 Energy Efficiency	94.4
11 Industry	17.7
12 Residential and commercial buildings, appliances and equipment	25.3
13 Transport	40.1
14 Other energy efficiency	11.0
19 Unallocated energy efficiency	0.3
2 Fossil Fuels: Oil, Gas and Coal	13.2
21 Oil and gas	7.0
23 CO2 capture and storage	6.2
29 Unallocated fossil fuels	0.1
3 Renewable Energy	92.3
31 Solar energy	45.9
311 Solar heating and cooling	5.0
312 Solar photovoltaics	32.2
313 Solar thermal power and high-temp. applications	6.4
319 Unallocated solar energy	2.2
32 Wind energy	1.9
34 Biofuels (incl. liquid biofuels, solid biofuels and biogases)	17.7
35 Geothermal energy	14.1
36 Hydroelectricity	12.5
39 Unallocated renewable energy sources	0.2
4 Nuclear Fission and Fusion	51.2
41 Nuclear fission	25.6
42 Nuclear fusion	24.3
49 Unallocated nuclear fission and fusion	1.2
5 Hydrogen and Fuel Cells	27.9
51 Hydrogen	11.3
52 Fuel cells	6.4
59 Unallocated hydrogen and fuel cells	10.2
6 Other Power and Storage Technologies	39.6
61 Electric power generation	7.6
62 Electricity transmission and distribution	23.3
63 Energy storage (non-transport applications)	8.7
631 Electrical storage	4.5
632 Thermal energy storage	2.3
639 Unallocated energy storage	1.9
7 Other Cross-Cutting Technologies and Research	26.5
71 Energy system analysis	24.9
72 Basic energy research that cannot be allocated to a specific category	1.0
73 Other	0.6
Total	345.1

International collaboration

Switzerland attaches a great deal of importance to international cooperation in the field of energy research. At the institutional level, the SFOE coordinates its research programmes with international activities in order to utilise synergies and avoid unnecessary duplication. Cooperation and knowledge exchange with the International Energy Agency (IEA) are of particular importance: via the SFOE, Switzerland is involved in a variety of IEA "Technology Collaboration Programmes" (formerly known as "Implementing Agreements", cf. www.iea.org/tcp).

At the European level, wherever possible Switzerland actively participates in the research programmes of the European Union. Here, at the institutional level the SFOE coordinates energy research with the European Strategy Plan for Energy Technology (SET Plan), the European Research Area Networks (ERA-NET), European technology platforms, joint technology initiatives, etc. And, in some specific areas (e.g. smart grids, geothermal energy), Switzerland is involved in intensive multilateral cooperation with a variety of selected countries.

Impressum

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Emergency radio and telecommunications must also function in the case of power interruptions. Fuel cell systems with hydrogen are able to provide emergency power in uninterruptible power supplies (UPS) over longer periods of time. In Switzerland, antennas with fuel cell UPSs are tested in field experiments. The picture shows an antenna of the Swiss safety network "Polycom" of the cantonal police Nidwalden (image source: HSLU).

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