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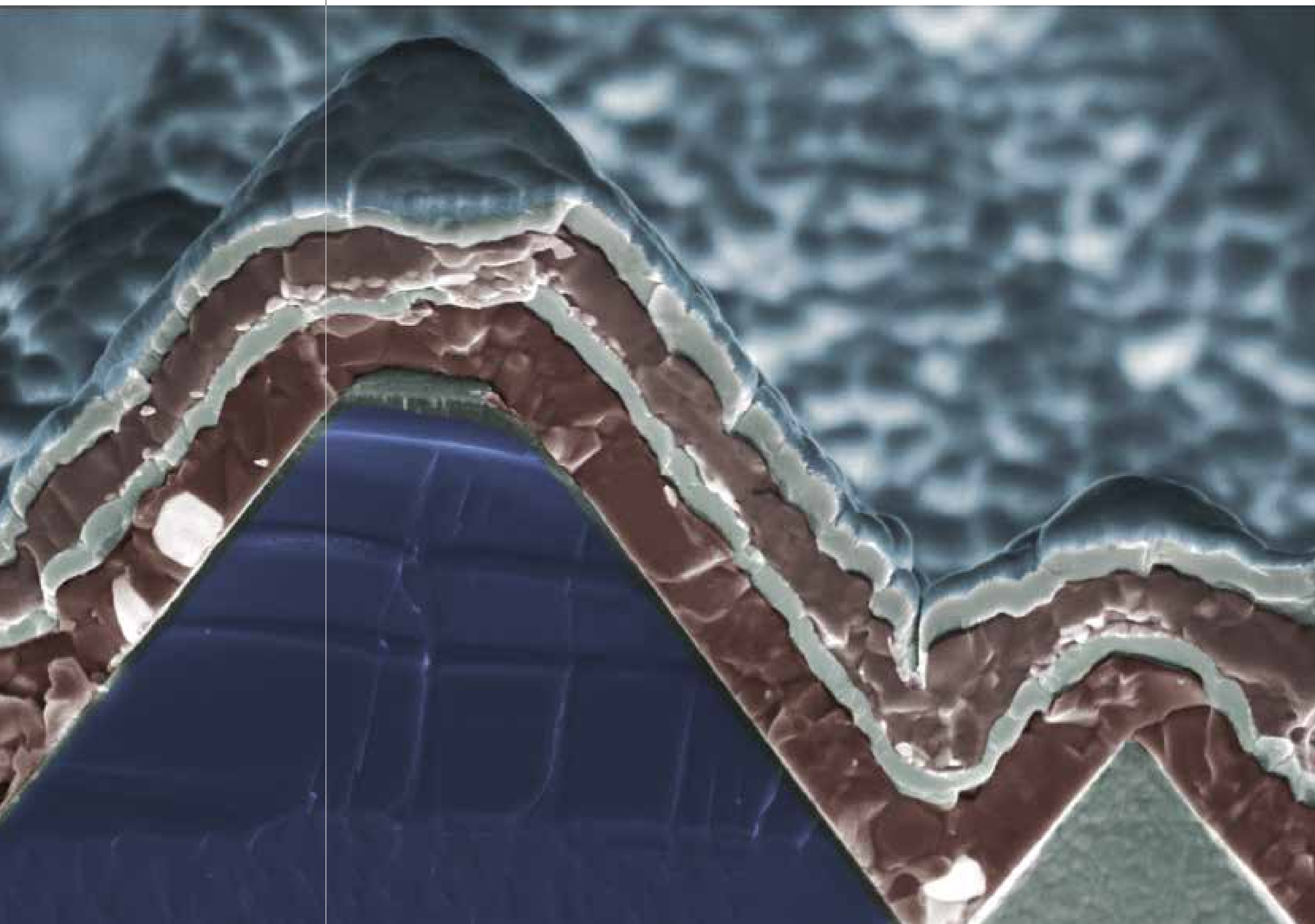
Swiss Federal Office of Energy SFOE

Energy research and innovation
Report 2018



Editorial

Strengthening renewable energies, stimulation to increase energy efficiency and phasing out nuclear energy: these are some of the key strategic steps aimed at maintaining a sustainable and secure energy supply for Switzerland. The transformation brought about by the Energy Strategy 2050 presents a variety of challenges characterised not only by economic and technological developments, but also by political decisions at home and abroad. At the same time, this transformation will open up opportunities for economic development as well as for innovation. The research that is essential for innovation has thus been expanded in a targeted manner in the context of the launch of Energy Strategy 2050.

Research should in principle take place free of stipulations. Nevertheless, in the energy sector a certain degree of coordination and continuity can serve to ensure that the focus remains on the objectives and needs of the general public. For more than three decades, the Swiss Federal Office of Energy (SFOE) has been playing a key role through its programme-based promotion of research and technological development. The examples presented in this brochure are representative of numerous projects that the SFOE supports and closely monitors.

Pascal Previdoli, Deputy Director SFOE

Left: Solar folding roof over the settling tanks of the sewage treatment plant in Chur, using the technology developed by the start-up company dhp-technology. In this aerial view the modules are semi-retracted. The solar installation was supported by the SFOE as a pilot project and was subsequently expanded to 643 kWp. The sewage treatment plant can directly use almost 100 percent of the electricity produced by the photovoltaic system (Source: dhp-technology.ch).

Cover: Solar cells can be stacked in order to increase efficiency. In 2018, researchers at CSEM (Centre Suisse d'Electronique et de Microtechnique) and the Federal Institute of Technology, Lausanne succeeded in depositing perovskite solar cells directly on the pyramidal structure of silicon cells. The image shows a structure with two perovskite solar cells (brown) on top of a silicon cell (blue). The pyramidal structure is essential for efficient light management (Reprinted with permission from ACS Enegy Lett. 2018, 3, 9, 2052–2058. Copyright 2018 American Chemical Society).

Contents

Wind power plant of the wind farm "Le Peuchapatte" in the Jura with an annual production of 13.5 GWh (equivalent to about 3 % of the consumption of the Canton of Jura (© Suisse Eole, www.suisse-eole.ch)

Promotion of technology and innovation

At regular intervals, the Federal Energy Research Commission (CORE), an extra-parliamentary body, draws up the Federal Energy Research Masterplan and thus sets guidelines for targets and support measures. With its programmes and through its role as coordinator, the SFOE functions as a central hub in the Swiss energy research landscape in order to support the implementation of the Masterplan.

The SFOE promotes and coordinates Swiss energy research and supports the development of new markets for the supply of sustainable energy. To facilitate the coordination task, SFOE funds are deployed in a targeted manner to develop innovative technologies and concepts aligned with specific research programmes. Funds deployed in a subsidiary manner aim to fill gaps in Switzerland's funding landscape (Figure 1). Grants are given to private entities, the domain of the Swiss Federal Institutes of Technology (ETH), universities of applied sciences, and universities. The SFOE provides specialist advice to funded projects by drawing on experts and representatives of other funding agencies on a case-by-case basis.

The SFOE maintains a regular exchange of information between various national funding initiatives, in particular with the Swiss Competence Centres for Energy Research (SCCERs), and supports measures whose aim it is to promote general knowledge transfer. In order to fully utilise the expertise and capacities built up in recent years at Swiss universities and universities of applied sciences within the framework of the SCCERs and to achieve the objectives of Energy Strategy 2050, the SFOE has proposed a new research promotion programme called "SWEET" (Swiss Energy Research for Energy Transition). The ten-year programme aims to launch thematic calls for consortia-based projects that focus on topics prepared by the SFOE. Consortia will be active over a period of six to eight years. Calls for tenders are designed to give preference to cooperation among various types of universities, academies, research institutions, the private and the public sector. Thus, the programme is designed to promote interdisciplinary and transdisciplinary consortia that make a significant contribution towards meeting the goals of the Energy Strategy 2050.

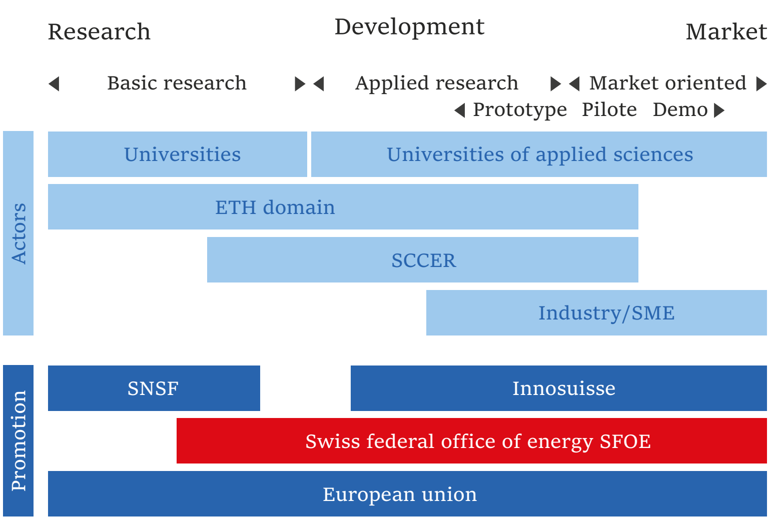


Figure 1: The SFOE coordinates research and innovation in the energy sector along a large portion of the value chain. (Innosuisse = Swiss Innovation Agency; EU = European Union; SNSF = Swiss National Science Foundation; SCCERs = Swiss Competence Centres for Energy Research).

Programmes

The main challenge for energy research is to strike a balance between long-term perspectives and visions, and short-term economic and political realities. The development of energy technologies is long term in nature: new technological approaches and systems require long lead-in times. Long-term SFOE research programmes and the SFOE's support of pilot and demonstration projects aim to ensure a faster transfer of results to market-ready technologies.

- Buildings and Cities
- Mobility
- Industrial Processes
- Grids
- Electricity Technologies
- Combustion based Energy Systems
- Fuel cells
- Batteries
- Heat pumps and Refrigeration
- Solar heat and Heat Storage
- Photovoltaics
- Solar energy at high temperature (CSP)
- Hydrogen
- Bioenergy
- Hydropower
- Geoenergy
- Wind energy
- Dams
- Energy – Economy – Society
- Radioactive waste

Additional information:
"Federal energy research concept 2017–2020", CORE (2016)
"Energy research concept of the Swiss Federal Office of Energy 2017–2020", SFOE (2016)

Funding energy research

Since 1997 the SFOE has been collecting data relating to research and development projects as well as pilot and demonstration projects. Only those projects are considered if they are fully or partially funded by the public sector (federal government and cantons), the Swiss National Science Foundation (SNSF), Innosuisse (Swiss Innovation Agency) and the EU.

Information derives from databases managed by the federal government, the SNSF and the EU, as well as from analyses of annual and business reports and self-disclosure by managers of research institutions. Information about individual research projects may be obtained from the openly accessible information systems of the federal government (ARAMIS database, www.aramis.admin.ch), the SNSF (p3.snf.ch), the EU (cordis.europa.eu) as well as websites of the various institutions.

Figure 2 shows public investment on energy research in Switzerland since 1990 (in million Swiss francs, inflation-adjusted) in the four main segments in accordance with the Swiss classification system. Investment in Swiss energy re-

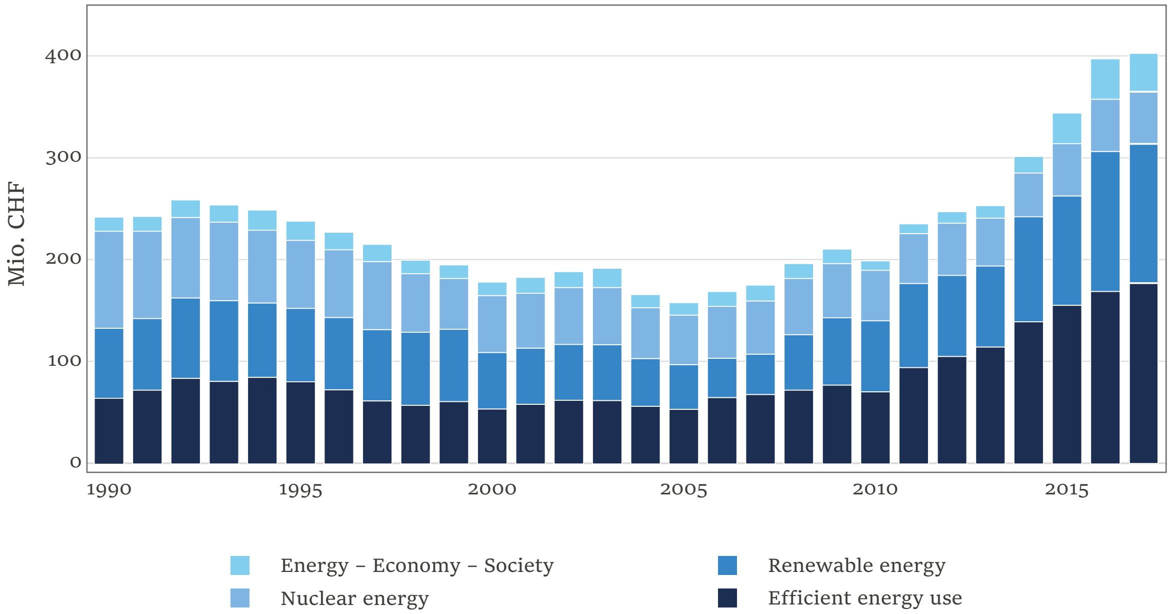


Figure 2: Long-term overview of public expenditure on energy research. Figures are shown as real data, i.e. after adjustment for inflation, and vary between 0.03 and 0.065 percent of GDP.

search has been generally expanding in recent years in the context of Energy Strategy 2050 and an associated specific Energy Research Action Plan. Major investments results from the following developments: (1) the establishment of the Swiss Competence Centres for Energy Research (SCCERs) by CTI/Innosuisse in 2013, which entered the second phase of operation in 2017 to 2020; (2) SNSF's launch of new national research programmes (NRP 70 and NRP 71) in the energy sector; and (3) the targeted expansion of pilot and demonstration activities by the SFOE. Additional funding was made available by the board of the Swiss Federal Institutes of Technology for the expansion of infrastructure and increase in capacity, both of which contributed towards the higher level of funding for energy research. To some extent, the increase is also attributable to adjustments in data acquisition methods, which now, for example, includes overhead in a consistent manner. Overheads are the main cause of an increase in in-kind contributions by the Federal Institutes of Technology and universities.

As shown in Figure 3, a large proportion of the public investment in energy research (42 percent) is defined by strategic goals set by the board of the Federal Institutes of Technology, which in turn sets research priorities and funds for the two Federal Institutes of Technology and associated institutions. The current Energy Research Master Plan prepared by CORE, which paints a common vision for Switzerland's research community and, together with recommendations for energy research financed by the public sector, serves as a guide. Additional substantial financial contributions towards energy research are provided by the cantons (16 percent) via their financing of universities and applied science universities. Another 41 percent of the funding provided by Innosuisse, the SNSF, the State Secretariat for Education, Research and Innovation (SERI), the EU and the SFOE is contestable. The vast majority of funding from the EU and SERI flows into European projects.

The SFOE focuses on supporting a broad variety of actors from the domain of the Federal Institutes of Technology, as well as from universities, universities of applied sciences, and the energy sector (Figure 4). In this way, the SFOE meets its role as coordinator and makes a key contribution towards the implementation of research and development outputs, and the creation of marketable innovative products.

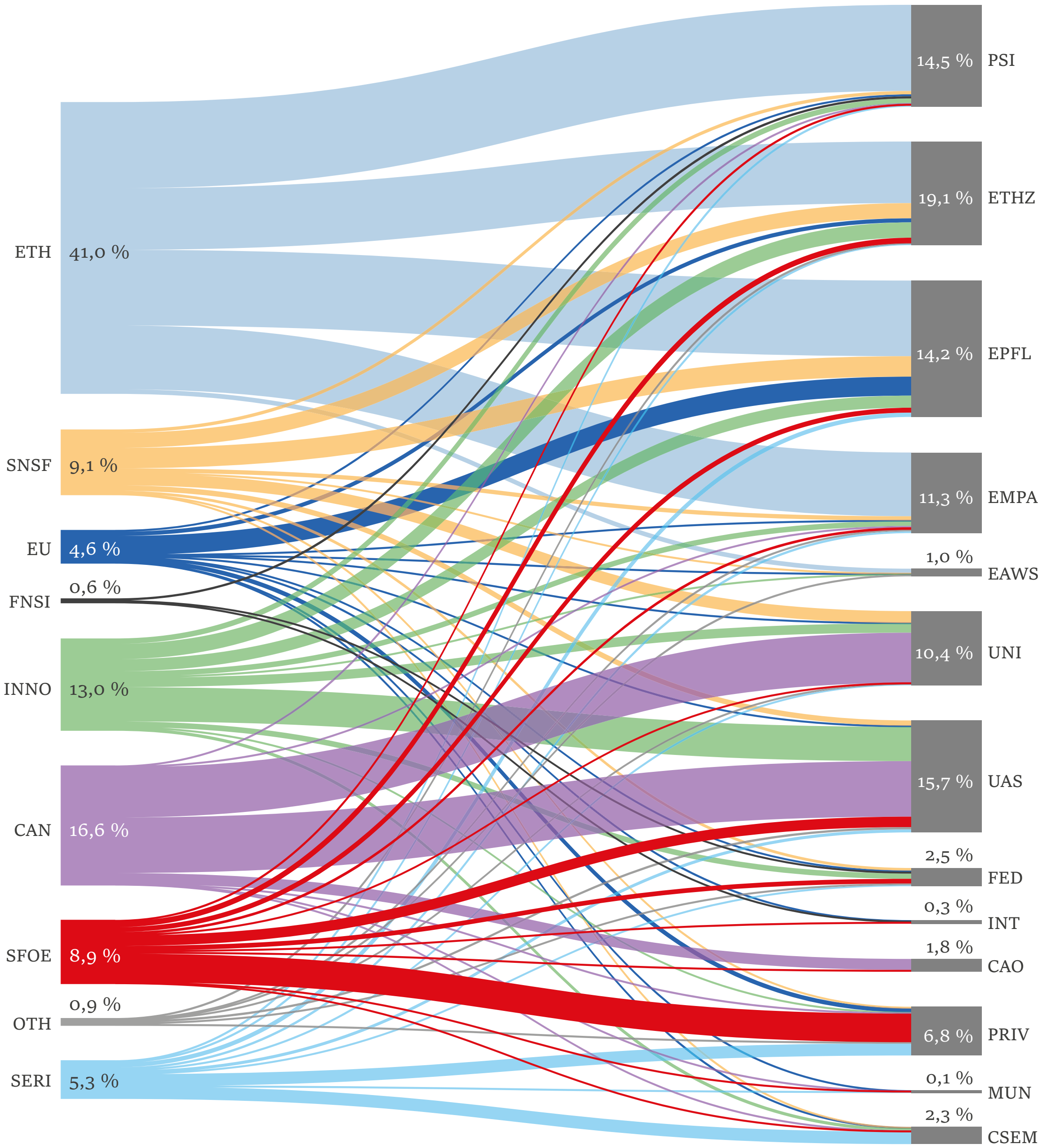
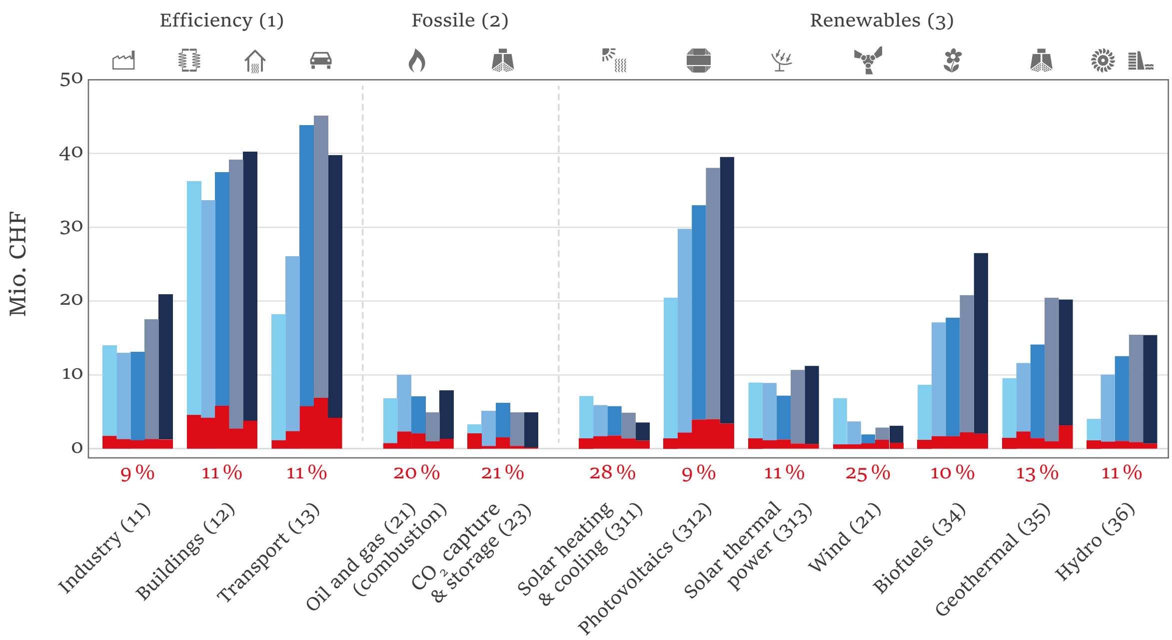


Figure 3: Sources of public funding (left) for energy research in Switzerland in 2017 (in total 410 million Swiss francs) and uses (right) by energy research institutions. Private sector investments (such as large in-kind contributions to projects of Innosuisse and SFOE pilot and demonstration projects) are not included.

Sources: Board of the Federal Institutes of Technology (ETH); Swiss National Science Foundation (SNSF); European Union (EU); Federal Nuclear Safety Inspectorate (FNSI); Innosuisse (INNO); Cantons (CAN); Swiss Federal Office of Energy (SFOE); Others (OTH); State Secretariat for Education, Research and Innovation (SERI).

Use of funds: Paul Scherrer Institute (PSI); Federal Institute of Technology, Zurich (ETHZ); Federal Institute of Technology, Lausanne (EPFL); Federal Laboratories for Materials Science and Technology (EMPA); Federal Institute of Aquatic Science and Technology and Federal Institute for Forest, Snow and Landscape Research (EAWS); universities (UNI); universities of applied sciences (UAS); other federal bodies (FED); international organisations (INT); other cantonal organisations (CAO); private sector (PRIV); municipalities (MUN); Centre Suisse d'Electronique et de Microtechnique (CSEM).



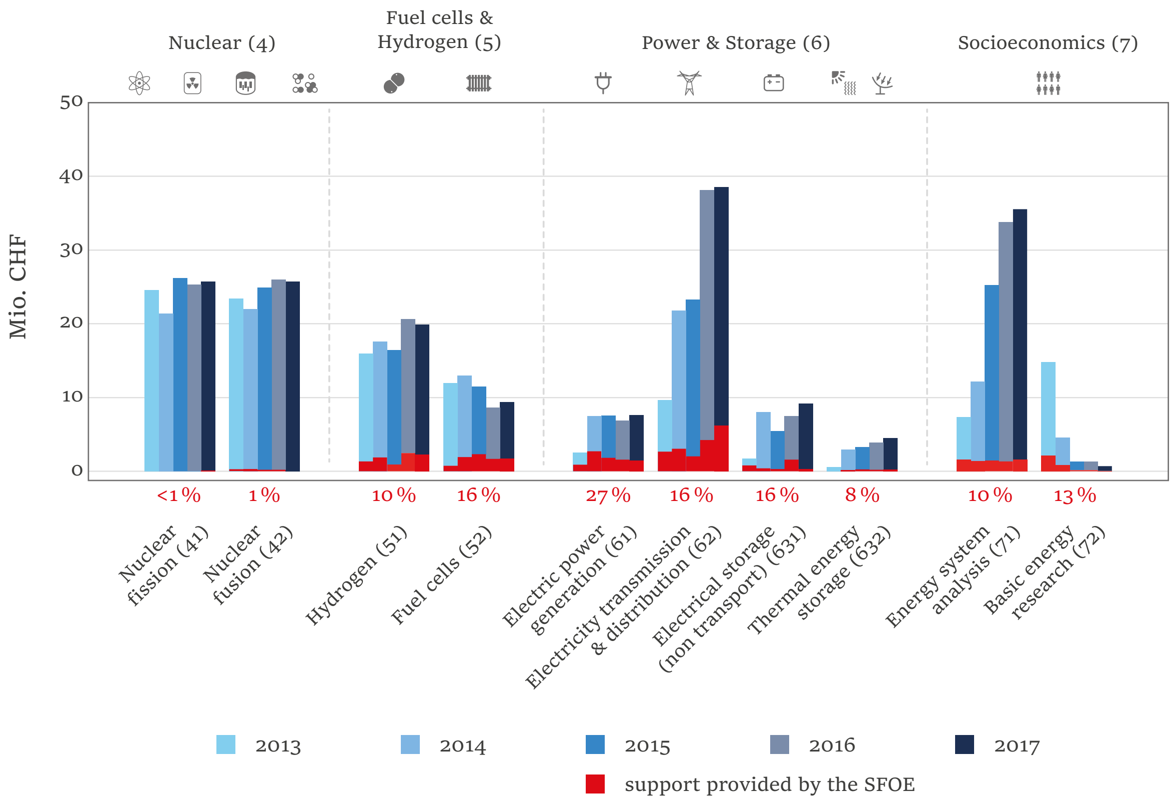


Figure 4: Development of expenditure for Swiss energy research in various sectors defined according to the classification of the International Energy Agency (IEA) for the period from 2013 to 2017. For the sake of clarity, only the main categories are depicted (i.e. no sub-categories are included). Detailed data are available on the energy research website (www.energy-research.ch). Topics such as heat pumps and heat recovery are included in the "Buildings" and "Industry" categories, respectively.

The figures shown in red correspond to the support provided by the SFOE (research and development projects / pilot and demonstration projects). The share of the SFOE varies from a small percentage up to more than 30 percent.

The increase in public sector funding for energy research (cf. Figure 2) and associated research activities is most clearly apparent in the areas of networks, transport, biomass and photovoltaics, as well as in the field of socio-economic research.

Efficient energy use

Efficient energy use is a crucial factor for achieving the objectives specified in the Federal Council's "Energy Strategy 2050". Since 2013 research capacities in the areas of grids, buildings and industry, mobility and storage technologies are strengthened. 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.

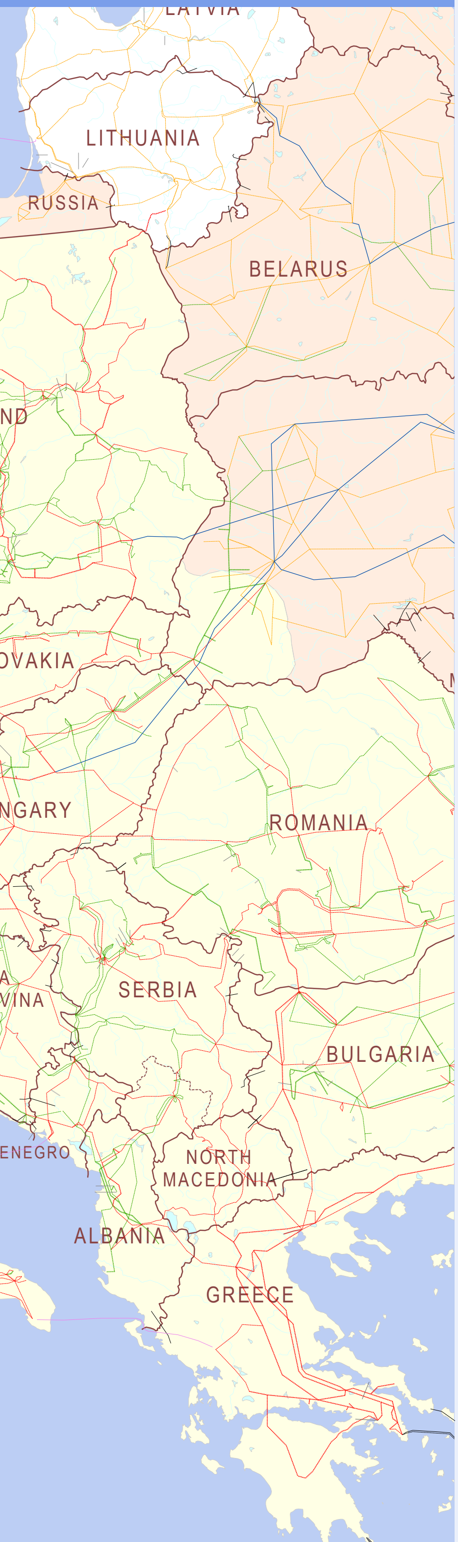
Decentralised renewable electricity production and network dynamics

The expansion of renewable energy sources influences the dynamic behaviour of the transmission network. Rotating generators, which historically had a stabilising effect on the network as short-term storage devices, are increasingly replaced by power inverters. In view of this, the operation of the transmission network needs to be adapted, which calls for the use of new instruments for real-time monitoring of grids and for maintaining grid stability.

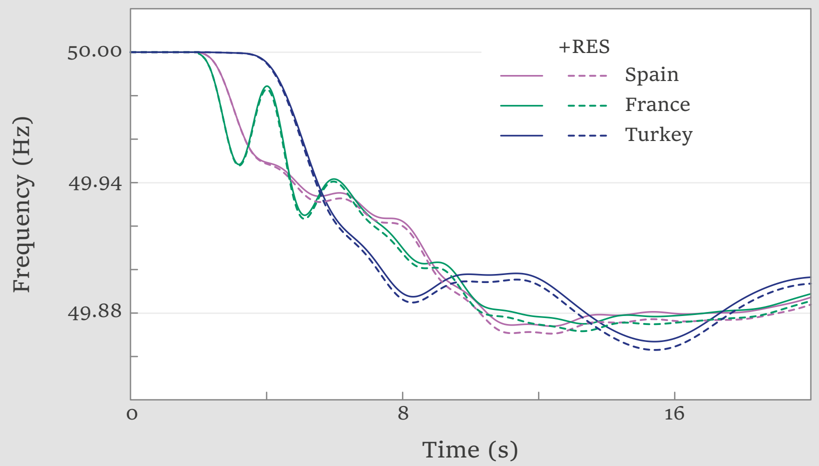
In order to meet their sustainability objectives, Switzerland, other European countries and the majority of industrialised nations promote an increased use of decentralised renewable energy sources. However, the European power system is still dominated by supply of electricity with synchronous generators (50 Hz), i.e. large rotating masses interconnected via the transmission network over large distances. Projects such as the "European Power System 2040" show that the current complexity of the European transmission system will increase further if 75 percent of the electricity demand in Europe is to be met from renewable energy sources, which will only be possible through cross-border exchanges.

The present-day transmission system in continental Europe can be likened to a system with three masses connected via three springs. Sudden outages of individual power lines and power plants trigger oscillations in the system and thus jeopardise safe operation. However, the increased use of renewable energy, especially wind energy and photovoltaics, poses new challenges for the real-time operation of the system, not only due to the variable feed-in behaviour, but also as the result of additional effects caused by network interconnection using modern high-performance power inverters.

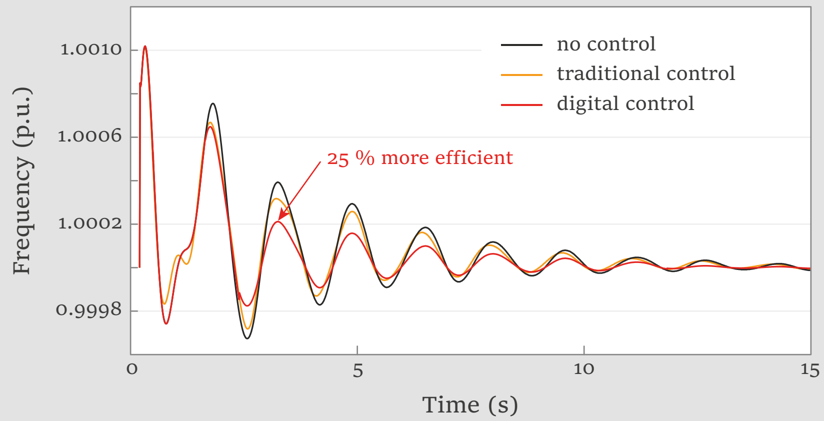
The extent to which this could influence the dynamic behaviour of the transmission network is not yet clear. This issue is the main focus of the transnational project, "CloudGrid". A large number of non-linear simulations of the European network will be required in order to find solutions. For this purpose the



Transmission line network in Europe (Source: www.entsoe.eu).



Frequency response at three randomly selected points in the European network (Spain, France and Turkey) after two synchronous generators (rotating masses) with 2,800 MW have been disconnected at t=0 in France. The solid lines indicate the present-day network (with nuclear power plants in Germany and Switzerland) and the dotted lines indicate the same network though excluding the nuclear power plants in Germany and Switzerland, offset by 10 GW of renewable energy (RES) at the same network nodes. Here it is not the renewable energy or its fluctuations that account for the difference, but rather solely the greatly reduced rotating mass of the "future" system (Source: Zurich University of Applied Sciences).



Comparison of the damping of oscillations in the frequency response (deviations from the reference level per unit) after a network interruption, depicting the existing control method versus the digital control technology developed in this project (Source: Zurich University of Applied Sciences).

most detailed dynamic network model available today, which was developed by the European Network of Transmission System Operators for Electricity (ENTSO-E), is to be used for the first time. A sudden outage of two synchronous generators in France with a total output of 2,600 MW causes frequency fluctuations depicted in the illustration above for three randomly selected locations in the model. In order to simulate the impact of the decommissioning of the nuclear power plants in Switzerland and Germany, the synchronous generators concerned are now replaced by feed-in of electricity (10 GW) from renewable energy sources. This has a direct influence on both the frequency and the rate of change. The illustration above depicts the resulting frequencies, which in principle are now lower. The already significant reduction is expected to become more pronounced with an increasing proportion of renewable energy.

This means that it is not only the dynamic behaviour of the system that changes, but also the way in which it has to be operated. The use of already available measurement infrastructure, such as wide-area monitoring systems, permits quicker and more reliable control than can be achieved with conventional systems. The methodology developed within the scope of the "CloudGrid" project is based on synchrophasor measurements in order to actively adapt the controller parameters and thus prevent a system collapse. In the illustration below a comparison is made between the performance of a conventional controller and that of the method developed in the "CloudGrid" project. As can be seen, with the new method oscillations can be reduced by up to 25 percent.

Rafael Segundo, ZHAW

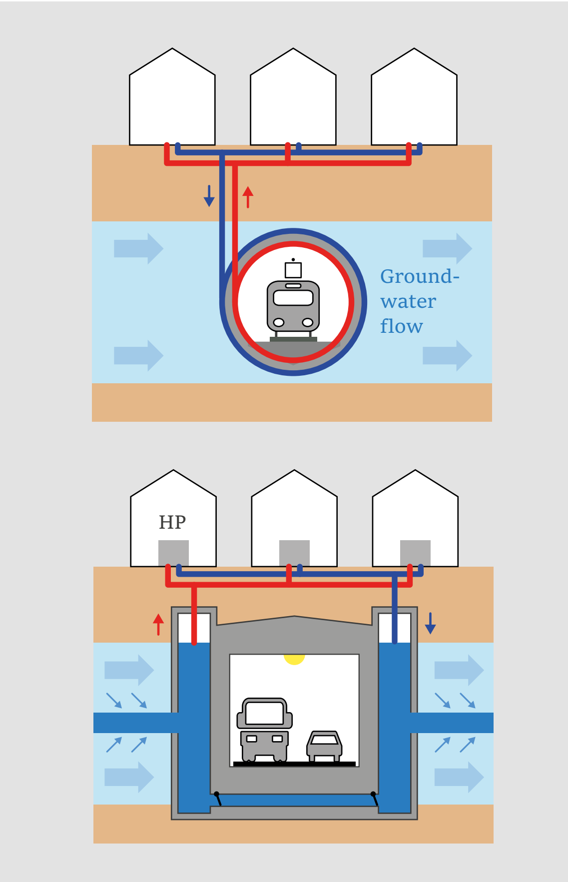
Thermal potential of urban tunnel infrastructure

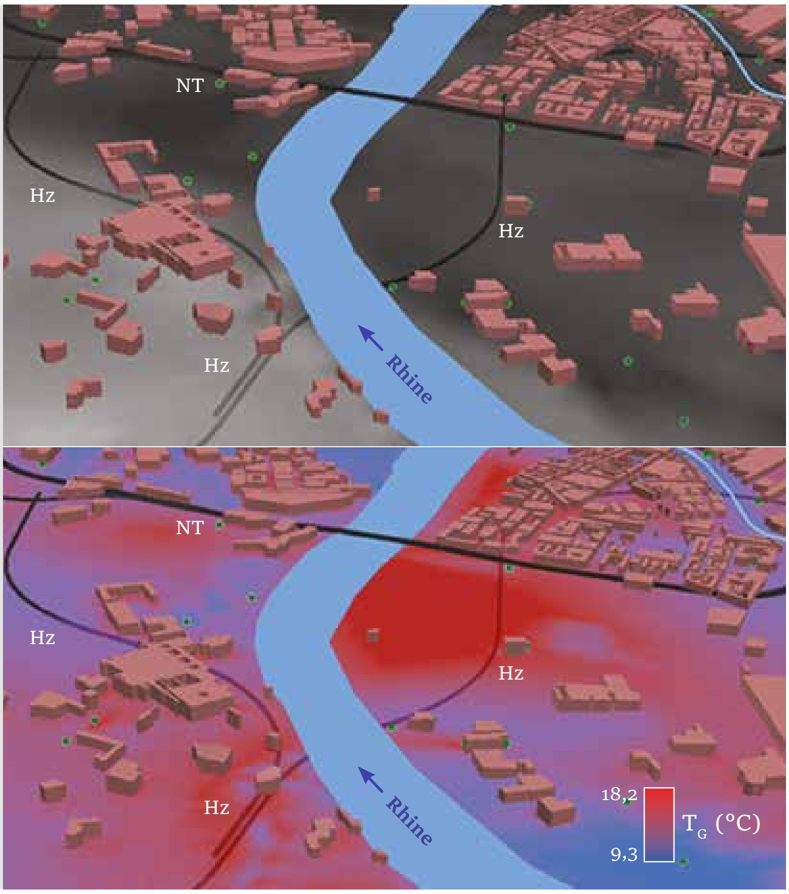
Tunnel tube of the subway in Munich (Source: Wikipedia, author: OhWeh).

In many urban areas, groundwater temperatures are often high and this means there is potential for the energy to be utilised when constructing underground transport routes. The feasibility of this utilisation of tunnel infrastructures is currently being studied in the agglomeration of Basel.

In the city of Basel, the use of ground heat in the context of the cooling of buildings and the heat generated by using subsurface constructions (buildings, tunnels, etc.) results in higher groundwater temperatures of up to 18° C. This poses the question whether the heat can be reused so that groundwater temperatures can be stabilised. Initial studies have shown that the enormous quantity of excess heat below the surface could cover 20 up to 100 percent of the demand for heating energy.

Researchers at the University of Basel are currently developing tools for studying thermal influences on groundwater resources and assessing the potential use of tunnel infrastructures for energy purposes. Here the focus is on the transport of heat through groundwater channels in highly porous unconsolidated rock formations. Large contact areas between tunnel structures and the underground enable the utilization of subsurface heat, especially in districts where major restructuring is planned and associated energy requirements can be met through the use of “active” heat pump systems that utilise groundwater,





Use of tunnel infrastructure for thermal purposes with absorber elements in the cladding. Bottom: Utilisation of groundwater with the aid of heat pump (HP) systems.

Top: Urban underground structures at the elbow of the Rhine in Basel: route of the planned suburban railway tunnel (core section) and the existing motorway tunnel infrastructure (northern bypass) in relation to the underground rock surface (grey zone). Bottom: Current groundwater temperatures at the elbow of the Rhine in Basel (Source: University of Basel).

and the use of "passive" energy absorbers. Heat exchangers installed in tunnel segments form "passive" systems (see illustration above). "Active" systems are used in aquifers beneath tunnels. They secure the flow of the groundwater and help prevent backwater effects and stagnation zones in the vicinity of tunnel structures.

There are various solutions for the use of heat from tunnel structures, depending on the type of tunnel and the local geological circumstances. In railway tunnels, excess heat from trains causing temperatures of around 30° C in the tunnel can be "passively" utilised, and at the same time heat extraction cools the tunnel infrastructure. Large-diameter motorway tunnels tend to be suitable for "active" utilisation, especially if the tunnel crosses a groundwater flow in an unconsolidated rock formation.

An ongoing study in Basel suggests that, in two sections with lengths of 740 and 280 metres respectively, near the entrance to a planned suburban railway tunnel one may utilise thermal output levels of around 4.8 and 1.8 MW. This would make it possible to provide 10, respectively 3.7 GWh of heat during the heating season. In the planned motorway tunnel crossing the Rhine, only those sections that cross the relatively warm groundwater flow are suitable for heat utilisation. In a section with a length of 320 metres, one may harness a thermal output of around half a megawatt. The results of the Basel study serve for developing strategies for the sustainable management of underground resources in urban regions.

Jannis Epting and Peter Huggenberger,
University of Basel

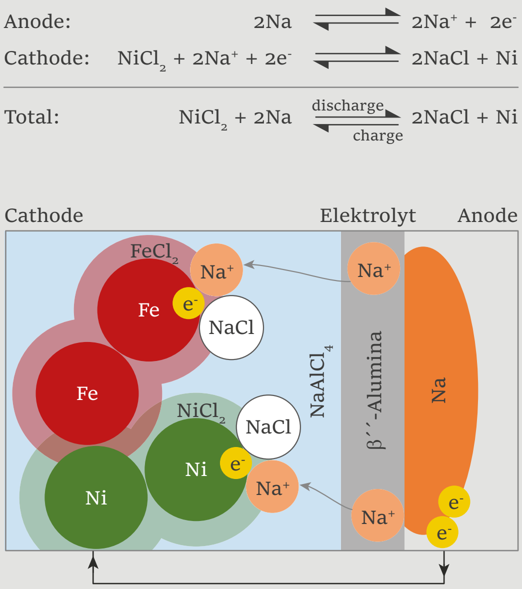
High-temperature batteries from Switzerland

Sodium nickel chloride (NaNiCl) batteries are a proven technology with extremely high levels of operational safety. Based on initial research carried out at the end of the 1970s in South Africa, in the past few decades this technology has undergone further development in the UK, Germany and Switzerland. Today, NaNiCl batteries are being manufactured by Swiss company FZSoNick in Stabio (Canton of Ticino). With more than 150 employees and an annual production capacity of 800,000 cells (80 MWh), FZSoNick is a global leader in the manufacture of sodium nickel chloride batteries.

For the production of these batteries, raw materials are used that are available in large quantities and are fully recyclable (stainless steel, nickel, iron, rock salt, aluminium-oxide-based ceramic electrolyte). The active components of the charged cells are a liquid sodium anode, a partially liquid cathode and a solid ceramic electrolyte (see Figure on page 16). To reduce the internal resistance of the cell and increase the energy efficiency of the battery, the operating temperature of the internal cell is around 270° C, while the external surface temperature of the battery is only a few degrees higher than ambient temperature. In addition to offering maintenance-free operation for up to 4,500 charge/discharge cycles, NaNiCl batteries also have a lifetime of around 20 years. Unlike lithium-ion batteries, they tolerate outside temperatures ranging from -20 to +60° C at constant output.

Based on these characteristics, NaNiCl batteries are a low-cost solution for storage in the fields of telecommunications, on-board rail transport systems and uninterruptible power supplies. With specific energy densities of 140 Wh/

One of the advantages of sodium nickel chloride technology is that the manufacturing process does not have to take place under inert gas conditions. Glove box tests (e.g. with metallic sodium) help identify the processes that limit the charge rate in state-of-the-art cells (Source: Empa).



Structure of a sodium nickel chloride cell: cathode comprising nickel and sodium chloride, iron to enable higher charge and discharge rates; an anode of sodium, and electrolyte of aluminium oxide. Anode and cathode reaction equations are shown at the top.

The operating temperature of such batteries is around 270° C for electrodes to be in liquid state and the electrolyte to have high conductivity. This means that NaNiCl cells have to be thermally insulated (Source: FIAMM SoNick, R. Simon).

kg and 280 Wh/litre at the cell level, they are also 70 percent lighter and 30 percent smaller than conventional storage systems based on lead-acid technology. State-of-the-art NaNiCl batteries are also used in large stationary energy storage units (up to 1.4 MWh, 400 kW) as well as in various e-mobility applications (utility vehicles, buses, mining equipment). However, in comparison with lithium-ion batteries, NaNiCl batteries feature lower charge and discharge rates and require a relatively complex cell assembly process. At present, the costs associated with this battery technology are not yet at the level of those for lithium-ion batteries, which in recent years have become significantly less expensive thanks to their increasingly widespread use.

Against this backdrop, the objective of the ongoing research is to find ways to increase the efficiency of the industrial manufacture of NaNiCl batteries. In doing so, their competitiveness increases as well as the efficiency of the use of the energy and resources required for the process per se. Researchers at the Federal Laboratories for Materials Science and Technology (Empa) and the Federal Institute of Technology, Lausanne are currently working together with FZSoNick to develop a new generation of high-performance NaNiCl cells. As part of a project initiated in 2018, these researchers focus on the further development of the cell design, ceramic electrolyte and electrodes. Their aim is to develop a flat cell geometry instead of the conventional tubular form in use today. This will reduce the complexity of cell assembly, increase charge rates and improve reliability. At the same time, researchers want to achieve a high level of operational safety and long service life.

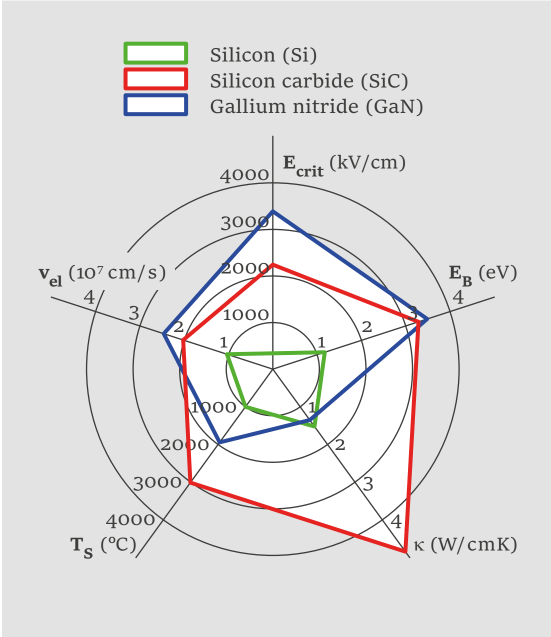
With the aid of multi-physical modelling in combination with electrochemical cell characterisation, processes will be identified that limit the charge rate of the new generation of NaNiCl cells. The composition and microstructure of the cathodes and current collectors will then be adapted on the basis of these findings in order to maximise the share of the active material and increase the charge rate. In addition, new cell assembly methods are to be studied in order to increase the degree of manufacturability and scalability.

Meike Heinz, Empa

Efficient power electronics

In comparison with conventional silicon, the use of wide band gap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) in power electronics components has the potential to significantly increase system efficiency. The sphere of application for such components is enormous, and ranges from small switching power supply devices (laptops, mobile phones) through to inverters for photovoltaic systems and higher output systems such as electric drives and motors. An American study carried out in 2015 estimated the annual savings potential in the area of laptops, tablets and mobile phones alone at more than 7,500 GWh. At the initiative of the SFOE, this potential is now to be examined in greater detail for Switzerland within the scope of the collaboration within the International Energy Agency (IEA). For this purpose, a broad-based technology assessment is to be carried out and a roadmap of the most promising applications is to be prepared. Roland Brüniger

Compared with silicon, the semiconductors SiC and GaN have a wider band gap (E_B), are faster (v_{el}), conduct heat more efficiently (k) and can be operated at higher voltage (E_{crit}) (TS = melting point).



Silica aerogel as thermal insulation

Thanks to its extremely low thermal conductivity, silica aerogel can be applied in thin layers for thermal insulation and is particularly suitable for use in the renovation of buildings in urban centres. Unfortunately, production is costly and inefficient. In a pilot installation by the Federal Laboratories for Materials Science and Technology (Empa), the technical feasibility and economic viability of its industrial production are demonstrated to transform a niche market product into a widely used technology.

Wim Malfait, Empa

Injection of water into diesel engines

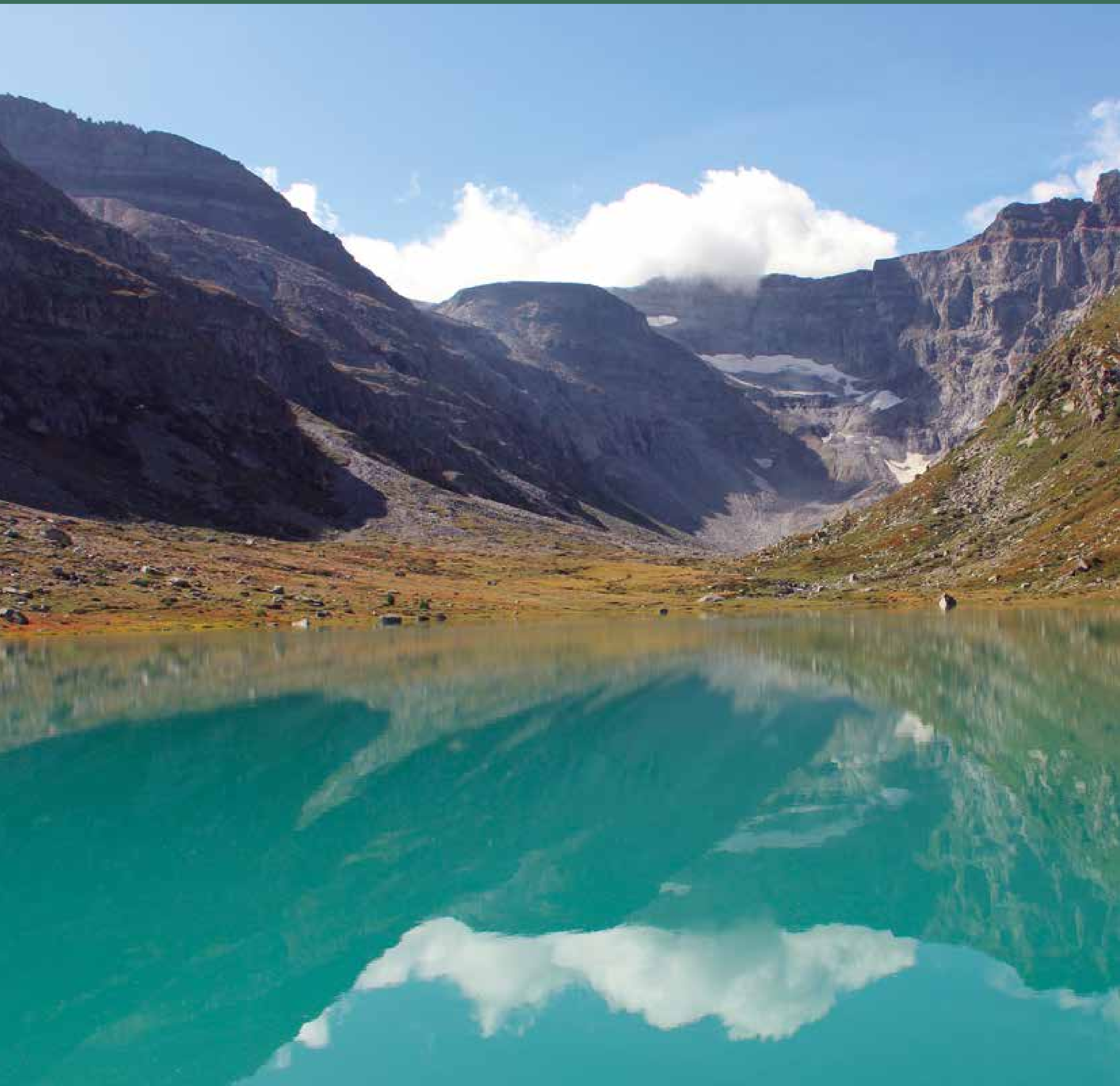
Large diesel engines are used for the operation of ships and the stationary generation of electricity. One of the main challenges associated with their use is to reduce emissions of nitrogen oxides (NO_x) and soot. In order to minimise the costs for the installation and operation of external components, such as catalytic converters and particle filters, research is underway to identify measures that can be applied within the engine in order to reduce the emission of pollutants. Exhaust gas recirculation is a well-known option to reduce formation of NO_x. But, at the same time combustion temperature are lowered leading higher soot formation due to insufficient oxidation. In an engine equipped with exhaust gas recirculation, the Paul Scherrer Institute (PSI) has demonstrated that by injecting water into the fuel it is possible to reduce soot emissions by up to 85 percent while simultaneously reducing NO_x-emissions. The efficiency of the engine was also increased by 0.85 percent. These effects can be attributed to the explosive evaporation of the drops of water in the engine, which improves the degree of atomisation and thus enhances the combustion process.

Stephan Renz

Top: Silica aerogel is a light and porous solid. Thanks to its very low thermal conductivity it is highly suitable for thermal insulation applications (Source: Empa). Bottom: Test bench for engines (Source: PSI).

Renewable energy

The proportion of renewable energy in the overall energy supply is constantly increasing throughout the world, especially in the electricity sector for technologies like wind power and photovoltaics. The use of other technologies such as hydropower, biomass and geothermal energy is also on the rise, with hundreds of gigawatts of additional capacity being installed throughout the world. 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 fi elds that have the potential to create industrial value-added in the country.



Planning tools for the renewal of hydropower plants

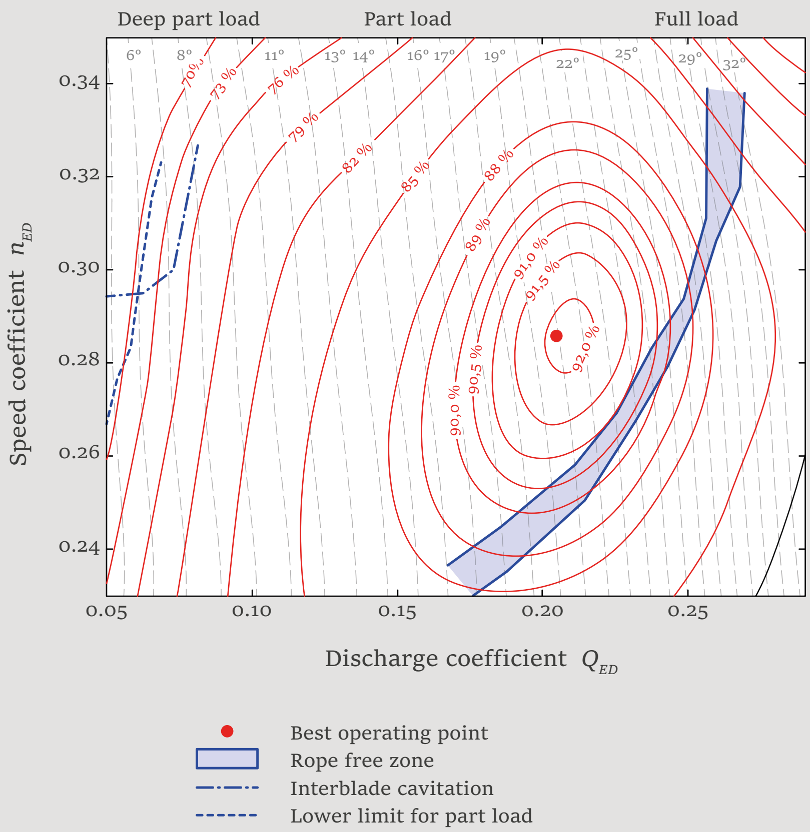
The majority of Switzerland's hydropower plants will have to renew their operating licences in the not-too-distant future. Switzerland's Energy Strategy 2050 calls for a significant increase in hydropower production. Swiss researchers are developing tools to determine the most suitable economic structural and electromechanical solutions from a broad variety of potential renovation and expansion options.

The strategy aims to compensate the loss in electricity production associated with the phase-out from nuclear energy, by increasing the utilisation of hydropower production in Switzerland and the use of new forms of renewable energy. In addition, stricter water protection legislation, the increase in the use of unregulated renewable energy sources and the associated need for flexibility in Switzerland's electricity grid, present new challenges for the hydropower production sector.

In the next few years, renewals of hydropower concessions will be required for production facilities accouting for around 24 TWh (or 70 percent) of the annual production of electricity from Switzerland's bodies of water. A broad range of conceivable options of a structural and mechanical nature exist, for example increasing the height of dam walls and enlarging the volume of reservoirs, or modifying mechanical installations by adding more turbines or replacing existing ones with improved or more flexible models. There are many potential scenarios that involve combinations of structural and mechanical options, and these need to be compared with one another. With the aid of a planning tool ("RENOVHydro") developed by the Federal Institute of Technology, Lausanne together with various partners, the very wide range of existing options can be compared with one another. The tool takes account of energy production and various network services, as well as background conditions such as protection of water bodies.

The empirical efficiency of turbines and reversible pump turbines at various operating points can be depicted with the aid of hill charts, where the level of efficiency is depicted as a function of flow-

Water reservoir "Chummibort" of a hydropower plant of Gommerkraftwerke AG (Source: Pedro Manso, EPFL).



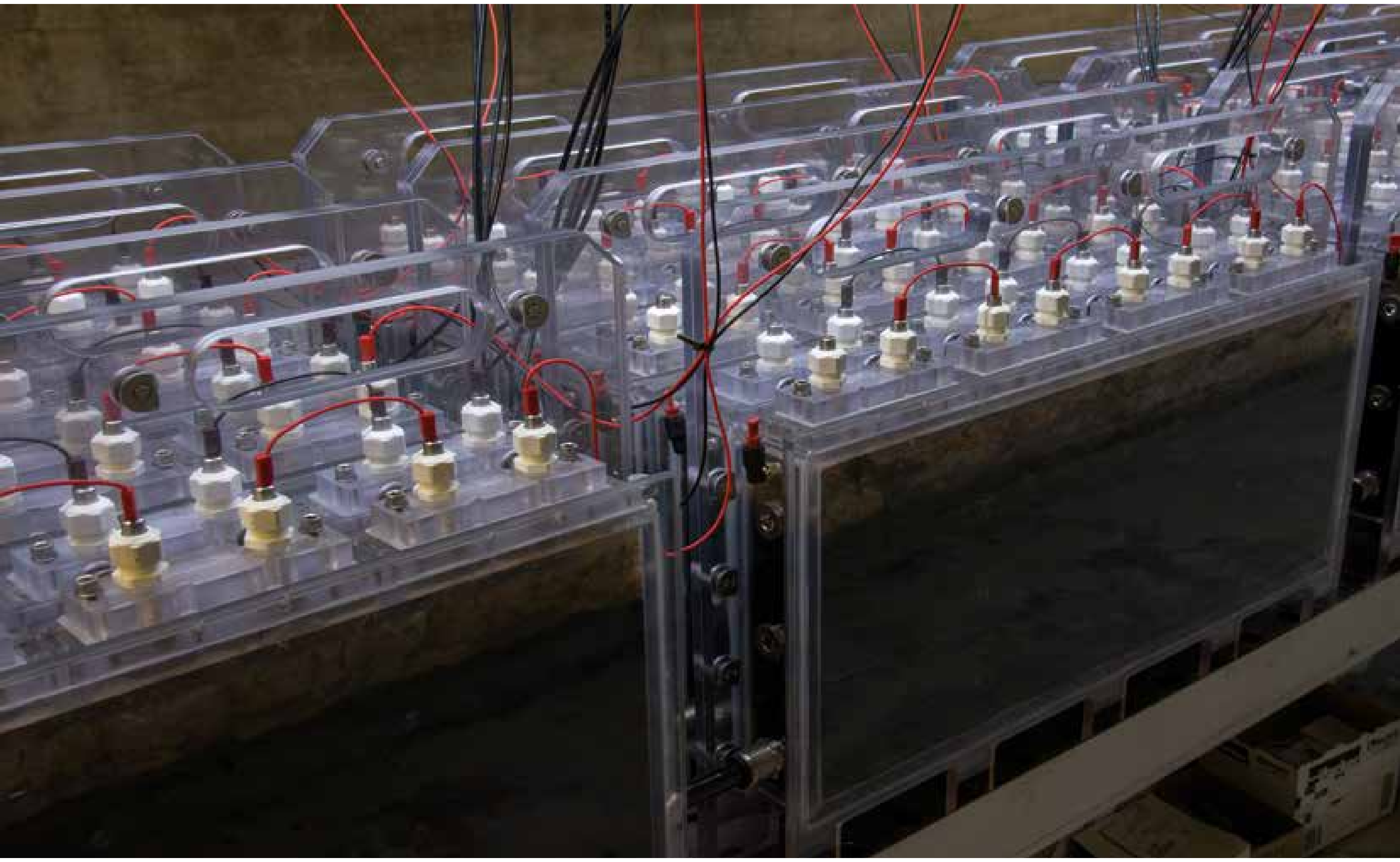
"Hill chart" for a Francis turbine, showing the efficiency as a function of the operating speed or rotation frequency n (s^{-1}) and flow-through rate Q (cubic metres per second). In order to compare different turbines with one another, operating speed and flow-through rate can be depicted as dimensionless parameters: speed factor $n_{ED} = nD/(gH)^{0.5}$ and discharge factor $Q_{ED} = D^2/(gH)^{0.5}$ with turbine diameter D, gravity g and fall height H. The dotted lines indicate the aperture angle of the blades.

A modelling tool developed at the Federal Institute of Technology, Lausanne and its partners creates generic hill charts to assess the impact of renovation of existing hydropower plants. The basis for this tool is a database of empirical tests (Source: Federal Institute of Technology, Lausanne).

through Q and rotation speed n of the turbine or pump. Based on the empirical data from the Laboratory for Hydraulic Machines at the Federal Institute of Technology, Lausanne, generic hill charts can be produced with the aid of special interpolation procedures. The laboratory is able to benefit from its unique testing facility, where over the course of the past 50 years, turbines of the world's most important hydropower plants have been tested using reduced scale models in accordance with international standards. With the resulting hill charts, it is possible to perform numerical simulations of any desired new or partially renovated turbines at various operating points, taking into account fall height H and flow-through Q as expected in a modernised hydropower plant. The modelling tool also takes account of the connection to the electricity grid.

In a practical test, this tool was applied to a system of hydropower plants operated by project partners Forces Motrices Valaisanne and Groupe E. For this system, which comprises several storage facilities and hydropower plants, more than 700 different scenarios were examined from the point of view of potential renovation and future operating modes. For this purpose, a specific hydrological year and a scenario for the attainable electricity market prices were defined. The ten scenarios with the best economic result were subsequently identified, together with the potential network services and resulting revenue. At the same time, the necessary investments for structural and mechanical modifications were calculated. These data can then be used for determining the most promising options for renovation and/or expansion for the renewal of the concession for the respective facilities. Through the use of the "RENOVHydro" tool, the required expenditure can be cut by a factor of around 20 versus the use of a conventional method for studies of this type.

François Avellan, Christophe Nicolet and Christian Landry, EPFL



Stacked individual microbial fuel cells: during the clarification and electricity production process, sewage flows from right to left through the interconnected cells (Source: HESSO Valais).

Microbes that produce electricity

In Switzerland, municipal sewage treatment plants account for around 1 percent of the total electricity consumption. Slightly more than half of this is used for the active ventilation of the biological clarification basins. The use of microbial fuel cells, which clarify the sewage and simultaneously generate electricity, may result in much lower electricity consumption.

In microbial fuel cells, living organisms process organic substances (substrate) and transmit the electrons that are produced during metabolism to an anode (cf. illustration on page 21). Much in the same way as in conventional low-temperature fuel cells, the generated protons migrate via a membrane to the cathode, whilst electrons flow from the anode via an external circuit and thus produce useful electricity.

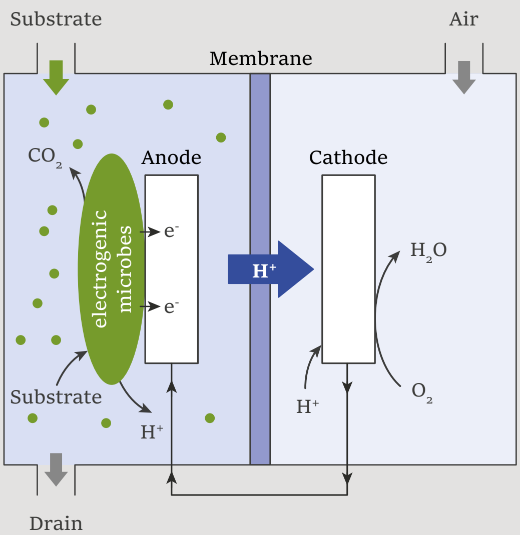
Electrical microbes occur naturally in municipal waste treatment plants and settle spontaneously on electrodes of microbial fuel cells. The resulting biofilms contain a broad variety of specialised microbes which break down the numerous contaminants in sewage. These anaerobic microbes do not require molecular oxygen and thus make the cost-intensive ventilation of the biological clarification stage superfluous.

A 1,000-litre upscaled microbial fuel cell tested in the sewage treatment plant in Sion. Here, alongside the construction of the plant, performance management plays a major role. Individual microbial fuel cells are stacked together to produce electricity as efficiently as possible. Voltage fluctuations among the individual microbial fuel cells are detected and balanced out in an adaptive electronic control system. In addition, the performance of the cells is optimised through maximum power point tracking, which increases the speed of the clarification process. Unexpected events such as inflows of toxic substances harmful to microbes may be detected, and any more negatively affected electrodes are automatically disconnected, regenerated and subsequently reinstated. An electricity storage module transforms the low output capacities of the 64 individual cells into useful electricity to be stored in lithium batteries.

In short: microbial fuel cells can be used to clarify sewage. They reduce the consumption of energy at the biological stage of a sewage treatment plant and simultaneously generate utilisable electricity.

Fabian Fischer, HES-SO Valais-Wallis

Microbial fuel cell:



How a microbial fuel cell functions: living microorganisms on the anode process organic substances (substrate) and transmit electrons produced during their metabolism to an anode. Much in the same way as in a conventional fuel cell, generated protons migrate via an ion-conducting membrane to the cathode whilst the electrons flow from the anode via an external circuit and can be used as power source.

The sewage treatment plant in Sion with microbial fuel cells. The 1,000-litre reactor with 64 fuel cells connected in series is more than 12 metres in length. The system produces electricity whilst it clarifies sewage. The produced electricity is then stored in lithium batteries (Source: HES-SO Valais-Wallis).

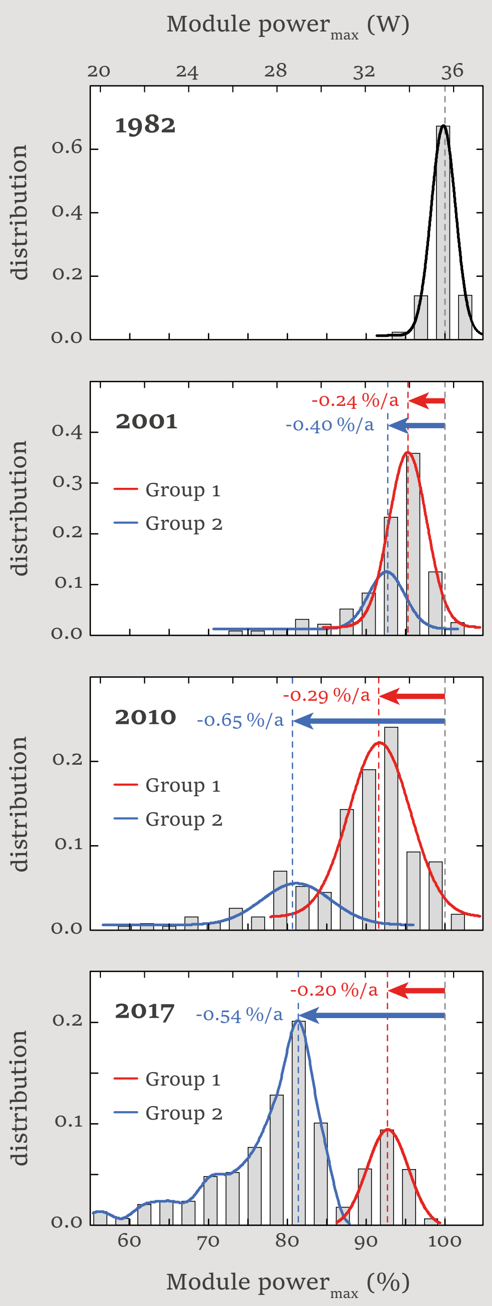
“Old” photovoltaic systems and what we can learn from them

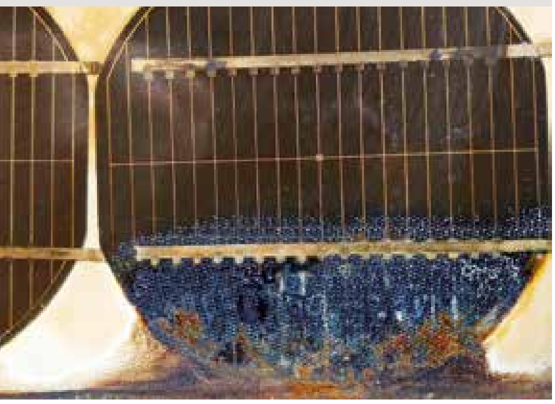
Knowing how much electricity a photovoltaic system is likely to produce over a given period is a decisive factor for making a reliable assessment of its economic viability. One of the main criteria is how the module and its performance develop over time. In order for modules to gain market approval, certain minimum quality standards have to be met which can be verified on the basis of standardised international testing procedures. Long-term analyses of modules operated under real environmental conditions are essential so that long-term predictions can be validated in accelerated ageing tests. Monitored since 1982 by the University of Applied Sciences and Arts of Southern Switzerland (SUPSI, Canton of Ticino), the TISO 10-kW plant has been making a valuable contribution.

In 1982 the TISO plant was the first of its kind in Europe to be connected to the grid. The plant comprises 288 monocrystalline silicon modules manufactured by ARCO Solar, with a nominal power of 37 W and an efficiency rating of around 10 percent. Apart from its age, what makes this facility unique is that 18 reference modules have been measured in the laboratory at regular intervals and thus allow a comparison with the original characterisation dating back to 1982. In 2001, 2010 and 2017 the entire plant was tested for performance, electrical insulation and visual damage. The resulting dataset can be used to detect any long-term degradation phenomena.

The crystalline silicon technology that now dominates the photovoltaics market has undergone significant develop-

The TISO 10-kW plant at SUPSI in operation since 1982 comprises 288 crystalline silicon modules manufactured by ARCO Solar. Views of the facility in 1982, 2002, 2005 and 2013 (Source: SUPSI).





Left: Chronological development of the distribution of the power of the 288 modules installed in the TISO 10-kW facility. While some modules (group 1) indicate a moderate degradation rate, for a second group (group 2) the degradation rate is much more pronounced (Data source: SUPSI).

Bottom: Example of severe damage, attributable to a combination of various effects (delamination at the edges of the module, mould infestation, oxidation, hot spots) (Source: SUPSI).

ment since the 1980s and the modules installed in the TISO plant at that time differ in many ways from the products that are widely used today. For example, the cells in use today are only roughly half as thick and the encapsulation materials that protect them from external influences are no longer the same as those that were installed in the TISO modules. Various studies show that the degradation of photovoltaic modules is a continuous process. Typically, the end-of-service life of a photovoltaic module is defined in terms of a 20 percent drop in performance compared to the original specification, and most manufacturers offer a warranty for at least 20 years.

In 2017 the entire TISO system was dismantled and all modules were individually inspected in collaboration with the Federal Institute of Technology, Lausanne. Performance characteristics were analysed as well as the insulation of the modules and the condition of the bypass diodes. In addition, measurements of the electroluminescence were made so that any damage to the cells (e.g. micro-fissures) could be detected. Finally, a visual analysis of all the modules was carried out. The various modules that were found to have defects were then statistically evaluated and compared with the findings from the previous inspection campaigns in 1982, 2001 and 2010. The analysis of these measurements revealed that, after 35 years, 56 percent of the modules still produce more than 80 percent of the nominal power and thus would still comply with a warranty for a maximum loss of 20 percent. In 2017 a higher degradation rate was observed than in the previous measurements. The development of the modules was also by no means homogeneous: while one group of modules ("red group", approximately 21 percent) indicated a degradation rate of only -0.2 percent power loss per annum, the degradation rate for a second, much larger group ("blue group", approximately 73 percent) was -0.5 percent or more per annum. Five percent of the modules no longer function.

Considering a study that involves photovoltaic technology dating back to 1982, the question inevitably arises which of these findings can be carried over to modern modules. It was discovered that the different degradation rates of the modules can mostly be attributed to the condition of the encapsulation. At that time, modules were installed in the TISO plant with three different types of encapsulation material. Fundamentally, it is necessary to gain an understanding of the interactions between the broadest possible range of degradation mechanisms in order to guarantee a longer service life.

Stefan Oberholzer

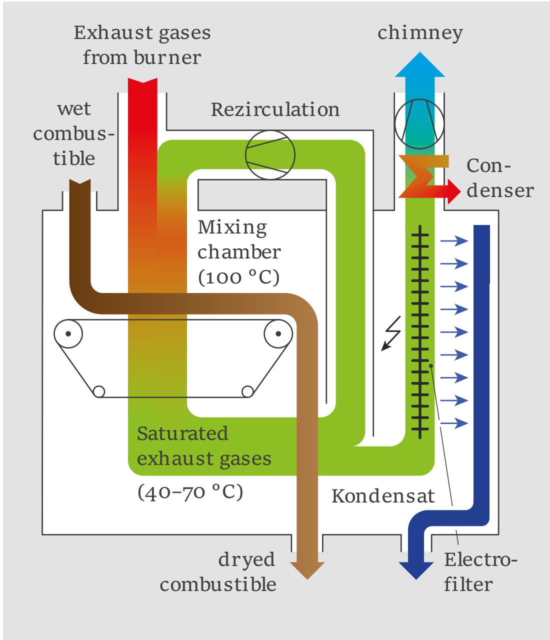
Detailled information:
A. Virtuani et al., Prog. Photovolt Res Appl. 2019;27:328–339.
https://doi.org/10.1002/pip.3104

Innovative pre-drying for biomass furnaces

OekoSolve AG has developed an innovative wood chip dryer for the heating system of Bérocad SA in St Aubin-Sauges. This new method involves pre-drying wood chips which increases the efficiency of the biomass furnace by more than 10 percent. Wood chips are transported from a neighbouring sawmill via a belt dryer and dried with the hot exhaust gases from the biomass furnace before they are conveyed to the furnace. Thanks to the use of wood chips a substantial proportion of particulate matter can also be held back. The belt dryer is also equipped with an electric filter which cleans the saturated exhaust gases. Pre-cooling results in the need of smaller filter. The successful trial with this method of fuel pre-drying will open up new options for efficient and economical recycling of moist biomass. Men Wirz

Reduction of abrasion damage in hydropower plants

Due to the increasing sedimentation of reservoirs, abrasion damage to turbines and diversion shafts resulting from the build-up of sediment in hydropower plants is occurring more and more frequently. This results in higher operating costs and loss of revenue, as well as reduced storage capacity. By applying improved abrasion models developed by the Federal Institute of Technology, Zurich, one can now more accurately predict flood events and the build-up of suspended sediment in the water, and thus optimise the operation of turbine and sediment diversion shafts. In this way, the required quantity of water can be reduced and damage to installations prevented, which results in higher energy production and lower operating costs for hydropower plants. Men Wirz



Top: Concept for pre-drying of wet biomass combustible.

Middle: Abrasion in a sediment diversion shaft (Source: ETH Zurich).

Bottom: Perspex model of a stoker screw furnace with droplets in the combustion chamber illuminated with the aid of a laser beam (Source: HSLU).

Stoker screw combustion

Automatic wood burners can supply district heating networks or replace oil and gas heating systems in large buildings. Given that Switzerland's wood combustion potential is limited, timber products or biomass pellets with higher ash content are increasingly used. This in turn calls for the development of furnaces in the 100 to 300 kW range suitable for such fuels. Modern concepts rely on stoker screw furnaces, which secure the continuous removal of ash, prevent the formation of slag and, owing to stepped combustion, produce low levels of particulate matter and nitrogen oxide emissions. In a trial using a 35-kW furnace, stoker screw combustion was shown to use biomass fuels with an ash content of up to 7 percent by weight and attain low emission levels. For the construction of a 150-kW furnace a scale-up was carried out based on key combustion-related data, and the air injection and the combustion chamber were optimised with the aid of flow calculations and measurements of models. Sandra Hermle

Socioeconomic aspects

The Energy Economy Society (EES) cross-sectional programme focuses on economic, social, psychological and political issues throughout the energy sector supply chain. The research programme serves to develop new energy political instruments and to monitor existing instruments. In 2018 a broad range of research projects was sponsored covering such diverse topics as the behaviour of energy consumers, investment in renewable energies, the design of the energy market, and mobility.

The Swiss gas market in a European context

The development of the European gas supply and the consequences for Switzerland were studied within the scope of a project called Modelling the Swiss Gas Market in a European Context. Here the focus was on issues related to modelling of the European and Swiss gas markets, as well as on security of supply, the possible structure of a liberalised market and the implementation of an “entry-exit” system in Switzerland. This project was supported by the SFOE within the framework of its “Energy - Economy - Society” research programme.

In order to assess the development of the market and supply security, a team of researchers developed a model of the European and global gas markets. With the aid of a scenario analysis, various expansion options (“Southern Gas Corridor”, “Nord Stream 2”), interruptions to supply (Russia-Ukraine) and potential strategies for improving security of supply in crisis situations (storage management, long-term agreements) were simulated and evaluated. The findings show that the existing network infrastructure and the planned expansions assure a generally high supply level in the EU as well as in Switzerland.

However, there is still a high degree of dependence on imports from Russia, especially in Eastern Europe, and even with the planned expansion measures it will not be possible to eliminate the dependence altogether. In order to address this risk, analysing a precautionary storage strategy is a cost-effective method. A reserve of 20 to 30 percent of the total storage volume could largely compensate a four-month interruption of supply via the pipeline from Russia through Ukraine if various storage facilities in Europe were to be efficiently coordinated. For Switzerland, with no domestic production or storage facilities, coordination with the EU makes particularly good sense. Since around 30 percent of the demand for gas in Switzerland comes from dual fuel consumers (e.g. availability of both gas and oil boilers), Switzerland has potential for a certain degree of flexibility.

The analysis of the security of supply also suggested that simple, static analyses of the supply situation, or studies based on purely technical parameters and structures,

Marking of the gas pipeline near Seeberg, Canton Bern (Source: Christoph Hurni).

are not sufficient for estimating the dynamics in times of crisis. It is therefore recommended to combine technical supply-security assessments with a global market evaluation in order to incorporate the relationship between dynamics on the supply and the demand sides.

Regarding an analysis of the possible structure of a liberalised gas market in Switzerland, a simplified Swiss "entry-exit" market model was developed and a variety of tariff options evaluated. However, findings suggest few differences. As before, the European market prices are the main driver for the future development of Switzerland's gas market. The use of the model is fairly limited in view of its highly aggregated structure and the unavailability of detailed network data.

Léo Chavaz and Hannes Weigt (University of Basel, Sustainable Energy and Water Supply Research Centre) and Jan Abrell (Centre for Energy Policy and Economics, Federal Institute of Technology, Zurich)

Solar concentrator of the Laboratory of Renewable Energy Science and Engineering at EPFL for the production of renewable gas (hydrogen). The combination of a concentrated solar energy with a photo-electrochemical system and intelligent heat management allows the conversion of solar energy into hydrogen with efficiencies of up to 17 % (see S. Tembhurne, F. Nandjou & S. Haussener, Nature Energy 4, 399–407, 2019).

Glazed solar thermal collectors attain temperatures above 180° C. This places high demands on materials and components in collectors and their circuits, which is reflected in the overall system costs. In a project called "ReSoTech", researchers from the Institute for Solar Technology at the University of Applied Sciences, Rapperswil, are developing cost-effective solutions for limiting the maximum temperature to 100° C. In a sub-project, the absorber surface of collectors is coated so that, depending on the temperature, it "switches" from black to white and thus more or less ceases to absorb solar radiation. The illustration shows a test collector in its <100° C operating mode (black, on the left) and in "off" mode (>100° C, white, on the right) (Text: Elimar Frank. Image: Institute for Solar Technology, Rapperswil).

International cooperation

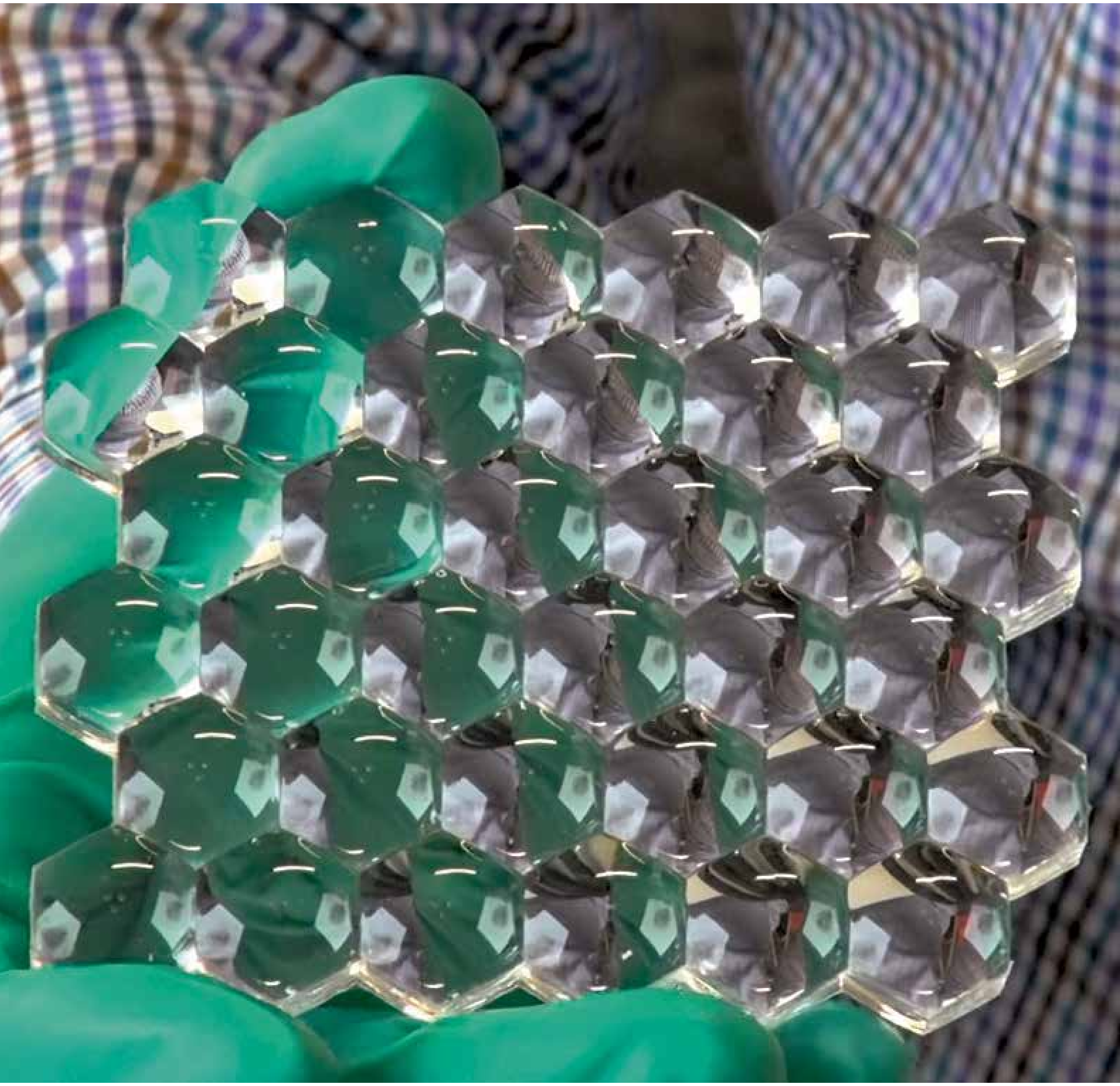
Switzerland attaches a great deal of importance to international cooperation in the field of energy research. At the institutional level, the SFOE coordinates its research programmes with international activities in order to utilise synergies and avoid redundancies. Cooperation and exchanges of experience within the framework of the International Energy Agency (IEA) are of particular importance to Switzerland. Here, for example, the SFOE participates in various IEA "Technology Collaboration Programmes" (formerly called "Implementing Agreements, cf. www.iea.org/tcp).

At the European level, wherever possible Switzerland actively participates in EU research programmes. Here, at the institutional level the SFOE coordinates its energy research in alignment with the European Strategic Energy Technology (SET) Plan, the European Research Area Networks (ERA-NET), the European technology platforms, joint technology initiatives, etc. Beyond that, intensive multilateral cooperation with selected countries also exists in certain fields (smart grids, geothermal energy, etc.).

Swiss participation in «Technology Collaboration Programmes» of IEA

- Energy Conservation through Energy Storage (ECES)
- Energy Efficient End-Use Equipment (4E)
- Energy in Buildings and Communities (EBC)
- Demand Side Management (DSM)
- High-Temperature Super Conductivity (HTSC)
- International Smart Grid Action Network (ISGAN)
- Advanced Fuel Cells (AFC)
- Emission Reduction in Combustion (Combustion)
- Advanced Motor Fuels (AMF)
- Hybrid and Electric Vehicles Technologies (HEV)
- Bioenergy
- Geothermal
- Hydrogen
- Photovoltaic Power Systems (PVPS)
- Solar Heating and Cooling (SHC)
- Solar Power and Chemical Energy Systems (SolarPACES)
- Wind
- Greenhouse Gas (GHG)
- Gas and Oil Technologies (GOT)
- Energy Technology Systems Analysis Program (ETSAP)
- Environmental, Safety & Economy (ESEFP)*
- Fusion Materials (FM)*
- Nuclear Technology of Fusion Reactors (NTFR)*
- Plasma Wall Interaction (PWI)*
- Reversed Field Pinches (RFP)*
- Spherical Tori (ST)*
- Stellarator-Heliotron Concept (SH)*
- Tokamak Programmes (CTP)*

* via Euratom (https://ec.europa.eu/programmes/horizon2020/en/h2020-section/euratom)



Swiss start-up, Insolight, has developed a photovoltaic technology where an array of small lenses collects incident solar radiation and concentrates it on high-performance solar cells. Unlike conventional concentrating photovoltaic systems, where modules have to be adjusted to the position of the sun, the adjustment mechanism is integrated into the module and thus enables the use of concentrating photovoltaic systems on buildings (Source: Insolight).

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