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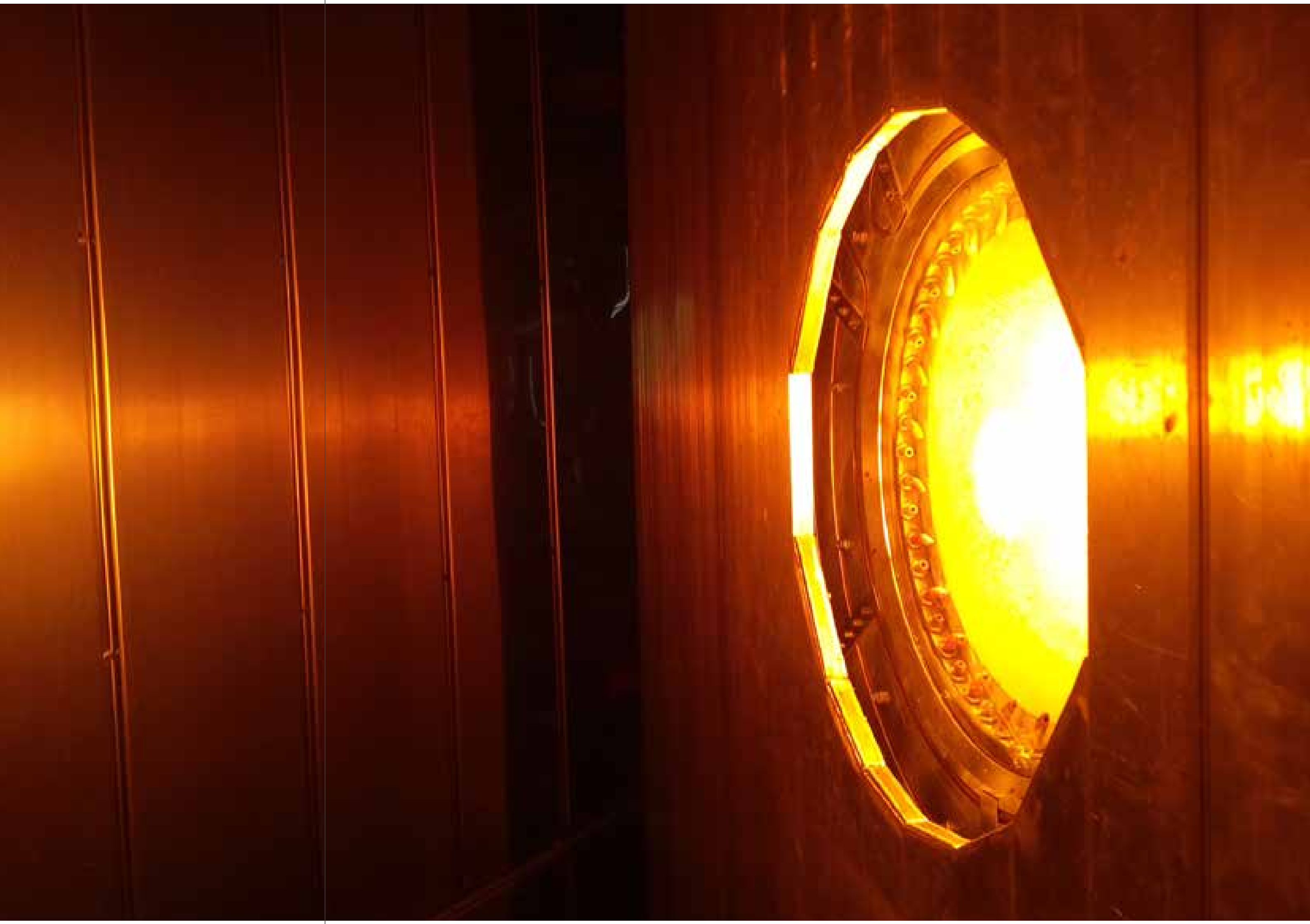
Swiss Federal Office of Energy SFOE

Energy research and innovation
Report 2014



“With its profound and comprehensive know-how and its thorough knowledge of the energy industry, the Swiss Federal Office of Energy is a highly valued partner in the promotion of energy-related innovation. We are able to benefit from its expertise, both in our own promotion activities as well as in the steering of the newly created Swiss Competence Centres for Energy Research.”

Walter Steinlin, President of the Commission for Technology and Innovation (CTI)

EDITORIAL

Energy research in Switzerland has always encompassed the entire breadth of the innovation chain, from basic to applied research, product-related development and pilot and demonstration projects. While some areas of technology are able to become quickly established on the market, other energy technologies require longer development timeframes that in some cases can encompass several decades. In Switzerland, alongside other support agencies the Swiss Federal Office of Energy (SFOE) plays a significant role in the coordination and promotion of energy research. This includes the development of expertise, the integration and cooperation of a broad variety of partners, international coordination and direct support for research, pilot, demonstration and flagship projects – all with the aim of supporting the restructuring of our energy system and thus securing Switzerland's electricity and energy supply over the long term.

This brochure presents a selection of innovative projects that are being supported by the SFOE.

Dr. Walter Steinmann
Director

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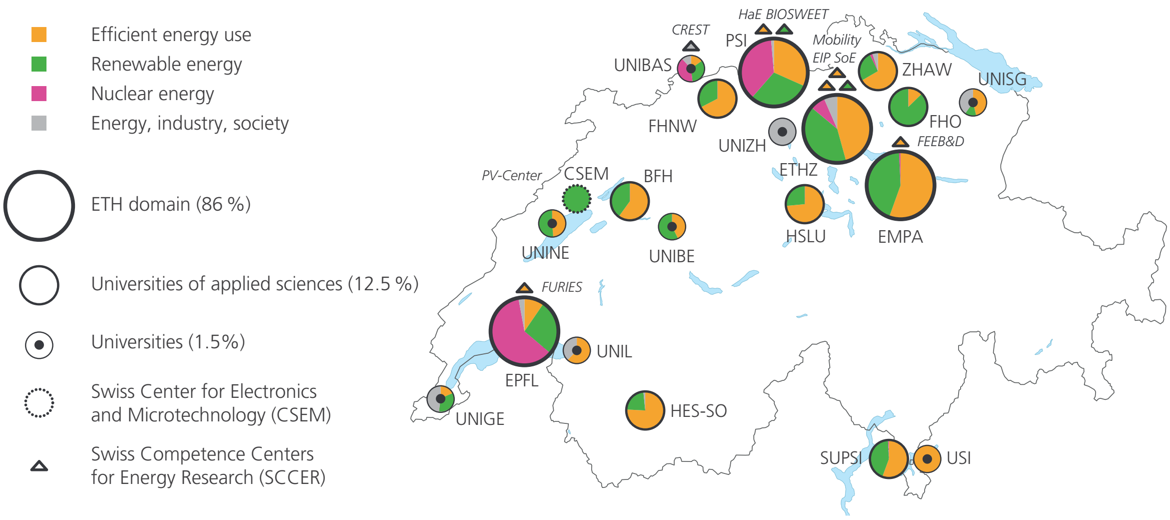
A list of projects running in 2014 in the field of energy is available in the supplementary document to this brochure, which can be found in electronic form on the website www.energy-research.ch.

ENERGY RESEARCH IN SWITZERLAND

Innovation is a significant factor for the competitiveness of a country's economy. The fact that Switzerland is among the world leaders in this area is repeatedly confirmed by its excellent international rankings. In 2014, Switzerland was placed at the top of the "Global Innovation Index" for the fourth year in succession. The key to innovation lies in research, which is the starting point for new findings and ideas that lead to innovative and competitive products.

In order to retain its leading position, Switzerland has to constantly review its research performance, identify existing gaps and, where necessary, expand its research capacities. In view of the Federal Council's proposed new energy policy ("Energy Strategy 2050") and its decision to gradually withdraw from the use of nuclear energy, this especially applies to research and development in the energy sector. In the wake of the Fukushima "major incident", the Federal Council closely examined Switzerland's research landscape and commissioned the formulation of an energy research action plan. During the 2013–2016 legislature, research capacities are being greatly expanded within the framework of eight new entities – Swiss Competence Centres for Energy Research – as well as at the two Federal Institutes of Technology.

The intention here is that the competence centers are to develop solutions for the technological, social and political challenges associated with the new energy strategy. In the area of energy efficiency, two competence centers have been created, one of which focuses on future energy efficient buildings and districts (www.sccer-feebd.ch), and the other on efficiency of industrial processes (www.sccer-eip.ch). The increase in the production of electricity from renewable energy sources places new demands on the electricity grid and calls for new efficient methods of storing energy. This area is being addressed by a competence center focusing on future Swiss electricity infrastruc-



Expenditure on research in the areas of efficient energy use, renewable energy, nuclear energy, and energy, the economy and society at various Swiss universities (figures for 2011). The involved sections of the Federal Institutes of Technology in Zurich and Lausanne, EMPA (Swiss Federal Laboratories for Materials Science and Technology), the Paul Scherrer Institute, Eawag AG and the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), account for the highest proportion by far of energy research activities (86 percent), followed by colleges of technology (12.5 percent) and cantonal universities (1.5 percent).

ture (http://sccer-furies.epfl.ch) and another on heat and electricity storage (www.sccer-hae.ch). Another competence center focuses on electricity supply (www.sccer-soe.ch) in the areas of geothermal energy and hydropower. With a share of around one-third of end energy consumption, the mobility sector is of particular importance. Here, a competence center was created for research into efficient transport concepts, processes and components (www.sccer-mobility.ch). The focus of another competence center lies on the use of biomass for the preparation of gaseous and liquid fuels and the production of renewable electricity and heat (www.sccer-biosweet.ch). The eighth competence center examines the regulatory framework and incentive mechanisms associated with the "Energy Strategy 2050" (www.sccer-crest.ch).

In a sustainability-oriented energy supply system, photovoltaics is gaining in importance at both the international and the national level. In accordance with the new energy strategy, photovoltaic systems are to account for almost half the electricity produced from new renewable energy sources. In this connection, in 2013 (prior to the creation of the eight competence centers) the Swiss Centre for Photovoltaic Systems was established at the Swiss Centre for Electronics and Microtechnology in Neuchâtel (www.csem.ch/pv-center), with the aim of accelerating the industrialisation of solar components and systems, developing new generations of photovoltaic cells and modules, and supporting the transition to a national energy system in which solar power is to play a significant role. This center has been granted 19 million Swiss francs for the period from 2013 to 2016.

The promotion by the federal government of highly promising innovations is taking place at a variety of levels. SFOE energy research (sector research) primarily encompasses applied research through to the development of prototypes and pilot/demonstration projects, while the focus of the Commission for Technology and Innovation (CTI) is on translating successful research results into products and services that are able to hold their own in the market. In this way, the research and development projects, as a rule together with universities and companies, help increase the competitiveness of Swiss companies. With the creation of the eight competence centers, the SFOE's budgets for pilot and demonstration projects, as well as the CTI's budget for the promotion of energy-related projects, have been greatly increased.

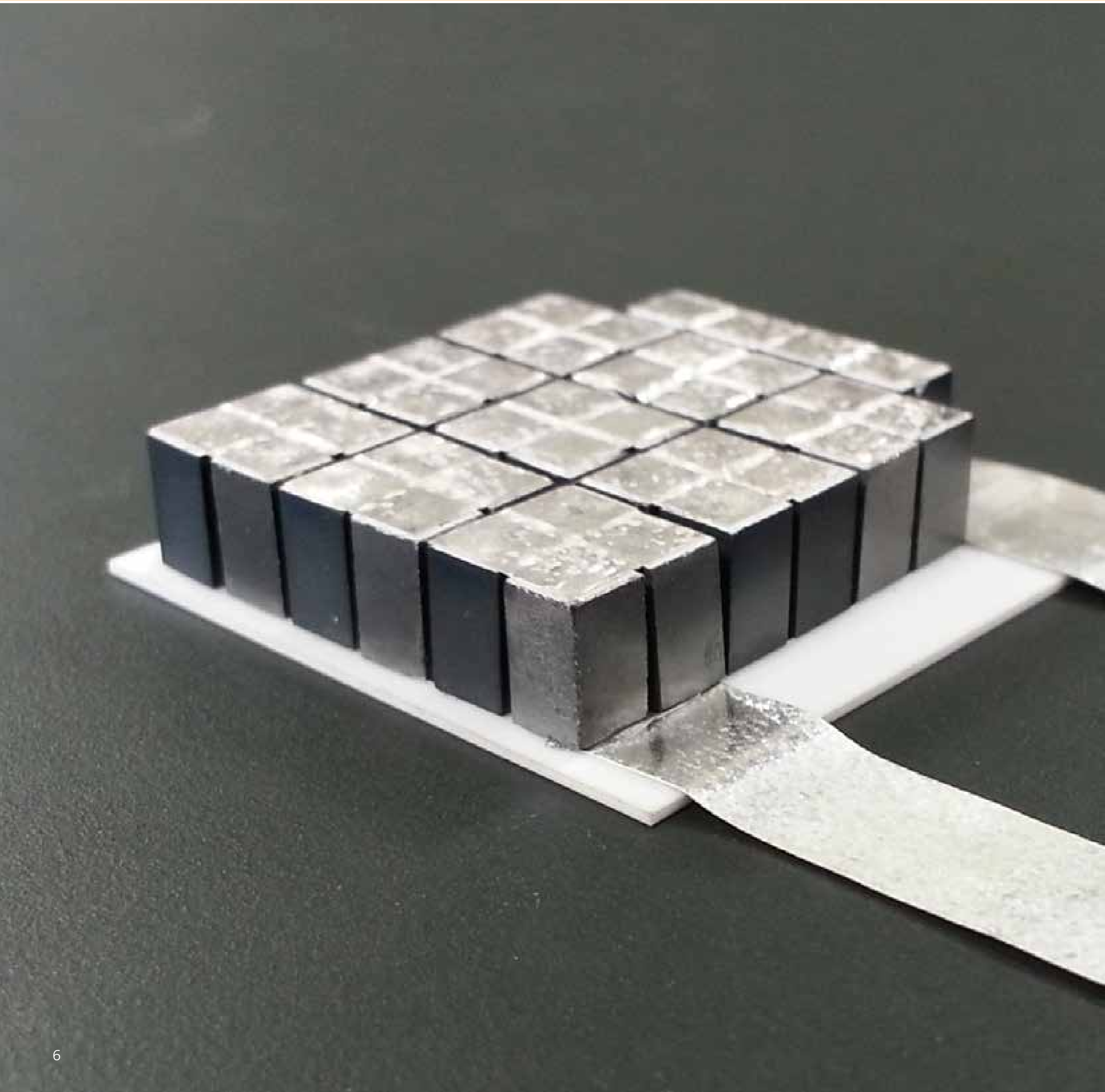
In the wake of the 2011 "major incident" in Fukushima, the Federal Council asked the Swiss National Science Foundation (SNSF) to call for tenders for National Research Programmes focusing on the change in energy strategy (NRP 70) and steering of energy consumption (NRP 71). While NRP 70 concerns scientific and technological aspects of the change in energy strategy and the associated shift towards a new energy system, NRP 71 examines the social, economic and regulatory aspects of the change in energy strategy and thus looks into ways in which players in both the private and the public sector can be encouraged to use energy more efficiently. The activities of the national research programmes are to be carried out in the period from 2014 to 2018, with a total budget of 45 million Swiss francs.

With the exception of the Radioactive Waste research programme, the SFOE does not manage any programmes in the area of nuclear energy. But, research activities in the field of nuclear fission are carried out at the Paul Scherrer Institute (PSI), while the Federal Institute of Technology in Lausanne conducts research into nuclear fusion, and the Swiss Federal Nuclear Safety Inspectorate (ENSI) is responsible for regulatory safety research.

Rolf Schmitz / Stefan Oberholzer

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, in the next four years, the sum of 72 million Swiss francs is to be spent on creating eight new 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.

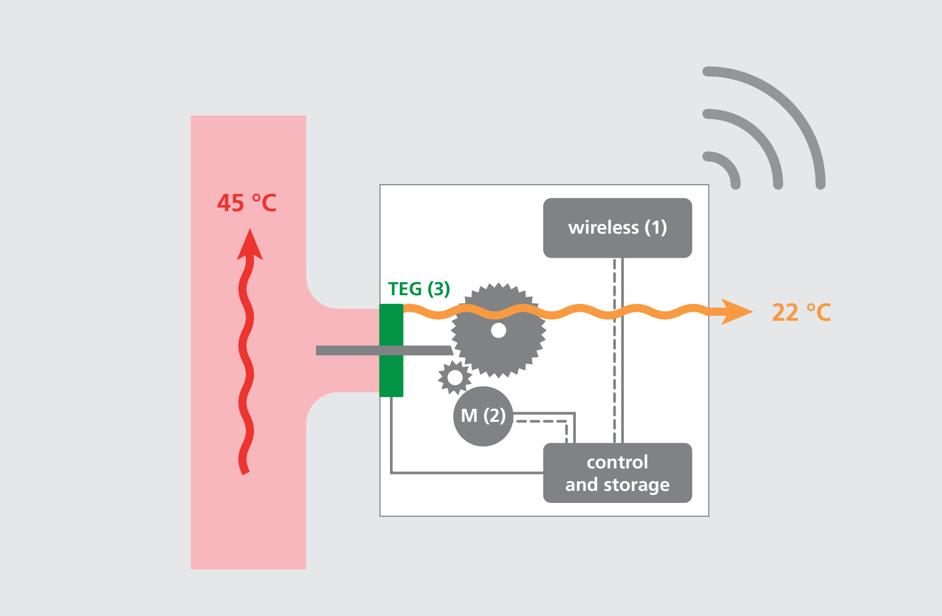


Thermoelectric generators: electricity from heat

Thermoelectric generators are able to produce electricity directly from a heat source without the need for movable components. The underlying physical effect (Seebeck effect) describes the production of electric voltage (thermoelectric voltage) at the point of contact of two electrically conductive materials that are at different temperatures. The effect is reversible, and has been used for many years, for example for cooling in noise-free mini-refrigerators, though the level of efficiency is relatively low. However, the production of electricity based on temperature differences can be an attractive proposition if waste heat can be utilised that would otherwise be released unused into the atmosphere. The potential regarding unused industrial waste heat is estimated at around 250 GWh in Switzerland alone.

In 2008, the Swiss Federal Office of Energy initiated a study on the potential of thermoelectricity in which the latter was compared with other competing technologies. One of the findings of this study was that thermoelectric materials need to be greatly improved in terms of performance and temperature stability. This led to the introduction of a number of research projects focusing on thermoelectric materials. At the same time, the first prototypes of thermoelectric generators were developed and tested. A study concluded in 2014 examined the feasibility of utilising heat produced on a large scale in industry, for example in steel mills and foundries, and concluded that thermoelectric utilisation is of interest. But it also became apparent that relatively voluminous components would be required in order to capture sufficient waste heat (in the kilowatt and megawatt range) and utilise it thermoelectrically. This raised the question of economic viability.

There is also a great deal of potential for thermoelectricity in the area of energy harvesting. This refers to the potential of "harvesting" energy from solar, heat or kinetic sources with the aid of mobile network-independent mini-generators. A thermoelectric generator heating valve, which obtains the necessary energy for the desired regulation from the difference in temperature between room air and heat flow-



Automatic heating valve to control the ambient temperature. The energy for the wireless unit (1) and the control/ storage unit (2) is provided by a thermoelectric geneartor (3).

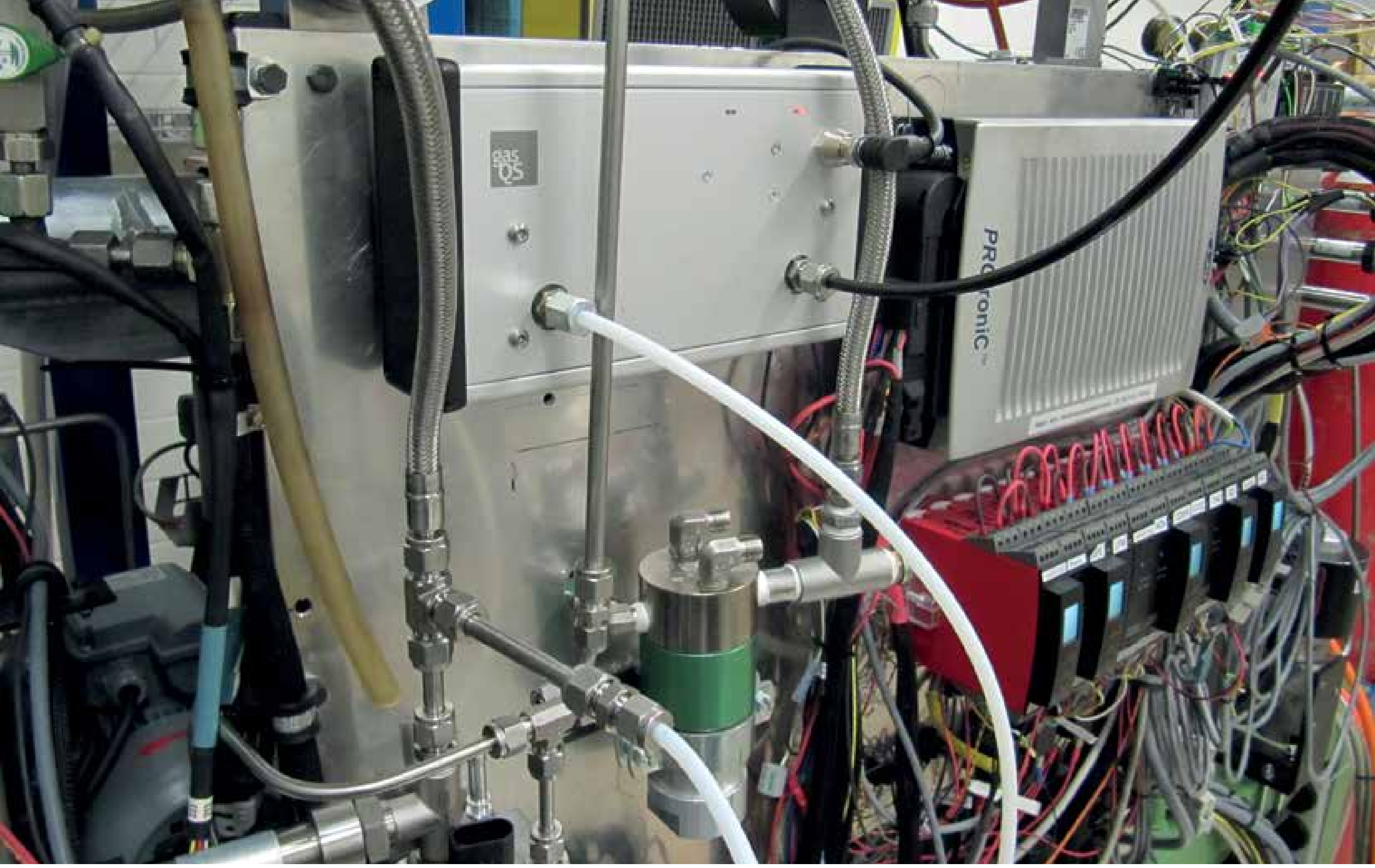
ing through a radiator, is a highly promising application. Conventional heat valves (thermostats) are very widely used. They work reliably, but in terms of energy efficiency they often do not optimally regulate the room temperature. Generally speaking, apartments tend to be heated throughout the day, even though no one is at home. And during longer holiday absences, radiators maintain the room temperature unless someone has taken the trouble to manually adjust the thermostat. This problem could be avoided through the use of an automated room temperature regulation system (building management system). These systems regulate room heating "intelligently": if someone is at home, the heating system maintains a desired temperature, otherwise it automatically reduces the temperature. Building management systems transmit their control signals wirelessly to the heating valves, which then automatically respond to the command they have received. In combination with automatic heating valves, such systems can reduce the heat consumption by around 25 percent, without any loss of comfort for the occupants of the building.

In comparison with conventional thermostat valves, automatic heating valves contain two additional components (see illustration above): (1) a radio receiver that receives the control signal; (2) a motor that opens and shuts the radiator intake as required. Both these components require electricity that is produced with the aid of a thermoelectric generator (TEG) integrated into the heating valve. As energy source, the TEG uses the temperature difference of 10 to 40 °C between the flow temperature of the heating system (35 to 60 °C) and the room temperature (20 ° to 25 °C).

A thermoelectric generator designed for this application could already become available by the end of 2015. Within the scope of a project supported by the SFOE, GreenTEG – a company based in Zurich – is currently working on the development of a fully functional prototype that can subsequently be manufactured in serial production. The mini-generator has to be able to produce enough electricity to operate the heating valve. The fingernail-sized TEG should be able to deliver between 100 and 200 microwatts, but this will not suffice to directly supply an automatic heating valve. In view of this, the TEG is to supply an interim electric storage device (supercap or accumulator) and the radio receiver and motor can then call up the necessary power from this device as required.

Generally speaking, thermoelectric technology has the potential to be used for a variety of promising new applications, and thanks to further research it should be able to make a contribution towards greater efficiency in a variety of areas.

Roland Brüniger / Michael Moser



Gas quality sensor in the "GasPot" project on the engine test bench at Empa.

Gas quality sensor to control combustion in a gas engine

Knocking ignition, a spluttering engine or insufficient output of a combustion engine can be caused by poor fuel quality. Gaseous fuels are gaining importance for the operation of vehicles or the production of electricity. They come from a variety of sources and vary considerably in terms of chemical composition. Losses in performance can be prevented by detecting the gas quality and adjusting the control of the combustion process in real time. This has been successfully demonstrated in laboratory tests with the aid of a new gas quality sensor.

Natural gas supplied to Switzerland is in quality category "H" (high methane content), the calorific value of which is guaranteed within a narrow bandwidth. However, the chemical composition can nonetheless vary. Gas from Russia, for example, has a 97 mol percent methane content, compared with North Sea gas, which has only 87 percent, but has a higher proportion of ethane, propane and carbon dioxide. In future, liquefied natural gas (LNG) transported by ship will be fed into the European network to an increasing extent, and this product in turn has a different composition. Furthermore, processed biogas or electrolytically produced hydrogen will also be increasingly added. The composition of directly utilised (i. e. non-processed) biogas constantly fluctuates, and this product also has a very high carbon dioxide content.

Fluctuations in the gas composition have an influence on ignition delay, self-ignition, the combustion process and pollutants in exhaust gases. The effects vary according to the combustion concept – for example, stoichiometric operation with exhaust gas recirculation, or lean-

Gas quality sensor developed by MEMS AG, which analyses the gas composition in real time so that the combustion parameters in a gas engine can be adjusted accordingly.

burn operation with excess air. The potential impacts of the various gas compositions include a higher degree of wear and tear and the shift of the center of combustion, which can result in a reduction in efficiency. In modern vehicle engines, some of the variability of the fuel can be offset through engine control. For example, knocking can be detected and the ignition point can be adjusted accordingly. However, unless the exact gas composition is known, it is generally not possible to correct other detrimental effects.

In order to directly adapt the combustion process to variable gas compositions, it is necessary to know the combustion-related properties of the fuel. For this purpose a measurement procedure is required that detects the gas quality in the engine and supplies the data to the engine control mechanism. Such a component has been jointly developed by MEMS AG – a spin-off of ABB Research Centre Switzerland – and the Swiss Federal Laboratories for Materials Science and Technology (Empa).

By measuring the temperature via a micro-thermal chip it is possible to determine the thermal conductivity, the specific heat capacity and the density of the gas. The specific volume can also be measured with the aid of a special device. A quantitative gas quality can then be determined with the aid of correlation algorithms by making a comparison with the reference values of a broad variety of different gases.

On an engine test bench at Empa a single-cylinder engine was equipped for operation with various combustion processes (direct intake, loaded, stoichiometric with exhaust gas recirculation, lean-burn with excess air) and attached to a set of measuring instruments. The engine was operated with six different gas compositions: 100 percent methane and methane with up to 40 mol percent carbon dioxide, 13 mol percent ethane, 25 mol percent nitrogen and 15 to 25 mol percent hydrogen. This ensured that a wide range of different gas qualities could be set up and measured.

The proportion of hydrogen strongly influences the ignition capability of the fuel, which results in a shorter ignition delay and a faster initiation of combustion. This is more pronounced with lean-burn than with stoichiometric combustion with exhaust gas recirculation. With a higher proportion of carbon dioxide, a marked slowing of combustion can be observed, as is the case with biogas.

In all the tests on the combustion engine, a gas quality sensor was utilised and the results of the measurements were compared. The change in gas quality was reliably detected and a correlation between the quality of the utilised gas and the impacts on the combustion properties in the engine was identified. By programming the engine control mechanism it is possible to adjust the operation of the engine upon detection of a particular gas.

In the meantime, however, the gas sensor has been developed from a laboratory instrument to a preliminary product. An interest in this sensor has been expressed not only by engine manufacturers and system developers, but also by gas network operators as an instrument for monitoring the quality of the gas in their network.

Stephan Renz

Reka Holiday village of Blatten (VS): The roofs are oriented to the east and west so that the solar energy yield is at its highest in the morning and afternoon, i.e. when energy demand in the holiday village is at its daily peak.

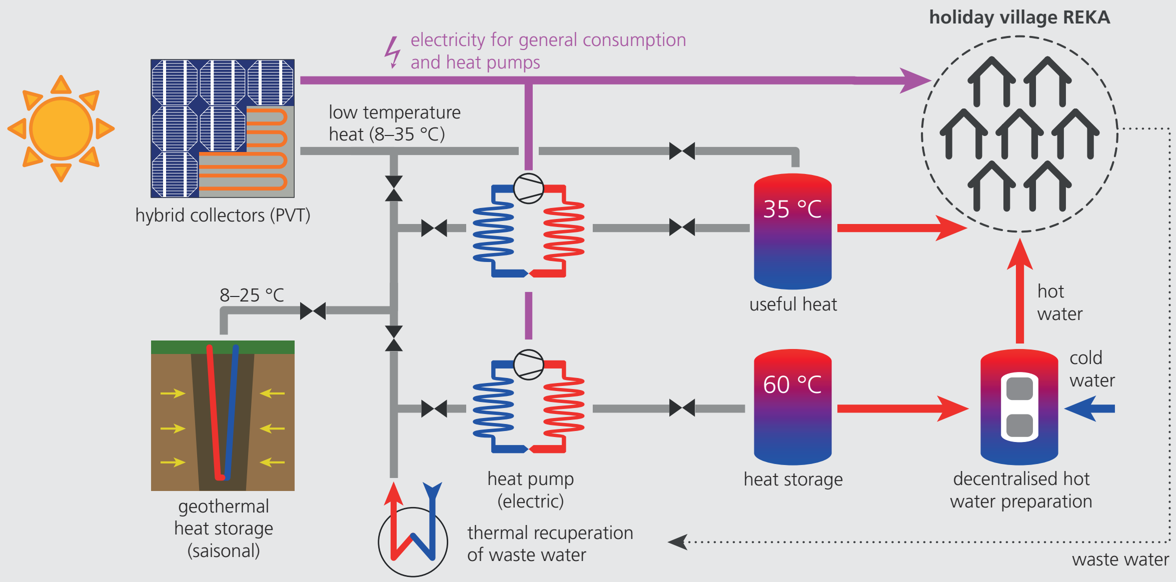
Dual benefit from the sun

People who spend their holiday in the Reka (Swiss Travel Fund) holiday village of Blatten (canton of Valais) can enjoy the benefits of the sun's rays in two ways at the same time: they can soak up the warm sunshine on the southern slopes of Valais, and can also make use of the sun's rays indirectly because these deliver more than two-thirds of the village's energy requirement. Hybrid solar collectors produce hot water and electricity, so that Blatten is free of fossil energy.

The Reka opened its holiday village in Blatten at the beginning of the December 2014 season. Blatten is the fourteenth holiday village operated by Reka in Switzerland and Italy, accommodating up to 350 guests in 50 apartments in nine buildings. Blatten is not only the most recent holiday village, it is also the most modern in terms of energy supply. Its heating system is based on a pioneering and appealing concept. Here, guests can enjoy their holidays to the full and simultaneously be aware that they are doing so without harming the environment.

When Reka began to plan its new holiday village in Blatten, it decided to focus on the aspect of clean energy. Originally the idea was to use wood energy, but this would have meant transporting wood from the valley to the village, so the project team opted for the use of solar energy. The conditions for this are very favourable in Blatten: thanks to its high altitude, the solar energy yield here is around 20 percent above that in Switzerland's central plateau. The cool temperatures also favour the production of solar electricity.

For their holiday village the planners chose new hybrid panels from Swiss manufacturer Meyer-Burger, which produce hot water as well as



Overview on the energy system of the holiday village in Blatten-Belalp.

photovoltaic electricity. Four roofs fitted with hybrid panels and a further three with photovoltaic panels supply up to 380 kW of heat and 180 kWp of electricity. This combination forms the basis for the supply of energy to the Reka holiday village.

The hybrid panels store low-temperature heat (35° C) and supply the village with hot water (60° C), which accounts for a relatively high proportion of the energy consumption here. If the sun does not provide the desired temperature, heat pumps are used as an auxiliary source. These are powered via their own photovoltaic system and, when necessary, via the electricity grid (Blatten hydropower plant). The holiday village is also equipped with a facility for recovering heat from waste water (showers, wash basins, toilets). These energy sources meet more than 70 percent of the village's energy requirements throughout the year.

But in order to make this possible, an additional component was required: a storage facility comprising 31 geothermal wells placed in rock at a depth of around 150 metres that are suitable for storing heat in, as well as extracting it from, the surrounding rock formations. With the aid of geothermal storage, excess heat produced during the summer can be used during the winter: during the warm months the ground is heated to around 14° C. This heat can be extracted during the cold months, and the ground cools to around 4° C. This means that a large portion of the heat obtained via solar collectors can be stored for extended periods (months).

Installing a complex energy system such as the one in use in Blatten holiday village is an expensive undertaking: According to the energy planners, for the heating system the investment and operating costs amount to around 24.5 cents per kWh, which is roughly 25 percent higher than the price of supplying energy via an oil-heating system. The investment costs of the solar energy concept are 1.6 million Swiss francs higher than the costs for the originally planned wood pellet heating system, which would have cost around 0.9 million Swiss francs.

The chosen energy system is an expression of the sustainability objectives to which Reka expressed its firm commitment in 2011. Six of the fourteen Reka holiday villages are now "up-to-date" in terms of sustainable energy supply, and three others are to be completely brought up to date by 2017.

Benedikt Vogel

Efficiency potential of electrical power transformers

When we speak of the economical use of electricity, we normally refer to commercial and private consumers. But there is still considerable efficiency potential in the electricity grid itself. A recent study set out to estimate the potential for distribution transformers in the medium and low voltage networks for the capacity range from 100 to 2,000 kVA. The voltage transformers of the approximately 700 Swiss distribution network operators and industrial and commercial companies account for annual energy losses of around 400 GWh. These losses could be halved by using state-of-the-art transformers with an amorphous core, which would be equivalent to savings of approximately 0.3 percent of Switzerland's electricity consumption.

Michael Moser

The efficiency potential of one single transformer is roughly equivalent to the annual consumption of a multi-person household.

Thermal ice storage

The complete renovation of two eight-storey apartment blocks in the center of Geneva owned by La Cigale cooperative, comprising a total of 273 apartments, was the largest building renovation project in the country based on the "Minergie-P" energy standard. Thanks to high-grade thermal insulation of the building shell and the installation of comfort ventilation, the annual heat requirement for room heating and process water was reduced by around 70 percent to 34 kWh per square metre. The integrated heating system comprises 1,680 square metres of solar collectors, 5 heat pumps and 2 ice storage units. The latter store excess energy from the solar collectors and thus act as a supplement to the low-temperature heating system.

Benedikt Vogel

Solar thermal installation on two apartment blocks in Geneva, comprising a total of 273 apartments with a total energy reference area of 19,000 m².

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.

Solar hydrogen production

The importance of electricity production from solar energy is increasing throughout the world. In 2014, the newly installed photovoltaic capacity exceeded 50 gigawatts for the first time. In view of this trend, attention is now being focused to an ever increasing extent on methods of storing this type of electricity. One of several options concerns the conversion of solar electricity by means of electrolysis of water and/or carbon dioxide in order to obtain chemical energy carriers, e.g. hydrogen. The charge carriers generated in a solar cell via the photoelectric effect can also be used for breaking down water into hydrogen and oxygen in order to directly store the energy contained in sunlight, similar to the way in which plants break down water by means of light into oxygen and hydrogen through photosynthesis and with the resulting hydrogen reduce carbon dioxide into glucose.

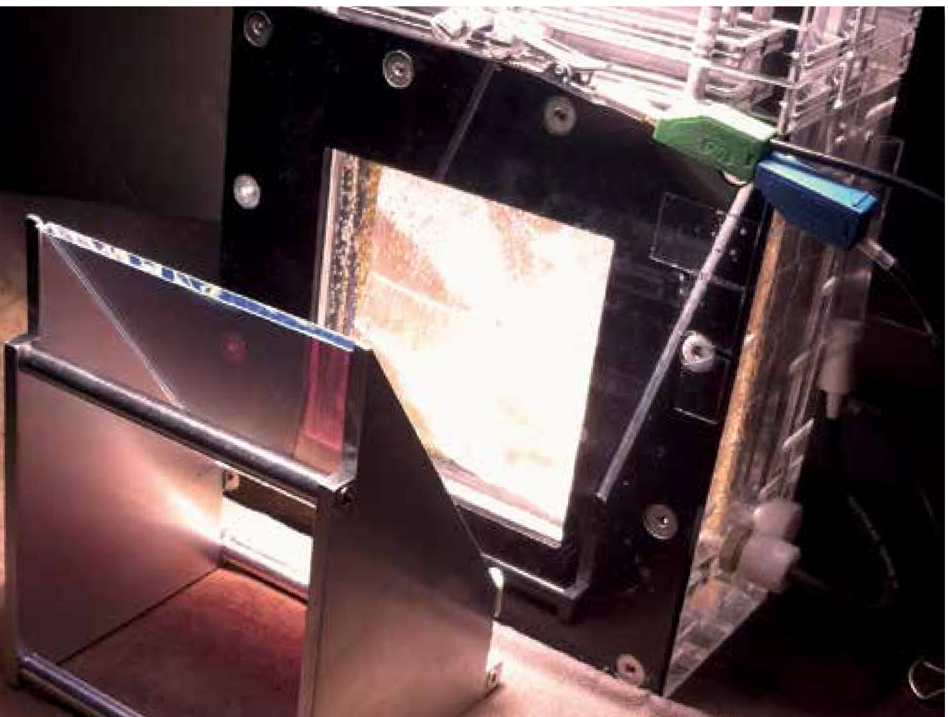
In Switzerland a variety of research groups are working in the field of photo-catalysis in order to directly produce energy-abundant chemical fuels using sunlight and water. Here, the minimum of 1.23 V (though in practice, 1.7 V) that is required for water splitting represents a major challenge. Typically, this can only be achieved by connecting a number of standard photovoltaic cells (based on silicon) in series. In 2014 a new concept was presented in a "Science"-publication by researchers at the Federal Institute of Technology in Lausanne. In a cell producing hydrogen from direct sunlight, new perovskite solar cells were used that have a high open circuit voltage of more than 1 V so that a total of 2 V – which is sufficient for water splitting – was achieved using only two of these cells. Here, new catalysts based on nickel and iron were also used, which greatly reduce overvoltage (the difference between the effectively required voltage for water splitting and the theoretically required 1.23 V). Under standard solar radiation, a solar-to-hydrogen (STH) efficiency rate of 12.3 percent was demonstrated in the laboratory. In the past such STH-rates have only been possible through the use of much more expensive solar cells based on III-V-semiconductor materials and with the aid of catalyst materials based on rare earths.

Thermochemical production of hydrogen using concentrated in a two-step process based on metal oxides: (1) thermal dissociation of metal oxides (here Zink), (2) hydrolysis of water and reoxdioxidation.

Another Swiss research consortium at Empa and the University of Basel was named one of the "100 Leading Global Thinkers" in the USA in recognition of its work in the area of solar hydrogen generation. Here, photo-electrodes based on ferrous oxide (haematite) are used in order to break down water into oxygen and hydrogen. In contrast to the method described previously, photocells and the electrodes used for splitting water are directly integrated into a photo-electrochemical cell. Haematite is corrosion-resistant and inexpensive, but charge carriers cannot move easily in these layers, requiring the light-absorbing layers to be extremely thin. The innovation lies in the special spherical arrangement of the haematite layers (moth-eye structure), such that the incoming light can be captured to attain sufficiently strong photo currents for water splitting, despite a thin absorber layer.

Another group of researchers at the Federal Institute of Technology, Zurich, and at the Paul Scherrer Institute works on concentrated solar energy, which is used to split hydrogen and/or carbon dioxide via thermo-chemical processes and thus obtain either hydrogen or synthesis gas (a mixture of hydrogen and carbon monoxide). Liquid hydrocarbons such as petrol or kerosene can be produced from synthesis gas via other intermediate chemical steps. Because this involves much higher temperatures, the material systems differ greatly from the cells used in photo-catalysis and photo-electrochemistry.

Stefan Oberholzer



Tandem configuration "PEC-PV" for solar hydrogen production scaled-up at EPFL: a dichroic mirror is used to split the incident light and reject one part on a photoelectrochemical cell (copper oxide anode), the other part on a silicon heterojunction solar cells.

Refueling with 100 % of biomethan at "Blue BONSAI" station in Reiden (LU).

Filling-up on the farm

How can we best replace fossil fuels with biofuels? One option is to transform biogas into engine fuel. Switzerland's local topography calls for special systems technology for small-scale, decentralised solutions. Large-scale systems cannot be accommodated, and for many years small-scale systems were regarded as unsuitable because they are not economically viable. But now, thanks to a project called "Blue BONSAI" it will be possible to tank up directly on the farm.

Between 50 and 62 volume percent of raw gas produced from a biogas fermenter is methane, with remainder mostly carbon dioxide. A cubic metre of raw gas contains 5 to 6 kWh of energy, which would suffice for a vehicle to travel a distance of around 10 kilometres. But before biogas can be used as a fuel for motor vehicles, it needs to be processed: moisture and various associated substances such as ammonia or hydrogen sulphide have to be eliminated. The methane content is then increased by separating the carbon dioxide. The result is a gas with a methane content of at least 96 volume percent.

Various technologies exist for separating the carbon dioxide like pressure swing adsorption, pressure washing or amine scrubbing. But for small facilities, the cost pressure is enormous: the basic costs for system and safety technology are the same as those for large-scale facilities. This means that costs have to be reduced in the ar-

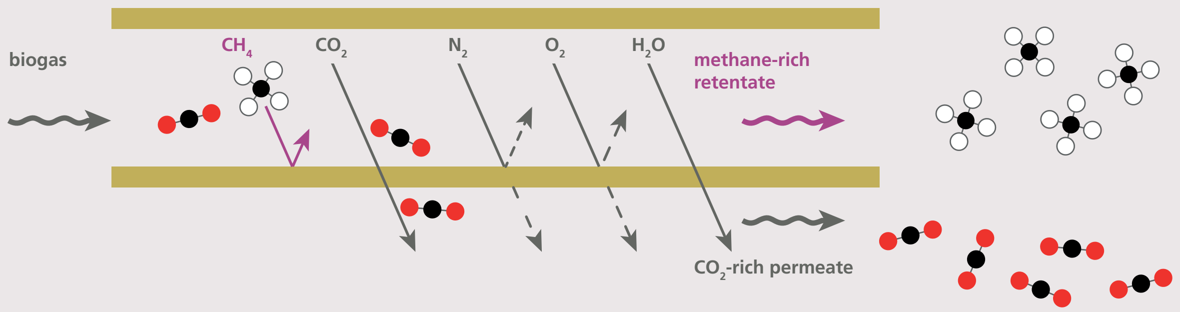


Illustration of a hollow fibre (cross-section): CO_2 (shown in red and black) passes through the pores, methane (shown in black and white) remains in the fibre and can then be separated.

eas of process management, steering technology and construction, and have to flow in to the development of "Blue BONSAI" (Apex AG and Duttwiler Energy Technology). Another special feature of Switzerland's biogas landscape also plays a role: substrates are more diverse because in Switzerland only biogenic residues are used for fermentation. In addition, the quantity and quality of the gas output also vary as a result of fluctuating input. This means that the system has to be able to cope with such boundary conditions.

In "Blue BONSAI", the method of membrane separation is used, which enables processing for very small facilities (the functional model at the Grossenbacher biogas plant in Reiden, canton of Lucerne, has a flow-through rate of only 2.5 Nm^3 per hour for raw gas or approx. 1.5 Nm^3 per hour for biomethane). The membrane functions under a pressure differential like a filter, letting the carbon dioxide pass through the pores but retaining the methane. A "Blue BONSAI" facility includes raw biogas scrubbing, biogas processing, high-pressure compression and gas storage in a biogas filling station with pump.

The ideal location for a "Blue BONSAI" is a farm or sewage treatment facility with a thermal power plant. Here a portion of the biogas can be processed into fuel and the remainder can be turned into electricity. With this method, gas production can be optimised, and more fuel or electricity can be produced, depending on demand, sales opportunities and price. Agricultural biogas plants are often situated in remote locations or a long way away from the gas network. With a "Blue BONSAI", these gaps on the Swiss filling station map can be filled.

In early 2015, a pilot facility with a nominal capacity of 6 Nm^3 per hour of biomethane has been put into operation at an agricultural biogas plant, sufficient to fill up between 30 and 60 small cars. With an estimated two-thirds capacity utilisation, around 340,000 kWh of fuel can be produced per annum.

Biogas completes the carbon dioxide cycle. Present-day biomass (residuals such as manure, dung, green waste, food leftovers, etc.) is fermented, and the fermentation residue is used as a fertiliser, while the gas is used for producing electricity, heat or (as described above), fuel. The carbon dioxide from the offgas resulting from biogas processing, as well as from vehicle exhaust, completes the cycle as "neutral" CO_2 and is used as a fertiliser for plants.

In the future, it might also be possible to directly use the carbon dioxide separated and concentrated during processing, for example as a fertiliser for use in greenhouses, for the cultivation of algae or for the production of methane through methanisation of hydrogen from "surplus electricity".

Sandra Hermle

Pilot production line for innovative high-performance solar cells

In a sustainability-oriented energy supply system, photovoltaics is gaining in importance throughout the world. In accordance with the new energy strategy, photovoltaic systems are to account for almost half the electricity produced from new renewable energy sources by 2050. One of the challenges for this technology concerns a further reduction in costs along the entire value chain – by increasing the efficiency of individual components and ensuring the industrial use of new products and new manufacturing processes.

Following a particularly difficult period for the global photovoltaics industry that was characterised by overcapacities, immense price pressure and a pronounced market shake-out, the worldwide photovoltaics market is now recovering more quickly than many experts had anticipated. An increasing capacity utilisation among Asian module manufacturers is particularly good news for the European supply industry. What is now required is the development of innovative technology to secure the low-cost production of efficient solar cells and modules in order to bring about a further reduction in the costs of solar power.

In 2013, a joint project called "Swiss-Inno HJT" was initiated by the Meyer-Burger industrial group and the CSEM Photovoltaics Centre in Neuchâtel on the development of a pilot production line for

In November 2014, a pilot plant installation for the production of high-efficient heterojunction solar cell modules was inaugurated at Meyer Burger Research SA in Hauterive, Neuchâtel.

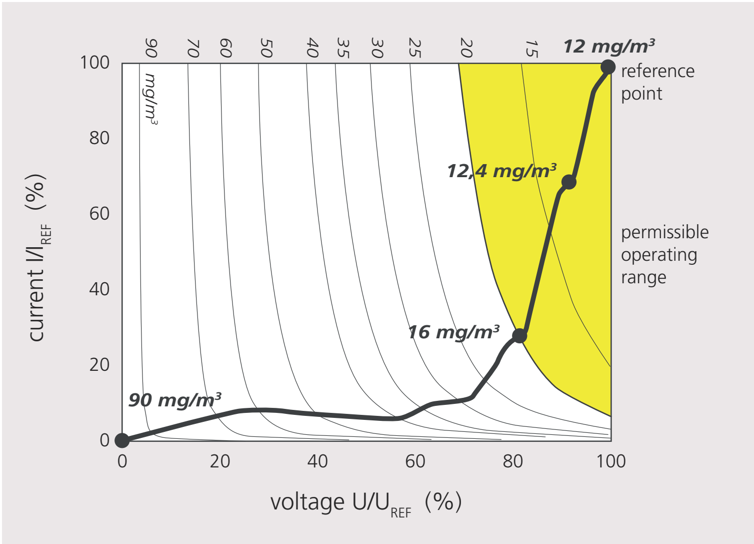
high-performance solar cells based on heterojunction technology – a project jointly Swiss Federal Office of Energy and the canton of Neuchâtel. The cell technology was developed in a close collaboration between the Lausanne Federal Institute of Technology's photovoltaics laboratory in Neuchâtel and Roth & Rau Research. Monocrystalline silicon wafers are coated with a few nanometres of amorphous silicon, resulting in a module efficiency rates of around 21 percent, which is significantly higher than the average rate achieved with crystalline silicon modules (16 percent). Furthermore, this technology is characterised by a particularly high energy yield (kWh/kW).

The development of this pilot production line, with a targeted production capacity of 600 kWp per annum, is intended to demonstrate the potential for low manufacturing costs (less than 0.65 Swiss francs per W_p). The project has the potential to contribute towards the successful introduction of this technology onto the market, and thus to promote Switzerland as a center for the development of photovoltaic technology.
Stefan Oberholzer

Automated wood burners and particle separators

As a rule, automated wood-fired systems with an output greater than 500 kW need to be equipped with electric separators in order to ensure compliance with the particle limit level specified in the Swiss Ordinance on Air Pollution Control. Owing to burners often only used at partial load or in on/off mode, electric separators are only effective to a limited extent. A survey conducted over a two-year period has revealed that if malfunctions are not rectified immediately, the availability of separators is significantly reduced and emissions consequently increase. The study emphasised the need to monitor such systems with the data obtained from the control mechanisms of boilers and electric separators.

Sandra Hermle

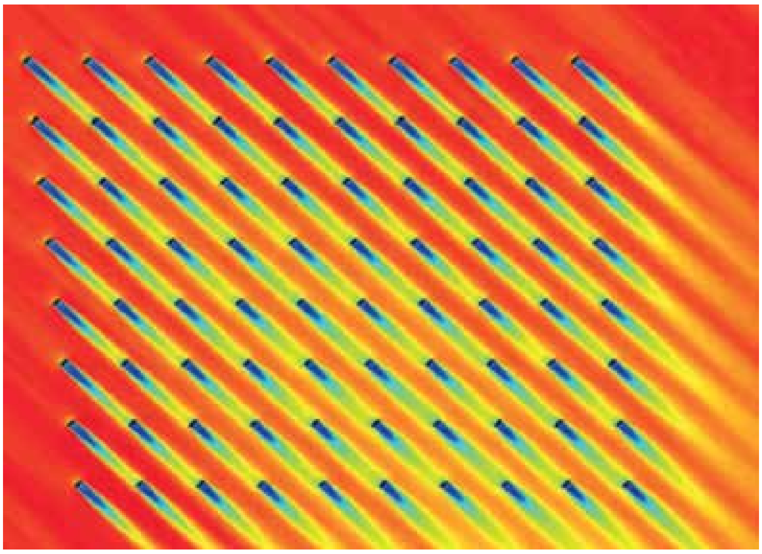


Current-voltage characteristics of an electric separator. The dots indicate the measured particle concentration. The reference point is shown at top right. The yellow segment indicates the permissible operating range.

Maximizing wind energy yield

The latest research findings indicate that "difficult conditions" for wind energy in Switzerland, such as a complex topography, turbulence and icing-up, can not only be overcome, but may even have positive effects. In hilly locations, of which Switzerland has a very large number, wind turbines can be placed much closer together than is possible in flat terrain because the weakened flow of wind behind a turbine can quickly strengthen again due to turbulence (further information: www.lec.ethz.ch). Thanks to new findings regarding the diurnal cycle of the boundary layer and the different length of the wake flow during the day and at night, yields can be increased through optimised turbine and wind park management (further information: http://wire.epfl.ch).

Katja Maus



Numeric modelling of the calculated wind speeds in a large-scale wind park for studying the influence of wake flows (wind from 312 °; red: > 8 metres per second < 4 metres per second).

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.

Impact of decentralised electricity storage and demand-side management on the development of the energy system

The fundamental decision by the Federal Council to withdraw from the use of nuclear energy gradually implies a successive expansion of Switzerland's energy system will be required. The energy mix is to be supplemented by a significant proportion of intermittent renewable energy. Since the meteorological conditions constantly fluctuate, the availability of solar and wind energy also varies. It therefore has to be assumed that only a very limited quantity of intermittent energy will be available during certain periods.

A variety of strategies for overcoming this problem are conceivable. Investments in readily available substitute capacities that maintain the balance in the electricity grid, investments in interconnection with the energy networks of neighbouring regions in order to facilitate the exchange of energy, and investments in storage technologies and the implementation of demand-side management mechanisms, are all feasible options. The objective of the latter option is to dynamically improve the balance between intermittent production and demand.

A study carried out within the scope of the "Energy / Economy / Society" research programme identified the impact of decentralised storage and demand-response mechanisms on the long-term development of the energy system. Storage mechanisms are intended to absorb excess electricity produced from renewable energy during periods of windy weather and/or intensive sunshine, and to feed it back into the grid when required. In their turn, demand-response mechanisms utilise the flexibility of demand. In order to model storage and demand-response mechanisms, a certain flexibility was introduced into the load profile curves. The calibration of this flexibility was carried out following a survey conducted in Western Switzerland, which revealed that around 80 percent of households would participate in storage mechanisms in electric vehicles, as well as in demand-response mechanisms, even if the associated financial incentives were not particularly attractive. It is also becoming apparent that demand-response tends to reduce the attractiveness of storage in electric vehicles, because demand-response gives rise to an alignment of prices and thus to a restriction of arbitrage opportunities. Decentralised storage in electric vehicles tends to increase the attractiveness of renewable (in particular, wind) energy.

Another study examined the potential for flexibility with respect to electricity demand in households. The aim here was to maximise the proportion of electricity production from photovoltaic systems that is consumed locally, and thus to improve the balance between local production and demand. A technical analysis of the typical characteristics of households and the influencing factors of flexibility indicated a theoretical flexibility potential of 6 to 8 percent. However, translating this potential into practice is by no means easy. With the aid of financial incentives, it was possible to increase the proportion of electricity consumed in the timeframe from 11 a.m. to 3 p.m. by 2.9 percentage points. This result can be regarded as noteworthy when we consider that the proportion of electricity that is normally consumed during this timeframe by the participants in the survey was around 20 percent. The result indicates that time-of-use tariffs can function as a useful demand-side management instrument.

Anne-Kathrin Faust

As part of an education programme, members of the regional conferences visit the Swiss interim storage site for radioactive waste (ZWILAG).

Participation in the search for suitable sites for deep geological repositories

In the six regions of Switzerland that could potentially house a deep geological repository for radioactive waste, a total of more than 500 people are involved in the regional participation process. They assist in the selection process, for example concerning the location of the surface infrastructure or the associated sociological studies. A regional participation process of this magnitude is unique not only at the national level, but also internationally. But to what extent would this process be transferable to other major projects? And what are its strengths and weaknesses? These questions are being examined in a research project called "Participatory Waste Management Policy".

The aim of the Swiss regional participation process is to enable the site selection process for deep geological repositories to incorporate regional concerns into the planning of radioactive waste disposal. For this purpose, special committees (referred to as "regional conferences") comprising representatives from the involved municipalities and organisations, plus local residents, were set up in all six potential site regions. The process of setting up the regional conferences between 2009 and 2011 was supported by a research project, which captured lessons learned. With respect to communication, for example, it was found that the objective of participation needed to be explained clearly and comprehensibly right from the start. Furthermore, during the process the roles and duties of the participants had to be precisely defined. With respect to the composition of the regional conferences, the study found that women and young citizens were underrepresented.

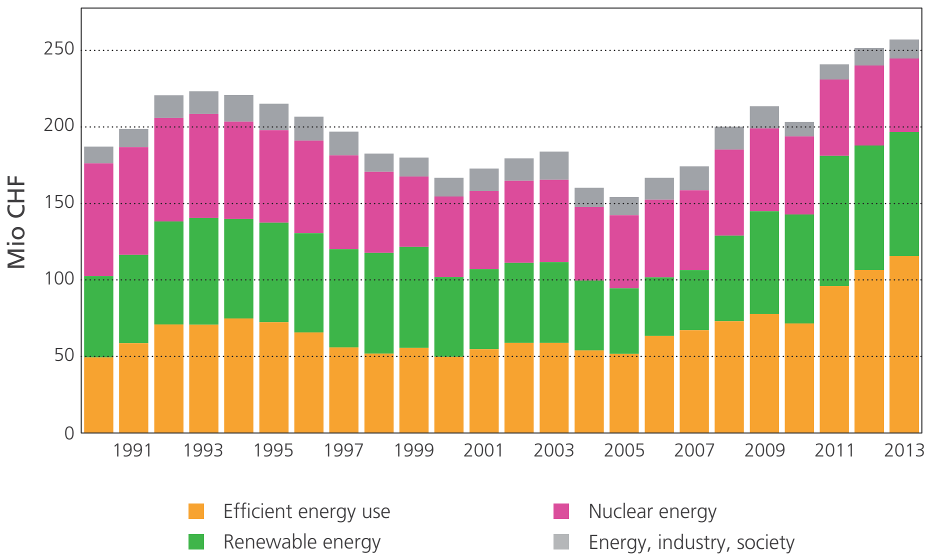
In 2014, a second project aimed at supporting the participation process was initiated in the form of a political science dissertation called "Participatory Waste Disposal Policy" at the University of Bern. The aim here is to analyse the ongoing implementation of the regional participation process in all six site regions. The findings are to be used by the SFOE to identify strengths and weaknesses and thus improve the participation process. In addition, a comparison is to be made with other large-scale projects so that it will be possible to benefit from the related findings and practical experiences. In order to incorporate the lessons learned from the development of the participation process, a subproject is currently focusing on the topic of the involvement of women and young citizens in technical long-term projects. The basis for the analysis includes numerous interviews with involved persons and a survey among members of the regional conferences, in addition to an evaluation of the relevant literature and observation of the participants.

Both these projects are part of the SFOE's "Radioactive Waste" research programme, which coordinates regulatory research activities of the federal government in the field of radioactive waste management. Alongside technological and scientific projects, which are the responsibility of the Swiss Federal Nuclear Safety Inspectorate (ENSI), this programme also addresses psychological and sociological issues.

Annatina Foppa

FACTS AND FIGURES

Since 1977 the Swiss Federal Office of Energy (SFOE) has been recording public expenditure for energy-related research and pilot and demonstration projects. The information is collected through self-reporting of project data, though the SFOE is responsible for the thematic classification and detailed examination of the projects. Actual levels of public expenditures are therefore probably somewhat understated. Each year around 1,500 projects are recorded, examined and statistically evaluated. An overview of the data collection process is published on the energy research website (www.energy-research.ch).



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.

	ETH	SNF	CTI	SFOE	ENSI	SERI (FP6)	EU	Kt./Gmd.	others
2012	146.3	4.3	22.8	22.7	2.7	0.5	25.0	10.7	16.5
	(58.2 %)	(1.7 %)	(9.1 %)	(9.0 %)	(1.1 %)	(0.2 %)	(9.9 %)	(4.3 %)	(6.6 %)
2013	148.9	5.0	21.5	28.5	2.4	0.2	23.8	12.6	14.0
	(58.0 %)	(2.0 %)	(8.4 %)	(11.1 %)	(0.9 %)	(0.1 %)	(9.3 %)	(4.9 %)	(5.5 %)

Sources of public funding for research, development and pilot and demonstration projects, in million Swiss francs. (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; 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 / Kt./Gmd. = cantons and municipalities).

	2012	2013
Efficient energy use	**106,5**	**115,7**
Energy in buildings	22,3	26,9
Mobility and transport	14,4	13,9
Accumulators and supercapacitors	4,8	3,4
Electricity technology and applications	15,6	13,1
Grids and systems	7,4	9,2
Combined heat and power	1,2	0,6
Fuel cells	12,5	15,3
Combustion	16,5	18,2
Power plant 2020 and carbon capture and sequestration	4,8	4,3
Process engineering	6,7	10,7
Renewable energies	**81,2**	**81,0**
Solar	39,0	37,6
Solar heat and heat storage	11,9	10,9
Photovoltaics	21,6	21,4
Concentrated and high temperature solar (CSP)	5,6	7,2
Hydrogen	12,3	12,2
Heat pumping technologies and refrigeration	1,3	1,7
Biomass and wood energy	11,5	12,7
Geothermal energy	7,3	9,6
Wind energy	6,7	6,7
Hydropower	3,0	3,3
Dams	0,1	0,6
Nuclear energy	**52,3**	**48,0**
Nuclear Fission	28,4	26,9
Nuclear Security	17,9	12,6
Radioactive waste	5,1	3,4
Future-oriented research	5,4	10,9
Nuclear fusion	24,0	23,4
Plasma physics and heating technology	17,3	16,3
Nuclear fusion technology	6,6	4,8
Cross-sectional themes	**11,4**	**12,3**
Energy, economy, society	7,7	10,2
Knowledge and technology transfer	2,7	1,8
General coordination	1,0	0,3
Total	**251,5**	**256,9**

Public expenditure on applied energy research, including pilot and demonstration projects, in million Swiss francs (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.

INTERNATIONAL COLLABORATION

International cooperation in energy research has a high priority in Switzerland. At institutional level the Swiss Federal Office of Energy (SFOE) coordinates its research programmes with international activities in order to exploit synergies and avoid duplication. The cooperation and exchange of experience within the International Energy Agency (IEA) is of particular importance. Switzerland participates through the SFOE to more than 20 out of the about 40 programmes of the IEA (Implementing Agreements).

At European level, Switzerland is – wherever possible – actively involved in the different research and technological development programmes of the European Union. The SFOE coordinates at institutional level energy research with the European Strategic Energy Technology Plan (SET-Plan), the European Research Area Networks (ERA-NET), the European Technology Platforms, the Joint Technology Initiatives (JTI), etc. In certain areas ("smart grids", geothermal energy) intensive multilateral cooperation exists with individual countries.

http://www.energy-research.ch -> International Affairs
http://www.seri.admin.ch -> International Cooperation in Research and Innovation
https://www.euresearch.ch
http://www.iea.org/techinitiatives
https://setis.ec.europa.eu
http://ec.europa.eu/research/energy
http://www.fch.europa.eu

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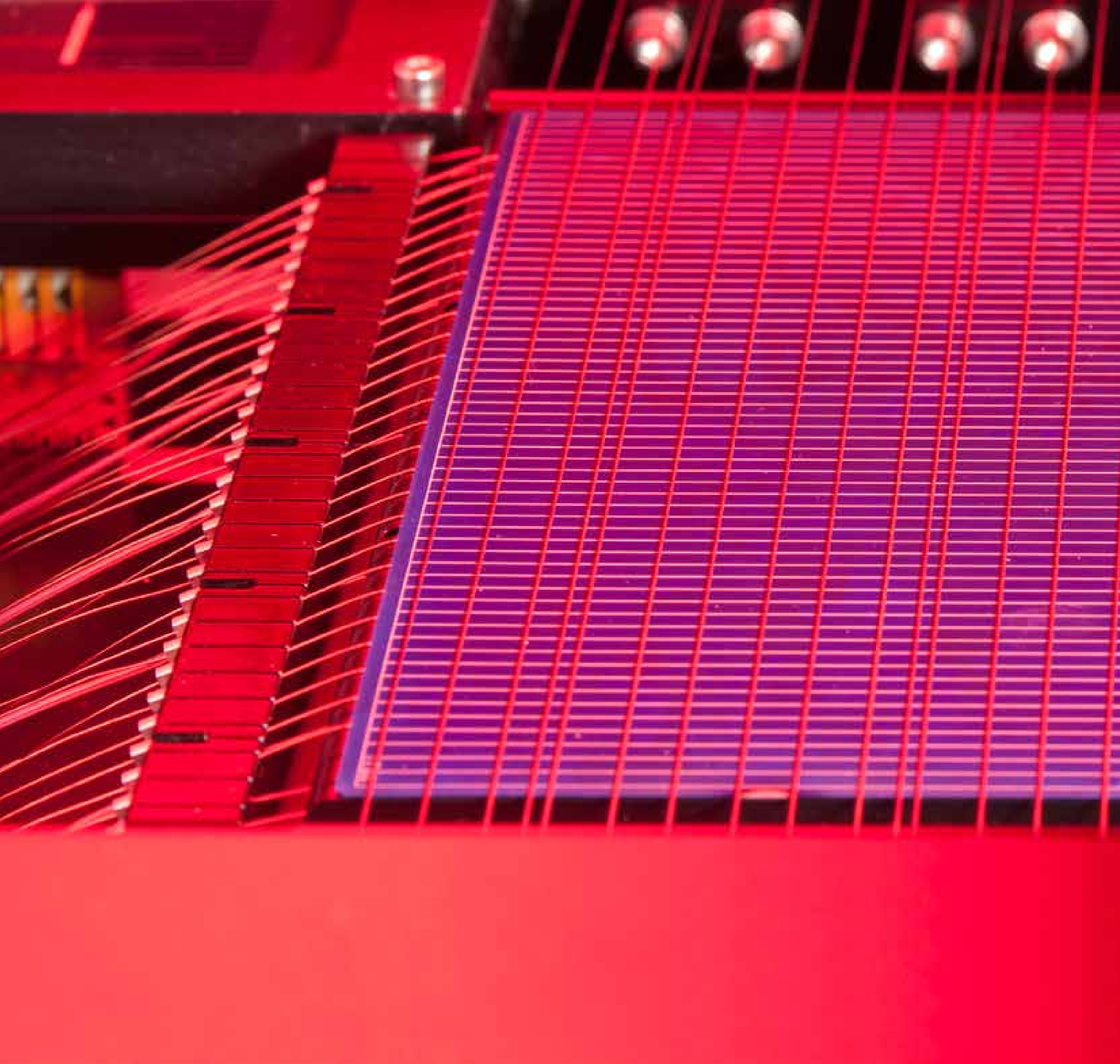
"In the energy sector, the SFOE's promotion of basic research is an important extension of the research carried out by the Swiss National Science Foundation (SNSF) and the promotion of market-related innovation by the CTI. For many years it has focused on the interface between these two areas of research in much the same way as the CTI/SNSF Bridge programme is doing in another area of technology. But with its financial support, the SFOE is also playing a major role in integrating Swiss researchers into the international programmes of the IEA and the EU."

Dr. Tony Kaiser, President of the Federal Energy Research Commission (CORE)



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