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Head of editorial team .... Tony Kaiser, President of CORE

Authors
General section .... Katja Maus and Rolf Schmitz
Socioeconomic aspects... Anne-Kathrin Faust
Housing and employment .... Andreas Eckmanns
Mobility.. Martin Pulfer and Katja Maus
Energy systems .... Gunter Siddiqi
Processes .... Stephan Renz

With the support and cooperation of the heads of the eight Swiss Competence Centres for Energy Research

CORE Secretariat
c/o Swiss Federal Office of Energy SFOE
CH 3003 Bern
Phone: +41 58 462 39 78
www.bfe.admin.ch

Address for ordering copies .... www.energieforschung.ch

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Vision

Swiss energy research is to make a notable contribution towards the efficient and low-emission conversion, storage, provision and use of energy in the future. In this way it is to help maintain a safe, economical and ecologically acceptable energy supply. It also contributes to an effective energy policy.[1]

[1)] The Federal Energy Research Masterplan is based on this vision, which was formulated by the Federal Energy Research Commission (CORE) and is shared by the Swiss research community.

Research for a successful energy future

The Federal Council and Parliament have decided that Switzerland is to withdraw from the use of nuclear energy in the medium term, and in response to this decision, the Swiss Federal Office of Energy (SFOE) has developed a new energy policy called *Energy Strategy 2050*[2]. With this new energy policy, Switzerland has set itself ambitious efficiency targets regarding the use of fossil energy and electricity consumption. The aim is to greatly increase the production of electricity from renewable energy sources (photovoltaics, wind energy, biomass and geothermal energy) by providing financial support in order to offset the gap left by the withdrawal from nuclear energy. *Energy Strategy 2050* will roughly double the level of energy efficiency per capita in Switzerland versus the current level, and reduce electricity consumption by 10 to 20 percent. Furthermore, Switzerland has entered into a commitment at the international level to reduce greenhouse gas emissions: its climate policy is calling for a reduction by 20 percent by 2020 versus the 1990 level[3].

Federal Energy Research Masterplan

The Federal Energy Research Masterplan is a vision shared by Switzerland's research community with recommendations for energy research in Switzerland. It is financed by the public sector. It also describes the research goals that are required for supporting *Energy Strategy 2050*.

The Masterplan has been approved by the Federal Council and thus takes the form of a planning instrument for all federal research bodies. But it also serves as an orientation aid for cantonal and municipal authorities with their own promotion tools in the area of energy research.

This Masterplan is valid for the 2017 to 2020 legislature, and was drawn up by CORE in cooperation with leading interest groups in the field of energy research. It is based on current, internationally recognised scientific findings and takes account of Switzerland's declared energy policy objectives.

According to the IPCC[4], the environmentally friendly and low-emission use of energy is absolutely vital for the entire planet. In its 2014 report, the IPCC cites a variety of potential ways in which global warming could be limited to 2 °C. This will not be possible with the existing reduction plans. In the scenarios examined by the IPCC, in order to limit global warming to around 2 °C it will be necessary to reduce global greenhouse gas emissions from all sources by between 40 and 70 percent by 2050 versus the 2010 level. The IPCC scenarios include accelerated improvements in energy efficiency as well as an energy supply with a threefold to fourfold increase in the share of non-carbon or low-carbon fuels through the use of renewable, nuclear and fossil energy, in combination with carbon separation and storage. The IPCC also proposes the use of bio-energy in combination with carbon separation and storage by 2050. With the aid of these measures, global CO_2 emissions from the energy sector would decline in the next ten years, and would fall by 90 percent below the 2010 level in the period from 2040 to 2070.

Alongside the federal *Energy Strategy 2050*, there are two other long-term visions developed by the Federal Institutes of Technology which are shaping the debate on the energy future in Switzerland: The "2,000-watt society" is a concept that focuses on energy efficiency. It is based on the premise that a sustainable energy future will require by 2100 reductions in primary energy demand throughout the world to a level that corresponds to a constant consumption of 2,000 watts per capita. In 2012 the level in Switzerland was 6,500 watts per capita, excluding grey energy.

By contrast, the concept of the "1-tonne CO_2 society" (per capita and year) permits a higher level of energy use if it is supplied from renewable energy. Both visions require that pollutant emissions and the volume of waste have to reach a non-critical level for human beings and the environment, and that the material flows associated with energy production have to be self-contained and significantly reduced versus the present-day level.

[2] www.bfe.admin.ch/themen/00526/00527/index.html?lang=de (Energy Strategy 2050), [3] www.admin.ch/opc/de/classified-compilation/20091310/201301010000/641.71.pdf (revised CO_2 Act, as of 1 January 2013), [4] IPCC: Intergovernmental Panel on Climate Change, www.ipcc.ch

The pragmatic objectives formulated by CORE for 2050 in previous energy research masterplans fit well into this strategic thrust and have also been confirmed in the proposed *Energy Strategy 2050*:

- Withdrawal from fossil combustibles for the provision of heat in both existing and new buildings
- 50 percent reduction of primary energy consumption in the country's buildings stock (current level: 500 PJ per annum)
- Threefold increase in the use of biomass as an energy source (current level: 37 PJ per annum)
- Reduction of the average consumption of fossil fuels by passenger cars to 3 litres per 100 kilometres (current level: 6 litres per 100 kilometres)

In the view of CORE, the most important objective concerns the interdisciplinary development of new, implementable and thus acceptable energy technologies. The increasing importance of interdisciplinary technologies therefore calls for greater cooperation both within the various areas of research as well as between technical and non-technical disciplines.

The Federal Energy Research Commission (CORE)

CORE was established by the Federal Council in 1986 as an advisory body for energy research. Its duties include drawing up the Federal Energy Research Masterplan every four years, monitoring Swiss energy research and commenting on energy-related federal sectoral research. CORE comprises 15 members representing industry, science and the political sphere. Its current composition can be viewed by visiting **www.energieforschung.ch**.

Key data [TWh]	2010	2050	Δ
Total energy consumption	233.6	125.3	-108.3
Total electricity consumption	59.8	53.1	-6.7
Proportion attributable to households	18.6	13.4	-5.2
Proportion attributable to mobility	3.2	11.4	8.2
Proportion attributable to industry	19.3	12.6	-6.7
Electricity production from renewable energy	36.5	62.7	26.2
Hydropower	35.1	38.5	3.4
Photovoltaics	0.1	11.1	11.0
Geothermal energy	0.0	4.4	4.4
Wind energy	0.0	4.3	4.2
Biomass / biogas	0.2	2.8	2.6
Other sources	1.0	1.6	0.6

Selected key energy consumption and electricity production data for Switzerland for 2010 and 2050 (Energy Strategy 2050); https://www.admin.ch/opc/de/federal-gazette/2013/7561.pdf
1 TWh = 1 billion kWh and 1 TWh = 3.6 PJ

Research policy background

In the framework of *Energy Strategy 2050*, an action plan called "Coordinated Energy Research"[5] was developed by the Federal Council for the 2013 to 2016 legislative period and approved by Parliament in addition to the Federal Energy Research Masterplan. The action plan supports the objectives, and thus the implementation, of *Energy Strategy 2050* in the area of application-oriented energy research by creating additional research capacity at universities and colleges of technology. Its main areas of focus are efficiency technologies, energy systems, networks and electricity transmission, provision of electricity, energy storage and socioeconomic as well as legal aspects. Thus social sciences will also play a significant role in the implementation of *Energy Strategy 2050*.

For the implementation of the action plan, in 2013 and 2014 eight competence centres (Swiss Competence Centres for Energy Research) were created in a competitive process and their scientific goals were subsequently defined. For this creation of additional research capacity at universities and colleges of technology, Parliament approved in the 2013 to 2016 legislature funding in the order of 72 million Swiss francs. In the same period, Additional funding was also provided for infrastructure projects and sponsored professorships at the two Federal Institutes of Technology. The action plan was allocated a total of 202 million Swiss francs.

The Federal Council also approved other measures in addition to the cited support: The financial resources at the disposal of the Swiss Federal Office of Energy for pilot and demonstration projects[6] were significantly increased, a promotion programme was created for flagship projects[7] and two National Research Programmes[8] were launched under the auspices of the SNSF[9] ("Energy Turnaround" and "Managing Energy Consumption".

During the forthcoming legislative period, a petition is to be submitted to Parliament within the framework of the "Education, Research and Innovation 2017–2020" Dispatch concerning the continued operation and financing of the eight competence centres. The recommendations concerning the scientific objectives are incorporated into this new research masterplan. The involved universities and colleges of technology are expected to assume responsibility for the operation of these competence centres with effect from 2020.

Energy research and innovation

Switzerland is one of the most innovative countries in the world, and has retained a top rating in a variety of studies for several years. In the *Global Innovation Index 2014*[10] it was ranked among the top 10 in the world; in the 2013 study[11] from the Swiss Institute for Business Cycle Research at the Federal Institute of Technology, Zurich (KOF) commissioned by the State Secretariat for Economic Affairs (SECO), Switzerland was named one of the most innovative economies in Europe; and it is currently ranked number 1 in Europe on the EU's *Innovation Union Scoreboard.*[12]

Numerous parameters are measured and compared in order to assess a country's innovation strength, including corporate activities and earnings, human resources, transparent, outstanding and attractive research systems, and the financing and promotion of research.

[5] www.admin.ch/opc/de/federal-gazette/2012/9017.pdf (Dispatch to Parliament concerning the Coordinated Energy Research action plan, 2013–2016), [6] From 5 million Swiss francs in 2012 to 25 million in 2016, [7] 10 million Swiss francs per annum from 2014 to 2020, [8] Total, 45 million Swiss francs, [9] SNSF: Swiss National Science Foundation, [10] www.globalinnovationindex.org/content.aspx?page=GII-Home, [11] www.kof.ethz.ch/de/medien/mitteilungen/k/weitere-pressemitteilungen/1108/2013/04/innovationsstudie/, [12] http://ec.europa.eu/enterprise/policies/innovation/files/ius/ius-2014-summary_de.pdf

In order to maintain Switzerland's position as a centre of research – and thus its energy research sector – at the current high level, further measures will have to be implemented:

- Switzerland needs effective measures for promoting innovation and for close collaboration between universities, colleges of technology and the private sector. This includes in particular the simple regulation of all issues relating to intellectual property
- Diverging opinions exist in the relevant literature regarding the role of the state in promoting research. Switzerland should find a suitably balanced policy[13, 14] between the contradictory positions of a clearly defined industrial policy and a policy that is restricted to defining suitable framework conditions

In order to maintain its innovation strength, Switzerland needs transparent, symbiotic systems for research and development. In the area of energy research, the eight competence centres for energy research present a good example of this. They promote cooperation between the Federal Institutes of Technology, colleges of technology, universities and industry, and also support the transfer of technology between the world of research and the economy.

Knowledge and technology transfer

The transfer of knowledge and technology from universities to the industry is of central importance, because it enables value creation from research results on the market place. For this purpose, pilot and demonstration facilities are a valuable instrument. Ideally, they are planned at an early stage together with industry. They can then be used to demonstrate the technical feasibility of large-scale systems with the aim to reduce the degree of risk for private investors.

Knowledge also has to be passed on and put to practical use, and here, the education of science and technology professionals plays a vital role.

International integration

International cooperation promotes the quality of research and the efficient use of the involved financial resources. The prerequisites for successful cooperations are active participation in international programmes, especially as an associate in EU framework programmes, and recognition for high-quality contributions by Switzerland.

In view of this, the integration of Swiss researchers into research activities of the IEA and EU is of the utmost importance. But international cooperation and exchanges among researchers also have to extend beyond the EU and industrialised nations, and include developing countries. This comprehensive cooperation therefore has to be secured and strengthened by the respective leading federal agencies, namely the State Secretariat for Education, Research and Innovation (SERI) and the Swiss Federal Office of Energy (SFOE).

Switzerland's "knowledge economy" is also dependent on foreign students, who are essential to secure the availability of future management staff and employees in academic professions and knowledge-based services. Even though the level of employment is stagnating, Switzerland needs qualified, university-educated personnel from abroad, who make a significant contribution towards the global network of Swiss (energy) research.[15]

[13)] B. Hotz-Hart und A. Rohner, «Wirkungen innovations-politischer Fördermassnahmen in der Schweiz», Bern 2013, [14)] M. Mazzucato, «Das Kapital des Staates», Kunstmann, München 2014, [15)] B. Hotz-Hart, «Die Wissensökonomie Schweiz ist auf Bildungsausländer angewiesen», Die Volkswirtschaft 6–2011, p. 47

The research priorities in context

Energy research has to be based on a holistic approach and be oriented on the principle of sustainable development. The Federal Energy Research Masterplan encompasses the entire value chain of *research / innovation / market,* and through energy research supported by federal funding it sets out to achieve not only high-quality results, but also to provide benefits for the national economy.

Technology
With all technological solutions for the provision, conversion, storage and use of energy, the objective is to come as close as possible to realising the highest possible potential at an acceptable cost. Here, the new opportunities provided by digitisation are to be exploited across all thematic priorities.

Resources
CORE regards new and improved technologies for increasing the efficient use of energy and resources, and the increased use of renewable energy, as a central element of energy research. This automatically goes hand in hand with a reduction of harmful emissions.

Supply security and the national economy
The Federal Energy Research Masterplan also sets out to improve Switzerland's energy supply security and guarantee it over the long term, as well as to generate added value in the form of jobs, know-how and the development of new marketable products for the country, and thus to enhance Switzerland's competitive capacity at the international level.

Society and behaviour
Questions have to be answered regarding the acceptance of new technologies and incentives for their rapid market penetration. Here, economic, social, psychological and political issues associated with the provision, conversion, storage and use of energy are to be examined. Furthermore, energy research should contribute towards an understanding of the fact that it will not be possible to implement either a national energy policy or a global climate policy with the aid of technical measures alone. In order to achieve sustainable energy use, changes in behaviour will also be necessary.

Socioeconomic and regulatory aspects
For the reasons outlined above (i.e. because technology and society cannot be separated), in this Masterplan the technological priorities are prefixed by a variety of reflections and questions. These non-technological aspects are dealt within the respective priority areas if they are technology-specific, but if they reach across priority areas, they are dealt with separately as overlying issues.

Four thematic priorities
CORE has selected four technologically defined priority areas to which all fields of energy research can largely be allocated. They reflect daily life and the associated aspects of energy provision and use. The aim is that, with the visions defined in these priority areas, key fields for research can be derived top-down, while system thinking and interdisciplinary research are encouraged.

This integral and implementation-focused approach to energy research also incorporates social science, legal, economic and psychological issues. In view of this, they are now included in the "Society and Transition" energy research competence centre, CREST, and in National Research Programme NRP 71, "Management of Energy Consumption".

The four priority areas

Living and working in the future
Switzerland's buildings stock is to be operated emission-neutrally and energy-efficiently in the future. By its decentralized nature, it contributes to match electricity supply and demand. Housing and employment requirements will be met in a way that conserves resources.

Mobility of the future
Achieving attractive, efficient and low-emission mobility with the aid of traffic telematics, advanced drive

technologies and driverless vehicles is a crucial economic and development factor. Total energy consumption is to be substantially reduced in the future, together with greenhouse gases and other pollutants, despite increasing mobility. This means that research and development in the fields of highly-efficient transport and mobile storage technologies need to be expedited, and it will be necessary to gain a better understanding of the obstacles to new forms of mobility.

Energy systems of the future

Networked energy systems form the basis for a safe, reliable and sustainable energy supply. The availability of such systems is essential for an effective energy policy, and in particular for *Energy Strategy 2050*. The main objectives are a high degree of efficiency, maximised utilisation of energy potentials, and minimised negative influences on the environment (waste) as well as risks for the population. The design of system components and their optimized interactions are aspects that open up a wide range of research questions and a wealth of opportunities for innovation.

Processes of the future

Resource-optimised and marketable products will be manufactured with new processes and materials that are to be developed under consideration of Life Cycle Assessments. The consumption of energy and materials by production facilities is to be minimised through the use of highly efficient components. Information technologies support process integration all the way to the energy optimisation of products. Here, renewable and readily recyclable raw materials take precedence. The aim is to leave behind as small an ecological footprint as possible.

Timeframes for the recommended research objectives

In the chapters that follow, priorities and objectives for the four key thematic areas are defined and oriented on two timeframes:

- medium to long term research priorities for the period from 2020 to 2050
- short-term objectives for the scope of application of the current Federal Energy Research Masterplan for the period from 2017 to 2020

Socioeconomic and regulatory aspects

Energy consumption and CO_2 emissions are to be substantially reduced in the future, despite economic growth. This calls for a further relaxation of the coupling of growth and well-being on the one hand, and energy consumption on the other hand. In addition, a transformation of the energy system is planned that will take the form of a withdrawal from the use of nuclear energy and the increased use of renewable energy. This reform should be carried out as economically efficiently as possible and be based on broad social acceptance.

The Federal Council's *Energy Strategy 2050* calls for a step by step withdrawal from the use of nuclear energy while simultaneously meeting the declared climate objectives and maintaining the currently high level of supply security in Switzerland. This requires an increase in energy efficiency and an expansion of energy production from renewable sources. In order to achieve these objectives, the development of new technologies will be essential, but technological progress on its own will not suffice. Alongside a transformation of the energy system, the implementation of the *Energy Strategy 2050* will require a paradigm shift in energy consumption, and thus a change in the behaviour of all involved players. The associated utilisation-focused approach calls for new concepts and structural changes in the areas of infrastructure, the economy, and politics, as well as the predominant social norms and behaviour.

The main goals of psychological, socioeconomic and regulatory research are to bring about a better understanding of the behaviour of the various players and the way the markets function, and to identify the relative potentials and costs of the various measures. Other goals include providing a global view of the transformation of the energy system and a better understanding of the interconnections and interactions of various measures and types of behaviour.

Society and technology are closely tied and cannot be separated. For technological solutions to be able to contribute towards sustainable energy use, the relevant scientific aspects of the social, economic and political environment have to be taken into account for their development. For this reason, socioeconomic issues continue to be directly integrated into the various technological priorities in this research masterplan if they are of a technology-specific nature or are of particular relevance to a given technology.

However, a strictly technology-related approach entails the risk that the interconnections between disciplines could be overlooked in the research. The determinants of the behaviour of home owners who simultaneously act as electricity producers are for example relevant both from the point of view of energy efficiency in residential dwellings and for the architecture of energy systems and the expansion of the network. Similarly, numerous political instruments and measures have an effect beyond the scope of a single priority area, and thus need to be examined accordingly.

Such an approach to socioeconomic topics also opens up an opportunity to utilise synergies in a variety of areas. In this way it is possible to prevent issues like the acceptance of technologies being examined separately in each area of technology, even though a comprehensive approach would be more efficient. There are also significant original socioeconomic issues that can only be integrated into priority technology areas to a limited extent, for example analyses of energy markets or the development of macroeconomic models for analysing energy policy.

The restructuring of the energy system thus calls for changes in the behaviour of the involved players, in addition to the development of technological solutions. Political and regulatory instruments and measures therefore need to be developed, and framework conditions have to be created that support the transformation of the energy system. And this is where psychological, socioeconomic and regulatory research comes in. The increased significance of this energy research is already reflected in Switzerland's present-day research landscape, notably in the creation of National Research Programme NRP 71 ("Management of Energy Consumption") and the Swiss Competence Centre for Research in Energy, Society and Transition (CREST), both of which are focussing on energy-related socioeconomic and regulatory issues until 2020. However, additional research will be required beyond this timeframe, particularly in the areas of energy consumption and individual behaviour, companies and markets, and energy and environmental policy measures and instruments.

Medium to long term priorities

Energy consumption and individual behaviour

The targeted reduction in energy consumption goes hand in hand with a change in individual behaviour. Here, the aim is to analyse the behaviour of various players based on psychological, social and microeconomic methods, and to formulate recommendations for action. The purpose of research in this area is to gain a better understanding of the motives of the respective players and the effects of specific energy policy instruments. The objective is to analyse the psychological, economic and social determinants of energy demand and the individual decision-making and dynamic group processes so that measures can be developed that could help reduce individual energy consumption. In this context, further studies are to be carried out concerning for example the interaction of various measures and rebound effects.

Companies and markets

Here the focus is on the energy-relevant behaviour of companies and the functioning of the markets. Companies are important players: their strategies influence consumer behaviour and their investment decisions have a significant influence on the development of new infrastructure. Research is required into adaptation measures within companies and into the development of framework conditions that promote innovation and technological changes towards better energy efficiency. The design of the energy markets also plays a major role with respect to the restructuring of energy systems. In view of this, it is necessary to research efficient structures of energy markets and the influence of their design on the promotion of renewable energy.

Energy and environmental policy measures and instruments

The aim here is to study energy policy measures and instruments with the aid of macroeconomic analyses, and to analyse future energy demand, supply and framework conditions with the aid of scenarios. One of the tasks of socioeconomic research is to analyse the political, economic and social framework conditions, including independently of the main research areas, as well as the interaction of various political measures and their effects. Here, the interactions with other (i.e. non-energy-policy) measures have to be taken into account, for example in the areas of spatial planning, climate and transport policy. This applies at both the national and the international level. International climate and energy policies have a major influence on the energy markets in Switzerland, and demonstrating this influence, as well as the interactions of domestic and international policy measures, is an important area of research. This also applies with respect to Switzerland's positioning on the international energy markets.

Areas of research for the period from 2017 to 2020

This section lists a selection of areas of research that are to be focused on in the period from 2017 to 2020. In most cases, the listed research topics are of relevance to several priority areas. For example, a better understanding of the factors that influence individual energy consumption is of importance in the future in the areas of mobility as well as housing and employment.

Energy consumption and individual behaviour

- Socioeconomic determinants and affective, normative and cognitive factors influencing individual energy consumption, rebound effects
- Relations between information (e.g. energy-specific know-how) and decision-making by individuals in their social context and their population groups, modelling of decision-making, including effects of rational (risk versus return) and "bounded rationality" influences
- Sociopolitical acceptance (by stakeholders and legislators), community acceptance, acceptance of political measures
- Acceptance and influence of new energy-saving technologies on the behaviour of households
- Innovation in the energy sector: behaviour of households, significance and impacts of social innovations

Companies and markets

Investments

- Attractiveness of investments in energy infrastructure from the viewpoint of investors and portfolio optimisation; analysis and normative evaluation of legal framework conditions in the case of long-term investments
- Obstacles to investment in energy efficiency and renewable energy

Corporate strategy and organisation

- Strategies for smart energy systems
- Energy sector as an innovation system; functionality and determinants; innovation incentives and obstacles; diffusion of new products
- Ways in which companies can influence the behaviour of employees, and vice versa (including labour law barriers)

Market design

- Design of the energy markets in Switzerland, efficient market design, options for promoting renewable energy, legal implementation of efficient market designs
- Liberalisation and aspects of market regulation

Energy and environmental policy instruments

Macroeconomic modelling, scenarios and analyses

- Macroeconomic models for scenarios and simulations of various energy policy options (withdrawal from the use of nuclear energy, support measures, incentive taxes, ecological tax reform) and their impacts on the energy supply and the competitiveness of Swiss industry
- Holistic analyses of the energy system; development of scenarios focusing on players and society to complement scenarios focusing on energy, i.e. development of social forms (including lifestyles, land use, employment, housing, procurement, leisure-time activity, mobility, etc.), that can be successful under the changed framework conditions; incentives and obstacles that favour or hamper these social forms
- Development of demand models and scenarios that take account of individual behaviour and social interaction
- Mechanisms aimed at further separating energy and economic growth
- Strategies for adapting to climate change (cooling, availability of water, etc.)

Analysis of energy and climate policy instruments and measures

- Structuring the transition from a promotion to an incentive based system
- Interactions between climate and energy policy instruments and measures

Legal and international aspects

- Positioning of Switzerland on the international energy markets and options for integrating Switzerland into the European energy (electricity) market, including pump storage plants in the European network
- Influence and interaction of foreign energy policy and international climate policy with Swiss instruments and measures
- Conformity of Swiss instruments and measures with international law
- Options for solving and/or mitigating target conflicts in spatial planning, environmental and energy legislation; options and limitations regarding the acceleration of planning and approval procedures

Living and working in the future

Switzerland's buildings stock is to be operated climate-neutrally and energy-efficiently in the future. By its decentralized nature, it contributes to match electricity supply and demand. Housing and employment requirements will be met in a way that conserves resources.

In accordance with the above vision, in the area of *Living and working in the future*, technologies and concepts are to be researched that will reduce energy demand and increase the efficiency of energy conversion and use. In addition, decentralised energy storage, the local production of renewable energy in buildings, complexes, districts, towns, and cities are to be researched, as well as the interaction between energy consumption, decentralised energy production and network infrastructure and operation. Decentralised energy systems have to be integrated into the future energy system in Switzerland in a purposeful manner so that it will be possible to guarantee a complete, efficient and economical energy supply.

Strategies for increasing efficiency and reducing the consumption of non-renewable energy in the buildings stock are essential in order to achieve the goal of climate neutrality in the buildings sector (i.e. attain an annual greenhouse gas balance of zero). The optimal extent of efficiency increases has to be rendered dependent of the cost/benefit ratio of additional efficiency measures in comparison with the use of renewable energy.

New buildings have to be operated so that they do not produce any pollutant emissions while providing a high degree of comfort in terms of interior climate, noise/acoustics, light and hygiene. Buildings have to be constructed in a manner that protects resources, and the same applies to the manufacture of the materials utilised within them. Greenhouse gas emissions that are produced during the construction of buildings and their end of life have to be significantly reduced in comparison with the present-day level.

In order to achieve these goals, technologies and concepts will have to be developed that facilitate the intelligent production, conversion, use and storage of energy in the buildings sector, while taking account of interconnections and exchange capacities with supply networks. This encompasses both technological as well as socioeconomic research. The generated know-how then has to be implemented in products, in planning, consulting and processing tools, as well as (where necessary) in energy policy programmes and instruments, and subsequently brought into the market. Here, whether it will be possible to meet the declared targets and whether the reduction and efficiency options can be achieved will depend on the behaviour of the owners, operators and users of the buildings.

The interfaces with the other priority areas also have to be taken into consideration, e.g. the influence of housing and area planning on energy consumption for mobility and infrastructure, or the influence of smart grid and smart metering technologies on the options for the use and storage of decentralised renewable energy production.

Sustainable retrofitting of buildings

Buildings account for around 45 percent of primary energy consumption and 40 percent of Switzerland's total CO_2 emissions. This means there is a great deal of reduction and optimisation potential in this sector. A variety of national and international strategies are calling for a consistent transformation of the buildings stock based on the criteria of sustainable development.

Based on the visions of a "2,000-watt society"[16] and a "1,000-tonnes CO_2 society"[17] referred to in the introduction, the Swiss Society of Engineers and Architects (SIA), the federal government, the Federal Institute of Technology, Zurich and the City of Zurich jointly for-

16) "Bilanzierungskonzept 2000-Watt-Gesellschaft". SwissEnergy for Municipalities, 2014, 17) "Energiestrategie für die ETH Zürich", Federal Institute of Technology, Zurich, 2008 mulated an intermediate target for 2050 for the buildings sector in "SIA Effizienzpad Energie" *(SIA energy efficiency path)*.[18] The target is an average consumption of 2,000 watts of non-renewable primary energy and 2 tonnes of CO_2 equivalents per capita and year by 2050. Here the aim is for the buildings sector to account for approximately half. In order to place the energy required for the operation of a building in an overall context, the grey energy incorporated in the building materials and technical installations has to be taken into account along with the energy consumption for mobility attributable to the location of the building.

This intermediate goal was specified based on the premise of technical feasibility and financial viability, and the preservation of design freedom for architects and urban planners.

Targets

SIA-Effizienzpad Energy (SIA energy efficiency path) postulates targets for 2050 for primary energy and the associated greenhouse gas emissions in the six buildings categories (housing, administration, schools, retail outlets, speciality shops, restaurants), and proposes a suitable calculation method. For each specific object, these targets apply as minimum requirements for pilot and demonstration projects.

In addition to these comprehensive targets, the SIA has defined separate reference values relating to operating costs and the construction of buildings, as well as for mobility. The associated research activities should look for ways to roughly halve these reference values for individual objects in order to take a step towards fulfilling the vision of CO_2-neutral building operation.

The objective of the site development "Suurstoffi" in Rotkreuz is to provide a CO_2-free operation of the heating and cooling systems for households, offices and commercial premises. The concept is based on a so-called "Anergy" network in combination with geothermal probes and on-site production of electricity from photovoltaic systems (during peak demand, purchase of certified electricity). The "Hot" supply serves as heat source for the heat pumps located in the individual buildings, the "Cold" supply is used for free cooling (without a heat pump). Picture: Zug Estates und HSLU T+A

[18] *SIA-Effizienzpfad Energie (SIA fact sheet 2040), SIA 2016*

Medium to long term priorities

Building shell and concepts, construction processes

Accomplishing a significant reduction in energy consumption and CO_2 emissions in existing buildings is a major economic challenge that calls for the optimisation of all potential measures relating to buildings. As far as the energy-related retrofitting of building shells is concerned, costs increase progressively in line with the quality of the insulation. If it is possible to achieve this increase in efficiency and thus reduce CO_2 emissions accordingly with the aid of other environmentally friendly measures, then it makes better sense from an economic point of view to invest in less costly measures with lower marginal costs.

In the case of new buildings, the focus of research is on energy demand and on pollutant and greenhouse gas emissions throughout the entire useful life of a building, including grey energy demand and the associated grey greenhouse gas emissions for the manufacture of the materials and the construction of the building. In order to reduce energy consumption during the operation of a building, technologies are required that not only substantially reduce energy losses, but also facilitate the production of energy from the building shell. At the same time, the scope of architectural diversity should not be affected.

Generally speaking, buildings have to be adapted to meet future requirements in terms of space and comfort. Research therefore needs to be carried out into ways in which these space requirements can be met with minimal infrastructure with the aid of innovative design and layout solutions.

Methods for evaluating the benefits of energy efficiency measures compared with the benefits of additional production of renewable energy from individual buildings already exist today, but what is lacking are criteria for the optimisation of the overall system in new and renovated buildings, i.e. including new (centralised and decentralised) storage options, smarter energy supply networks and demand-side management. With the aid of smart-metering, automated and smart-grid technologies, it would be possible to utilise synergy potentials in individual buildings as well as in entire complexes and districts. For this purpose, innovative instruments for integral planning and the evaluation and optimisation of potential solutions need to be developed.

For residential buildings, research has to be carried out into new, low-cost and highly efficient insulation solutions that meet architectural and aesthetic demands, as well as the requirements placed on the conservation of listed historic buildings.

For other buildings, e.g. office blocks, schools and public buildings, the need is to develop innovative solutions to protect against heat during the summer, combined with solutions for reducing the necessity for artificial lighting (daylight use). Here, ways in which the heat emitted from appliances and lighting, as well as from human beings, can be used have to be researched, and together with the anticipated influences of climate change have to be taken into account when designing the shells of new buildings or renovating existing building shells.

For all types of buildings, innovative window and glazing concepts need to be researched that permit an optimal interior climate and minimal energy requirement in both winter and summer.

Building services system

In the future, buildings, whether separate or in groups, should as far as possible be able to meet their energy requirement self-sufficiently (i.e. "zero energy buildings") or indicate a positive energy balance throughout the year (i.e. "plus energy buildings"). In addition, buildings should also help compensate demand and production peaks in the electricity grid. The challenge for research is to develop innovative technologies for producing as much energy as possible in and on buildings. On the other hand, technologies and operating algorithms need to be researched and developed that facilitate the best possible harmonisation of energy consumption in the building with the energy that is produced at the building's location. Other research is required into the suitability, choice of technology and design of local storage facilities, especially for the daily, weekly and seasonal storage of surplus energy produced in the building that cannot be directly utilised.

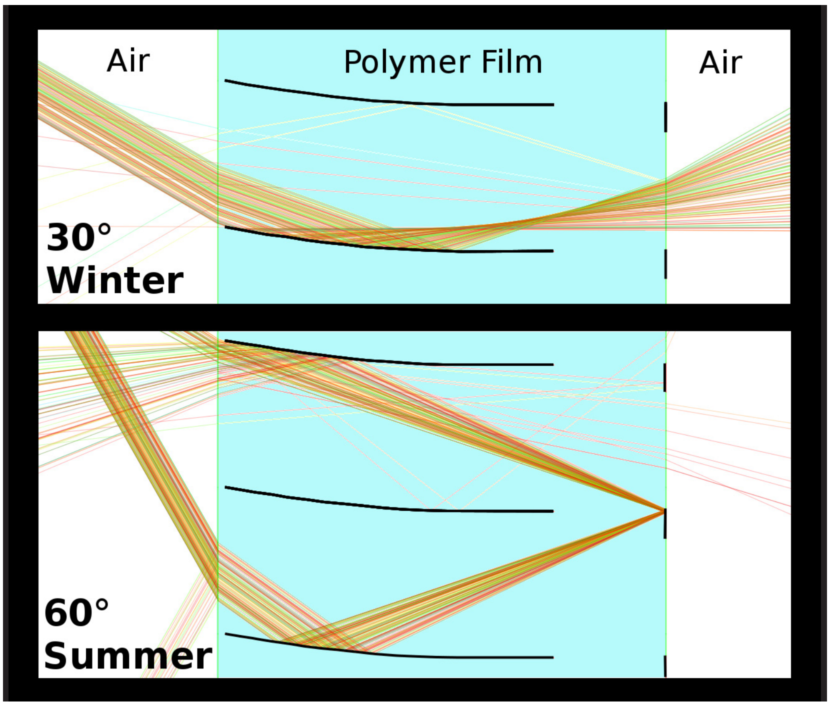
Technologies for producing renewable energy in and on buildings and for the use of waste heat need to be further developed and rendered more economically viable. Here, architectural integration into buildings, as well as the development of active multifunctional building shell elements to facilitate architectural integration and reduce costs, are important factors. It is also important to increase the degree of standardisation and reliability of these technologies.

Researching low-cost decentralised heat and cold storage technologies that can also help stabilise the electricity system is another important aspect. Here, in addition to technical feasibility, the economic viability of such solutions is a major factor.

Highly-efficient heat pump technologies support the ecological transformation of the provision of energy to buildings. They are often essential for reducing the residual energy consumption of buildings to the extent that it can be met with renewable energy.

Exergetically beneficial, ecological, decentralised combined heat and power technologies should be further developed from the point of view of proportion of electricity production, useful life and costs.

In view of the tendency towards a rising number of hot weather periods, we have to anticipate an increase in the demand for cooling systems in buildings in the future. This means that these systems will have to be



In the project "Integrated multifunctional glazing for dynamic day lighting" an innovative integrated concept and the development of advanced glazing for dynamic day lighting are being studied in this project. The new type of glazing is to combine the functions of day lighting, glare protection, overheating protection in summer and thermal insulation in winter. Innovative micro-structures will re-direct incident solar radiation, thus enabling the projection of daylight deep into the room at selected angles in the same manner as an anidolic mirror-based system, as well as glare protection. The solar gains will be reduced for selected angles. Technological progress includes the manufacture and improvement of micro-structures by selective deposition of micro-mirrors.
Picture: EPFL-LESO-PB

equipped with more flexible control mechanisms, which in turn will place greater demands on efficient operation at partial load.

Innovative solutions with ICT and automation, measurement, control and adjustment technologies need to be researched in order to facilitate the monitoring and adjustment of a building's own energy consumption, i.e. for the harmonisation of its internal consumption, the energy produced in the building and decentralised storage, as well as for external networking.

Sites and districts

Complete solutions are necessary in order to meet the electricity and heating requirements in Switzerland to the greatest possible extent with locally available renewable energy sources. Here, sites and districts can be turned into decentralised, networked energy systems. This is often required in order to economically utilise locally available renewable energy and waste heat, and to secure the demand for electricity and heat in a district or site with as high a proportion of locally produced energy as possible.

Decentralised energy systems are able to take over the provision of energy-related services (supply, conversion, management, storage and distribution) for a site or district, or even for an entire region. These are not self-sufficient systems, but the aim is to incorporate them as active elements into the energy system of Switzerland / Europe, where they will function as subsystems in the future energy system.

There is a need for research into the energy-related and economic optimisation of networked solutions in developed sites, including innovative information and communication technology for controlling and optimising energy production and load management in sites and districts. This could result in a significant contribution to the progress of the debate on smart cities and communities.
The development of networked solutions for existing sites with a number of owners and players is a major challenge. Models for finding promising sponsors and for promoting acceptance and procedures relating to the consideration and development of such solutions, as well as for supporting legal framework conditions, energy policy and planning instruments, and financing solutions, need to be studied and evaluated.

People, market, politics

In the area of *Living and working in the future*, the behaviour of the relevant players in the buildings sector (owners, investors, users, consultants, developers/contractors) and the background conditions, influencing factors, obstacles and drivers that determine their behaviour, need to be studied, and the options for accelerating the transformation of the buildings stock need to be researched. Here the degree of acceptance of new technologies, concepts and models among investors and users has to be discussed, as well as options for overcoming any obstacles that may be encountered.

On the other hand, the behaviour of companies that are active in the area of *Living and working in the future* has to be researched, including the factors that influence their activities and business models. Here the drivers and incentives for network solutions have to be analysed from the point of view of home owners. It is also necessary to examine how network benefits should be distributed, respectively which criteria should be applied in their distribution.

In order for sustainable housing and employment to become possible in an optimised buildings stock, it will also be necessary to develop housing concepts and new housing and employment models and to research their potential impacts on the declared energy objectives. The interaction between user behaviour and utilised technologies has to be optimised, but of course technology also has to support appropriate user behaviour.

Areas of research for the period from 2017 to 2020

This section lists a selection of areas of research that are to be focused on in the period from 2017 to 2020.

Building shell and concepts, construction processes

New technologies and concepts

- Innovative construction concepts (longer useful life of support structures in order to conserve resources, more consistent use of renewable, separable, and recyclable building materials, lightweight construction), new technologies and construction processes
- Materials with minimal grey energy consumption and grey greenhouse gas emissions; development of criteria for grey energy consumption and technical installations
- High-performance insulation components and materials for renovating buildings that meet the requirements for processing on site (fitting) and significantly reduce the amount of labour required at the construction site
- Improvement of the thermal properties of glazing and windows; "switchable" glass, glass with variable g value, etc.
- Development of criteria for improving the flexibility of use of new buildings and comprehensively renovated existing buildings, for increasing the duration of use or reducing the requirement of grey energy in future renovations or changes in the use of the building

Calculation methodology, tools

- Planning instruments for reducing energy consumption and CO_2 emissions in renovated buildings throughout their entire useful life with the best possible cost-benefit ratio; development of an evaluation method
- Integration of energy-related aspects into building information modelling systems, and research into the possibilities for using such systems to reduce energy consumption throughout the entire useful life of the building; examination of the options for using energy-relevant geographic information system data

Building services system

Use of solar energy for the production of heat and electricity

- Solar façade elements (photovoltaics, solar thermal energy) with flexible geometric design and pleasing appearance for better integration into the building or suitability for use as a design element
- Simplification of solar heating systems in order to reduce costs and increase reliability
- Optimisation of the harmonisation of the energy requirements of the building itself vs. decentralised solar energy use and decentralised storage options

Heat pumps

- Improvement of the quality of heat pumps and cooling machines, and their optimal integration into the energy system of the building and the electricity network
- New and more economically viable types of refrigerants with high thermodynamic efficiency, low greenhouse gas potential and zero ozone-depleting effect

Combined heat and power (cogeneration)

- Optimisation of cogeneration systems: integration for variable renewable electricity production

Geothermal energy (max. 500 metres below ground)

- Opportunities and risks associated with the exploration of protected underground water zones using geothermal sensor systems
- Development of fundamentals and design tools for seasonal heat storage with geothermal sensors

Provision of cooling capacity

- Optimised solutions in terms of use of resources and costs for active and passive cooling of buildings

Decentralised storage

- New components and materials, and innovative concepts for decentralised heat, cold energy and electricity storage (daily, weekly and seasonal storage for buildings and complexes, units with high storage density, activation of heat storage capability of buildings, etc.)

Ventilation systems

- Optimisation of the primary energy consumption of ventilation systems in operating mode, and of their grey energy consumption

Information and communication technologies

- Research into the longer-term influence of information and communication technologies on the consumption of heat and electricity by appliances and buildings (including own consumption, grey energy, costs, acceptance)
- Load and production management in buildings in interaction with the electricity grid and potential internal technical storage devices and storage capacities (including electric vehicles)

Monitoring and operational optimisation

- Analysis of the harmonisation of design values with real consumption values in new and renovated buildings, identification and analysis of causes for discrepancies, and derivation of recommendations
- Development of inexpensive methods for calculating the consumption of operating energy and energy for building-induced mobility
- Analysis of technical options for self-regulation of systems and assessment of their longer-term effectiveness

Sites and districts

- Demonstration of concepts for the sustainable development of sites, districts and cities ("2,000-watt sites" and "smart cities and communities") targeting climate neutrality
- Research into transformation paths and strategies, as well as support instruments and framework conditions, for site and district development targeting climate neutrality in building complexes and 2,000-watt sites [19)]
- Quantification of the influence of global climate development and microclimate in housing developments and urban centres on heating and cooling demand in buildings; implementation of planning instruments
- Development of criteria for urban and district development that results in a reduction of the heat island effect and thus lower cooling loads and higher comfort
- Examination of design and optimisation options for low temperature networks for the use of different renewable energy sources and storage devices, environmental and waste heat for heating and cooling purposes utilising new information and communication technologies for metering, management and control
- Models for finding promising sponsors, for the promotion of acceptance and procedures relating to the examination and development of site and district networked solutions as well as for supporting legal framework conditions, energy policy and planning instruments, and financing solutions need to be researched and evaluated
- Digital platforms for integration, multi-discipline and collaborative planning, taking account of energy-relevant aspects; where applicable making use of the options offered by a geographic information system

[19)] Certificate developed by SwissEnergy and issued by the Energy City Agency. Brochure on the 2,000-watt site concept, published by SwissEnergy for Municipalities, 2015

People, market, politics

Individual behaviour

- Analysis of the drivers for choosing where to live and their impacts on mobility-related energy consumption, development and recommendations for action; analysis of the degree of acceptance of new housing and employment models and their impacts on energy consumption
- Concepts for new types of housing that save space and conserve resources
- Identification of energy reduction potentials of sufficiency strategies
- Determinants for energy-relevant needs and options/instruments for influencing these needs in the area of housing and employment (e.g. sharing concepts, surface area/occupancy criteria for providing support)
- Socioeconomic determinants, affective and cognitive factors influencing energy-related consumer decisions and consumption behaviour in the area of housing and employment
- Energy-related construction and retrofitting decisions by investors in the buildings sector, determinants governing these decisions and instruments for influencing energy-relevant decisions
- Analysis of influencing factors, drivers and obstacles, and of potential incentives that encourage building owners to form a network
- Options for building owners to influence tenants, and options for tenants to influence building owners, including rental law limits
- Analysis of user behaviour in the buildings sector, and of the impacts of new energy technologies in the buildings sector on user behaviour

Companies and markets

- Demand-side management with new energy, information and communication technologies: options, required instruments, framework conditions
- Analysis of different viewpoints, and coordination of the involved players (especially building owners and network operators) regarding the optimisation of consumption, production and storage in energy networks, and derivation of recommendations for action
- analysis of training and further education requirements and associated implementation tools for improving the quality of consulting and implementation among consulting intermediaries and companies active in the area of construction and renovation of buildings

Mobility of the future

Bringing about attractive, efficient and low-emission mobility through the use of traffic telematics, progressive drive technology and innovative travel concepts: in the future, overall energy consumption and emissions of greenhouse gases and environmental pollutants are to be substantially reduced despite increasing mobility demand. This means that research and development in the fields of highly-efficient transport technologies, fuels from renewable sources and mobile storage technologies need to be expedited, and it will be necessary to gain a better understanding of the obstacles to new forms of mobility.

In order to realise this vision for the mobility sector, all areas of mobility will have to be optimised and wherever possible physical mobility (i.e. traffic) will have to be reduced. In addition to the availability of lighter and more efficient vehicles, the widespread use of automation technologies and the partial substitution of fossil fuels, this will call for new integral solutions. Here, the behaviour of each individual and of society at large will play a decisive role. Entirely new solutions will have to be found by adopting an interdisciplinary approach.

Material sciences form an essential basis for lightweight construction, the efficiency of storage systems and the safety of integral systems. New materials and technologies (bionics,[20] nanotechnologies, information and communication technologies and state-of-the-art sensor technology) are already in use in the mobility sector, but there is still potential for further development. Alongside major opportunities, however, there are also certain risks, e.g. the increased risk of accidents associated with the use of electric bikes or the danger of fibres that can penetrate the lungs arising from burning carbon-fibre reinforced plastics.

Traffic telematics and automation technologies are to be used for increasing the efficiency of mobility by enhancing traffic flows, preventing unnecessary journeys, vehicle sharing, etc. The consequences of comprehensive information and communication technology, for example the constantly available car-sharing online platform, on physical mobility are still unclear. These gaps in knowledge need to be filled and rebound effects have to be prevented as far as possible.

It is particularly important to regard mobility in the context of modern-day civilisation, and thus in the context of the other priorities.

Low energy consumption despite increasing mobility

Mobility accounts for around 35 percent of Switzerland's overall end-energy consumption today. The volume of traffic is continually increasing, in absolute as well as relative terms. Both road and rail traffic are increasing at a faster rate in Switzerland than population growth. The main reasons for this are greater travel distances, followed by population growth and increasing individual mobility. As a consequence, the number of traffic jam hours on the motorway network has risen twice as quickly as the traffic volume. Since it is not possible to keep pace with traffic growth by expanding the infrastructure, new forms of mobility will have to be found. Public transport, too, reaches the limits of its capacity during peak periods, even though the average capacity utilisation in regional and long-distance rail transport is relatively low, at 23 and 31 percent respectively.

In order to assure a high degree of mobility in Switzerland in the future, and have a generally attractive, efficient and environmentally friendly transport system at our disposal while meeting the objectives of *Energy Strategy 2050*, progress will have to be made in a variety of areas. This includes new technologies such as

20) Bionik: «Lernen von der Natur als Anregung für eigenständiges technisches Weiterarbeiten» aus Grundlagen und Beispiele für Ingenieure und Naturwissenschaftler, W. Nachtigall 2002

With the new type of electric bus developed by the ABB, TPG, Opi and SIG consortium, the need to connect the vehicle to overhead trolleybus lines is eliminated, but all the other advantages of an electric bus are retained. The bus's power unit is recharged with a conductive charging system at the termini and rapid chargers at certain bus stops. Picture: EPFL

electrified drives that can also help reduce emissions. Other new solutions that will be required include new traffic management concepts that can refer to comprehensive mobility information across the entire range of forms of transport, changes in user behaviour (with or without the aid of political measures) and sharing economy models. And over the long term, new developments in control technology will open up entirely new ways of achieving efficient and environmentally friendly mobility. Significant new trends in the mobility sector include driverless vehicles, comprehensive traffic information systems based on information and communication technology, and (in the private segment, and especially among the younger generation) the tendency towards sharing instead of owning vehicles.

In order to avoid peak loads on the infrastructure and thus be able to use it more efficiently and effectively, desynchronisation strategies will also have to be transformed into implementable and acceptable concepts. Peak traffic attributable to holiday travel, travelling to and from work, school, etc., could be eased by introducing greater flexibility in terms of working hours and location (tele-working), or through options such as road pricing.

Medium to long term priorities

For researching, developing and subsequently implementing innovative technologies, consideration of the entire system (safety for people and the environment, recycling, availability of materials, acceptance and financing) is an absolute prerequisite.

Energy storage and substitution of fossil fuels

The biggest single challenge at present regarding the substitution of combustion engines with electric drives is to find a low-cost solution for the storage of electricity in vehicles. As a rule, the energy density of electrochemical storage devices (batteries and accumulators) is only around five percent of that of fossil fuels. This means that such storage devices tend to be relatively heavy. At present, lithium-ion batteries are dominating the market: these offer an approximately five times higher specific energy than lead batteries. The development of lithium-ion batteries was an important factor in the widespread use of electric bikes, but a similar boom in the use of electric cars has failed to materialise to date. In view of this, additional research needs to be carried out with the aim of increasing the energy and power density, as well as the service life of batteries, while simultaneously reducing their costs.

Supercapacitors (or supercaps[21]) store energy with a very high power density. They are suitable for peak loads and are already in use today in trams and buses. Because they are very expensive, however, they are seldom installed in electric cars, and it is therefore necessary to find ways of manufacturing them at lower cost. Here, the potential lies in developing less expensive materials and manufacturing technologies.

With respect to decarbonisation in the area of road transport, the main options are to increase the efficiency of combustion engines, use biogenic fuels or partially / fully electrify road vehicles. In all these cases, in addition to optimising the respective technologies it will be necessary to ascertain how beneficial they are in ecological as well as economic terms.

High efficiency through the use of intelligent mobility and traffic management systems with the aid of information and communication technology

In the public transport segment, ways of attaining a more balanced distribution of passengers by partially shifting traffic flows from peak periods to off-peak periods need to be researched. This process could be supported by introducing financial incentives on the road and railway networks. Flexible school and working hours, combined with tele-working, can also help reduce peak traffic loads and in particular the volume of commuter traffic. Desynchronisation concepts and strategies therefore need to be developed and examined from the point of view of their energy-relevant, economic, ecological and social impacts.

In developed countries, leisure-time activities account for more than half the traffic volume, a large proportion of which takes the form of private motorised transport. Public transport, which has a great deal of free capacity outside of peak periods, could influence the modal split in its favour with the aid of new tariff models and routing concepts, and thus not only utilise energy savings potential, but also help reduce CO_2 emissions.

Driverless road vehicles could potentially trigger a major revolution in the mobility sector in the not-too-distant future. They could conceivably be used for taxi services, as an economical supplement (or even substitute) for buses and trams or in the last leg of railway journeys, during off-peak periods. New forms of car pooling and the use of telematics could also open up considerable potential, for example with the aid of information and communication technology. The existing gaps in these areas need to be closed and the obstacles to their implementation need to be identified and eliminated.

Efficient vehicle systems

Reducing energy demand absolutely and specifically, but in particular the consumption of fossil fuels, remains a key area of focus in the mobility sector. In the area of private motorised transport, a reduction in the fuel consumption of new cars by a factor of 3 by 2050 is technically feasible and should therefore be targeted. There is still considerable potential for more efficient drive systems[22] (combustion engine, hybrid and electric systems) and auxiliary units, recuperation mechanisms, lightweight construction and reduction of air and rolling resistance.

With new materials and manufacturing technologies it is possible to increase the degree of efficiency in vehicle concepts in general, as well as in lightweight construction. Here, gaps in knowledge primarily need to be closed in the areas of safety and life cycle assessment of materials (including their recycling). Active

[21)] Doppelschicht-Kondensatoren: Leistungselektronische Bauelemente. 2nd edition. Springer Verlag, Dierk Schröder 2006, [22)] Vehicle Propulsion Systems, Springer Verlag, Lino Guzzella, 2005

The driverless vehicles at the Federal Institute of Technology, Lausanne, provide energy-efficient, low-noise and local emission-free mobility throughout the entire campus. This revolutionary type of vehicle could drastically transform future road transport. Picture: EPFL

safety systems are a prerequisite for radical lightweight construction of vehicle systems, and their further development is a decisive factor.

By reducing resistance in battery systems or using ultracapacitors in hybrid and electric vehicles it is possible to significantly increase the degree of efficiency of recuperation (i.e. energy recovery during braking).
By optimising vehicle systems, the use of rare earths and the degree of utilised grey energy can be reduced. The question of later recycling needs to be considered already during the development phase of vehicle systems

Progress is anticipated through the use of interdisciplinary solutions such as bionics. Simulation and diagnostic methods facilitate a better understanding of (for example) the combustion process and thus also open up new potentials for optimisation.

User behaviour and social change
The trend towards a collaborative society, and thus towards a lifestyle that attaches less value to the ownership of a car than to the benefit it offers when required, opens up fresh opportunities for efficient mobility that conserves resources. Sharing a vehicle could substitute between five and ten private cars[23]. With its well-developed infrastructure and as a country that pioneered car sharing, Switzerland is in a good position to develop new, integrated transport concepts (with the inclusion of public transport, human-powered mobility and automated driverless vehicles) and exploit the resulting economic and ecological potential. A comprehensive understanding of mobility with very little influence on the environment calls for research into acceptance and consideration of all the above solutions, including traffic reduction strategies such as road pricing and anti-rebound measures.

[23] According to Knoflacher, H.; TU Vienna, 2014

Areas of research for the period from 2017 to 2020

Energy storage and substitution of fossil fuels

- Further development of vehicle components and systems for the efficient and economical use of alternative fuels (including electricity) and energy carriers (including hydrogen, synthetic and biofuels)
- Study of the impacts resulting from the use of new forms of energy storage and carriers such as power to gas (P2G), taking account of ecological and economic performance
- Increase in the energy density of accumulators for mobile applications from the present-day level of around 150 Wh/kg (based on the accumulator block) to at least 300 Wh/kg, and increase in useful life to at least 4,000 cycles with simultaneous improvement of handling safety
- Minimisation of the impacts of rapid charging on the useful life of accumulators
- Determination of the options and quantification of the potentials in order to substantially influence the load profile of the power supply with plug-in hybrid and electric vehicles, or additionally using vehicle batteries and stochastic energy production in network operation

High efficiency through the use of intelligent mobility and traffic management systems with the aid of information and communication technology

- Interdisciplinary research projects for the development of mobility systems
- Development of concepts for desynchronising, including detailed clarification of efficiency, capacity, acceptance and other potential consequences
- Demonstration of new mobility models, including comprehensive support research (e.g. efficiency, capacity, safety, acceptance, assessment of consequences)
- Further development and implementation of concepts for smooth operational management in the public transport network (dynamic driving recommendations, timetables, etc.)
- Development of innovative car sharing and pooling concepts, including those based on new communication technologies
- Reduction of inaccuracies in ecological balances and life cycle assessments by improving the data collection criteria and methods, thus permitting an integrated approach to mobility or the mobility system

Efficient vehicle systems

- An increase in the degree of efficiency of combustion engines for vehicles by 10 percent (capacity range up to approx. 250 kW) to be demonstrated on the test bench
- Further development of information technologies and sensors as the basis for active safety systems in vehicles in order to improve the prerequisites for lightweight vehicles
- Combination of lightweight construction, aerodynamics, low-resistance tyres, information and communication technology, the most efficient drives, etc., to reduce consumption by cars so that for the latter an energy consumption of only one to two litres petrol equivalent per 100 kilometres is required

- Pilot vehicles and demonstration projects for hybridisation concepts that indicate fuel savings of at least 25 to 35 percent versus reference vehicles, with minimal additional costs
- Integration of incentive systems for efficient and less dynamic driving behaviour, for example in combination with GPS

User behaviour and social change
- Development of measures and services that increase the attractiveness of public transport and combined mobility in order to bring about a shift from private motorised transport, as well as air travel, to public transport
- Development of measures and services that lead to the transfer of goods transport from road to rail
- Development of measures, concepts and components, as well as initial applications, aimed at increasing energy efficiency in public transport by up to 10 percent (increases in capacity utilisation, optimisation of drives, etc.)
- Further development of socioeconomic and socio-technological understanding (e.g. efforts to break down fears of the unknown following the introduction of new technical systems), taking account of the rebound effect, as to which technologies, instruments and incentives help reduce commuter mobility, induced traffic and leisure-time mobility
- Studies and field trials in order to identify options and limits of desynchronisation of commuter and leisure-time traffic flows to achieve a balanced capacity utilisation of the various forms of transport
- Identification of types of sustainable mobility infrastructure and business models for work and leisure-time, and their user-friendly, standardised implementation; updating of the criteria for the corresponding energy policy framework conditions
- Pilot projects with new mobility concepts and forms in selected regions of the country in order to promote the implementation of new technologies and business models, create acceptance among the population and prepare the bases for future energy policy decisions
- Field trials on a local scale in order to evaluate the effectiveness of the various road pricing options

International cooperation

Fundamental clarifications at the international level need to be made with respect to:
- Standardisation of important vehicle components such as charging infrastructure, onboard power system, (hydrogen) tank
- Research into the hazard potential of electromagnetic radiation in view of a possible future inductive charging of vehicles
- Standardised life cycle assessments of new vehicle systems and major components, with an increased focus on recyclability

Energy systems of the future

Intelligently networked energy systems form the basis for a safe, reliable and sustainable energy supply. The availability of such systems is essential for the development and implementation of a sustainable energy policy, and in particular for *Energy Strategy 2050*. The integration of energy subsystems enables the networking of all energy carriers such as electricity, heat/refrigeration and fuels, with infrastructure components such as high-voltage, water and transport grid, as well as with information technology infrastructure. The objective is to achieve maximum efficiency and minimise unexploited energy potential, adverse impacts on the environment and risks for the population. The design of components and subsystems, and how they can optimally interact, are aspects that need to be researched and which open up broad scope for innovation.

The Federal Council's "New Energy Policy" (NEP) scenario calls for major reductions in end-energy consumption which in turn require research results and innovations in the market place. The energy system of the future is also the backbone on which the necessary progress in the areas of *living and working, mobility* and *processes of the future* will be achieved.

Integrated energy systems comprise a variety of interlocking and mutually dependent elements, and also possess a number of closely linked components.[24]

The first of these elements encompasses the physical components that supply, convert, store and transport energy. These components are primary energy supplies, above all for renewable energy, equipment for conversion into products such as combustibles, heat and refrigeration, electricity, etc., as well as installations for the storage and transport of energy carriers. Their use leads to interventions in nature and the environment, which calls for an integrated management of hazards, plus measures to minimise risks. This means that a thorough understanding of life cycle assessments is required right across the board.

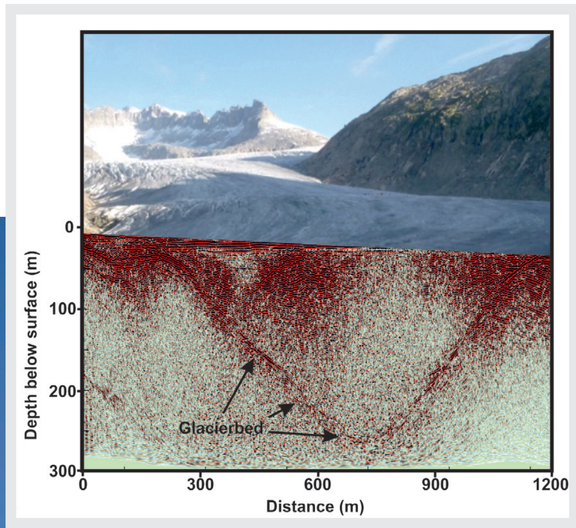
A second group of elements encompasses the physical components that link the energy system and enable it to react to external signals. Alongside this, and ideally integrated into it, is a third element, comprising the information and communication technology service systems and the platforms for secure data transmission in order to ensure control of the energy system.

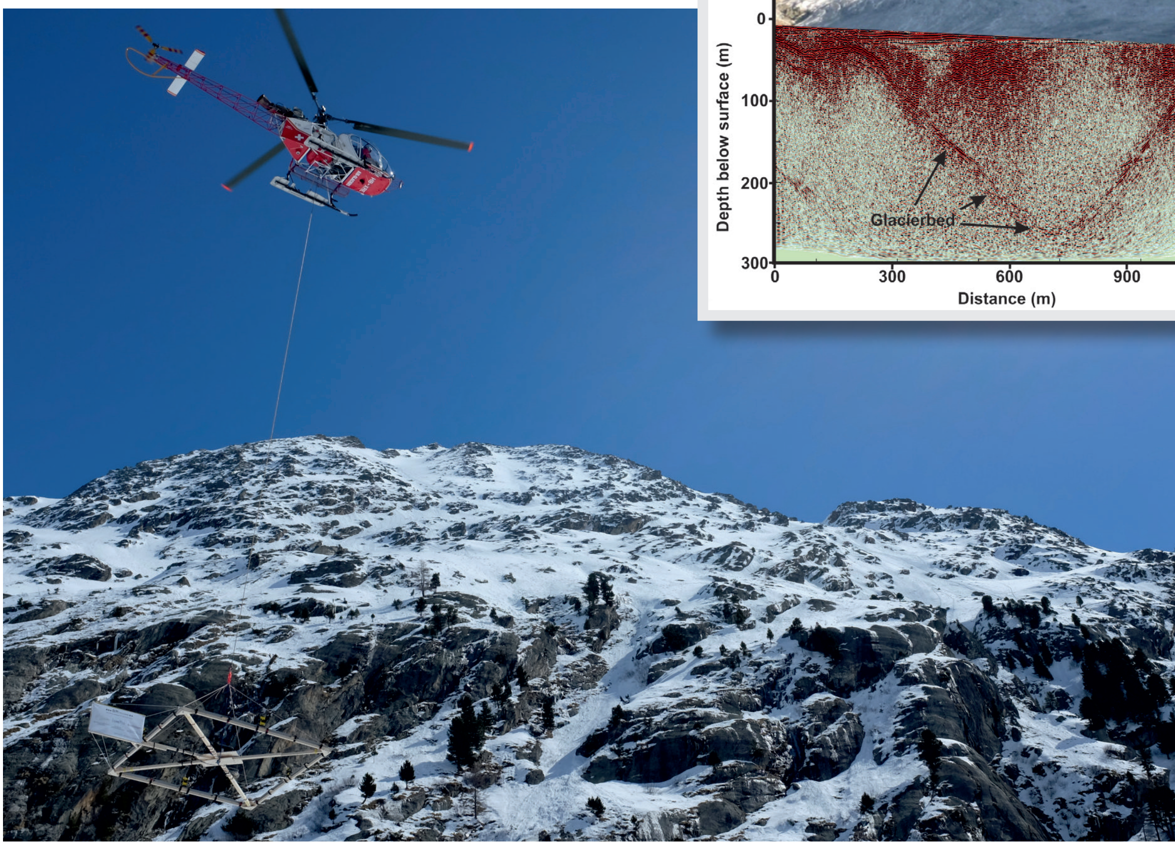
The system controls overlie the energy control system and are closely linked to it. This element monitors, tests and ultimately assures the safety and reliability of the equipment that is connected to the energy infrastructure.

The increasing liberalisation of the energy markets is giving rise to a fundamental change in investor behaviour, as well as to more dynamic business models and a broader range of technologies that can be brought onto the market. This development is in tension with the longevity of infrastructure components. There is therefore an increasing awareness of the fact that, alongside the technical and engineering aspects, the interaction of the energy system with a comprehensive final element, namely the dynamic market environment, also needs to be understood. This environment is determined to a great extent by economic, regulatory and political framework conditions. In order for Switzerland to implement *Energy Strategy 2050*, research and innovation have to be used to optimally meet the three requirements of sustainability (economic benefit, social wellbeing and protection of

[24] This solution is based on a concept of an integrated energy system described by the National Renewable Energy Laboratory of the US Department of Energy

nature and the environment). Gaining social acceptance of the restructuring of Switzerland's energy system with new technologies and concepts represents a major challenge, in terms of both the use of domestic resources and the change in energy consumption behaviour among a population that is growing increasingly sceptical about technology. In addition, political and economic upheavals within Europe are giving rise to increasing concerns over national supply security. Switzerland is very firmly integrated into the European energy market, and will remain so, regardless of the political and commercial nature of future foreign relations. Despite external factors, physical integration gives rise to greater domestic supply security.





The Alps without glaciers
A major step towards an accurate Swiss-wide map of glacier thicknesses has been taken: in April 2015, a crystal clear image of the bed of the Otemma glacier in the canton of Valais was recorded during an airborne radar survey. After one year of joint research by the Hydraulics-Hydrology-Glaciology Division (VAW) and the Exploration and Environmental Geophysics Group (EEG) at the Federal Institute of Technology, Zurich, the new and improved helicopter-borne ice penetrating radar system was successfully tested. The overall goal of the glacier inventory project is to create a Swiss-wide map of the relief of the Alps without glaciers, as well as of glacier thicknesses. It is being funded by the Swiss Competence Centre for Energy Research – © Supply of Electricity (SCCER-SoE) and the Swiss Geophysical Commission (SGPK).
Picture: Beat Rinderknecht, BR-Technik. Radargramm: Lasse Rabenstein, ETH Zürich

Medium and long term priorities

In order to achieve the targets defined for end-energy consumption over the long term, research and innovation will be essential: the target for Switzerland's national consumption in 2050 is 125 TWh, which is around 54 percent below the figure for the reference year (2000).

And the target for Switzerland's climate policy is to halve greenhouse gas emissions by 2030 versus the 1990 level.[25] In accordance with the scenario based on these targets, end electricity consumption (after adjustment for losses and parasitic consumption) would amount to around 53 TWh per annum, which is equivalent to a decrease by 18 percent versus reference year 2000, despite increasing prosperity and a growing population. On the supply side, hydropower, which forms the backbone of Switzerland's electricity supply, provides around 39 TWh. In 2050, the aim is for around 24 TWh to be produced from other renewable energy sources. Medium term targets for 2035 call for an overall energy demand of 152 TWh, or a per capita reduction by 43 percent in accordance with the scenario.

Energy efficiency, availability and reliability
With respect to the supply of heat/refrigeration and electricity, the expectation is that the operators of existing systems and installations will continually optimise their operation from the point of view of ecological sustainability and energy efficiency. One of the tools for accomplishing this is life cycle assessment in combination with decision-making analyses. Efficient use of resources, a focus on development and the use of technologies for enhancing efficiency and reducing and preventing greenhouse gas emissions will reduce the ecological footprint.

For electricity supply systems and their integration in the various networks, efficient control mechanisms, a high degree of availability and safe operation are essential. The reliable integration of renewable energy sources into electricity networks requires intelligent procedures and new control systems.

Electricity from renewable sources
Alongside energy efficiency and reduced consumption, the use of renewable energy for the production of electricity is a cornerstone of *Energy Strategy 2050*. By 2035 the aim is for around 14.5 TWh of electricity to be produced from new renewable energy (in 2014 the figure was just 3 TWh), which is equivalent to an annual growth rate of 8 percent. Sustainability criteria, reliability and availability will result in a mix in order to keep additional costs for energy storage and network modifications to a minimum on the basis of the anticipated substantial increase in the capacities of photovoltaics and wind energy.

The aim is to increase the average level of electricity production from hydropower plants by 1.5 to 3.2 TWh per annum. This can be achieved while taking account of the various environmental protection, nature conservation and socioeconomic factors if innovative solutions for use in existing hydropower plants, and suitable new locations for pump storage plants, can be found in addition to the established solutions (increasing the height of dam walls, expanding the installed capacity). But climate change will not only affect the availability of water, it will also affect the condition of the catchment area as a consequence of increased sedimentation, and give rise to a higher frequency of occurrence of natural hazards.

For Switzerland's hydropower production, the winter months are the critical period, during which production can fall by around 50 percent. This factor on its own means that storage capacities that can be used flexibly will play a significant role with respect to supply security, not only for Switzerland, but also for Europe.

In *Energy Strategy 2050*, a great deal of importance is attached to the use of photovoltaics, since this technology is to account for around half the electricity produced from new renewable sources. The main challenges for this technology are to further reduce the associated costs along the entire value chain, primarily by increasing the efficiency of individual components and through the industrial implementation of new

[25] *http://www.bafu.admin.ch/klima/03449/12696/index.html?lang=de&msg-id=56394*

products and new manufacturing processes. In addition, it is also important to find solutions for integration (both in buildings and in the electricity grid) and to deal with issues relating to sustainability (reduction of the use of energy and materials in the areas of production and recycling).

Efficient smart grids

Significantly higher demands will be placed on modern, efficient electricity networks: safe and reliable operation of an internationally integrated network with a large number of participants; centralised and decentralised producers, as well as both large-scale and small consumers who can freely choose their electricity supplier. At the same time, the requirements on environmentally friendly production, efficient use and a high degree of flexibility for the optimal adaptation of (intermittent) electricity production to consumption have to be met.

In order to be able to accomplish this demanding task, at the technical level a high degree of integration of electricity production from variable renewable energy sources into the network is called for. This will be characterised by an involvement of electricity consumers via demand-side management, the provision of sufficient storage capacity and a comprehensive integration of information and communication technologies in order to master the new complexity in the grid. Promising concepts, causal correlations and multivariate system analyses can be tested and developed through the use of "big data" infrastructure components and analysis methods from the point of view of data security.

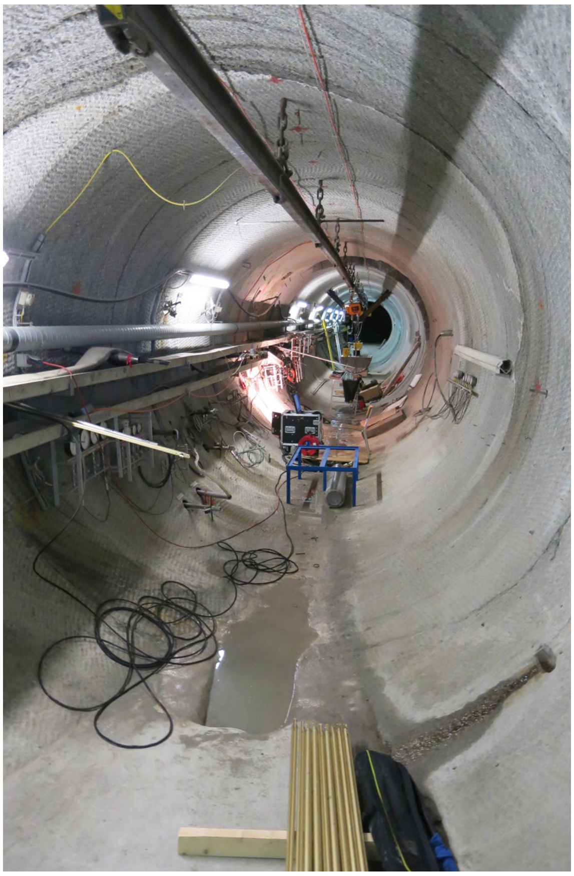
Energy storage

New telecommunications and data acquisition systems, data analysis and network control will facilitate the use of distributed energy storage systems in the medium term. In addition, indirect storage of electricity in the form of heat, or chemical storage in the form of hydrogen or hydrocarbons, can facilitate a balance between supply and demand. In this way it will also be possible to achieve a balance between energy carriers for thermal and motorised energy services.

Nuclear technology

Independent regulatory safety research is to be continued in order to obtain findings and learn lessons from the Fukushima nuclear accident.

Research activities relating to the disposal and reduction of nuclear waste also have to be continued. In order to ensure that the three phases of the selection process for a suitable site for a deep geological repository for radioactive waste can be implemented successfully, social and psychological criteria need to be defined.



Application-oriented geological research is being carried out at the Grimsel rock laboratory in the Bernese Highlands with the aim of exploring geothermal resources in Switzerland. Geophysical tests are being conducted in tunnels at the laboratory in order to comprehensively characterise the rock formations before a controlled test can be initiated to pave the way for hydraulic stimulation.
Picture: Florian Amann (ETHZ, SCCER – Supply of Electricity).

Switzerland is to play its part in the development of technologies for safe and more efficient reactors right through to nuclear fusion to the extent that it remains able to make its own judgements. New Generation IV reactor technologies have to be constantly evaluated from the point of view of safety and the storage and disposal of radioactive waste. Fusion research is to be continued to the extent to which it can be financed within the framework of multilateral research activities and does not interfere with research funding for other energy technologies.

Safety and risk monitoring in the energy sector

Switzerland's increasing dependence on renewable energy calls for a constant and comprehensive monitoring of safety and risks. This includes assessments of energy resources, safety and availability in relation to climate changes, as well as other environmental influences and the political framework conditions. New framework conditions also have to be developed for the continual optimisation of supply and demand in a changing market environment. Socio-political developments urgently call for an up-to-date evaluation of risks and the necessary measures for mastering natural or energy-related hazards induced by human beings (especially threats to infrastructure). The involved measures depend greatly on the degree of acceptance of new technologies and also have to take the aspects of risk aversion and supply security into account.

Need for demonstration experiments

When it comes to demonstrating the technical feasibility of the planning and operation of future infrastructure, the complexity of research and technology often means that the objects concerned have to be more or less equivalent in size to commercial systems. Such platforms make it possible to study new technologies and infrastructure components and assess their potential in a realistic situation. Here, examples include load management and the behaviour of integrated energy systems with a large proportion of variable renewable energy sources and the necessary storage capacities. The demonstration of petro-thermal, or engineered geothermal energy systems in Switzerland is another example: its demonstration, which has been assigned a significant role in the new energy strategy, can only be carried out on a scale of 1:1. In the currently prevailing market environment in the electricity industry, it will only be possible to demonstrate this technology with a high level of government support.

Areas of research for the period from 2017 to 2020

CORE recommends the following areas of research for the period from 2017 to 2020, which are oriented on the implementation of *Energy Strategy 2050* and are intended to maintain and further develop Switzerland's strengths as an internationally competitive centre of research and innovation. CORE does not want to arbitrarily single out winners. Instead it aims to encourage competition for ideas under the applicable framework conditions for Switzerland, which are of a natural, sociopolitical and economic nature. In view of this, CORE is avoiding a prescriptive approach to the definition of priorities.

Essential links in the energy system

- Importance of large-scale energy storage in integrated energy systems
- Assessment of integration options for existing pump storage facilities with new storage technologies
- Optimal planning tools for active distribution networks that encompass storage technologies
- Calculation of aging models for storage systems (with focus on electrochemical storage) for use in instruments for the planning and operation of networks
- Simulators for large-scale distributed energy storage systems
- Efficient and competitive storage, especially for short-term and seasonal heat storage systems (latent heat and thermo-chemical sorption systems)
- Efficient and competitive storage, especially for decentralised storage systems for variable electricity supply (water electrolysis, power-to-gas with associated electrolysis of CO_2 and H2O; production of high-energy combustibles)
- Chemical storage of liquid and gaseous synthetic fuels from renewable energy sources
- Reconversion into electricity of hydrogen from renewable sources via stationary fuel cells
- Distributed stationary battery systems (including Li and Na ions and redox flow technologies)
- New materials for energy storage and conversion at different temperatures

Renewable energy

Hydropower

- Impacts of climate change on production potential and availability of water (glacier retreat, snow accumulation and snowmelt, water runoff status, transport and deposit of sediment) and on operating safety (floods and slope instability)
- Increased capacity utilisation and efficiency of existing plants to enable flexible operation in order to meet additional and greatly fluctuating demand
- Technology for adapting existing infrastructure to increase production efficiency and permit flexible operation during seasonal and daily periods of peak demand
- Impacts on aquatic ecosystems of new and challenging operating methods and a larger number of small hydropower plants; strategies to minimise impacts
- Definition of future framework conditions for an operating strategy for hydropower with multiple targets (maximum production, reliability and flexibility, economic viability and conservation of ecosys-

tems) in consideration of the future development of demand, an increasingly dynamic market environment and socio-political challenges
- Safety and long-term improvement of hydropower infrastructure (e.g. aging of dam wall concrete, increased frequency of floods and higher flood levels, powerful earthquakes and their consequences, up-to-date monitoring systems and improved vulnerability assessment mechanisms
- Integrated pilot and demonstration projects for new production methods and technologies in large-scale hydropower plants

Use of the deep subsurface for energy supply and storage
- Physical, chemical and mechanical properties of rock (rock fluid interaction, cap rock integrity,, creation of permeability)
- High-resolution exploration methods for the discovery and evaluation of resources, and the associated fault architecture
- Integrated numerical simulation methods for dynamic flow processes in the subsurface
- New methods for increasing rock permeability in order to create optimal heat exchangers and geothermal reservoirs
- Predictable, reliable and low-cost exploration and development methodologies (including on surface) for geothermal reservoirs
- Methods for risk assessment, monitoring, avoidance of induced seismicity and minimisation of potential consequences of damaging earthquakes
- Testing and validation of subsurface technologies, processes and procedures in-situ, and installation of a corresponding national infrastructure for subsurface geothermal research
- National pilot and demonstration projects for deep geothermal, CO_2 and other gas storage options

Non-silicon-based photovoltaics
- New materials for thin-film solar cells
- Improved solar cells and associated infrastructure for large-scale processes and production facilities
- Production technologies for thin-film cells
- Quality assurance of modules and electrical systems technology

Bio-energy
- Commercially viable use of sustainable forms of biomass in Switzerland
- Pre-treatment of biomass for standardised production, storage, transport and efficient conversion into energy carriers and services
- Fermentation technologies (including those of a microbiological nature) for increased gas yield and for the direct production of liquid fuels
- Step-by-step biomass combustion processes with reduction of emissions
- Improved gasification technologies for wet and dry biomass (efficiency, pollutant emissions, closed material cycles, corrosion resistance, deposits, useful life of catalytic converters, systems integration and cost efficiency)

- Development of polyvalent process technologies for biomass gasification
- Optimised production of electricity from biomass (exergy, economic viability, market development)
- Assessment of the potential of non-wood-based biomass in Switzerland
- Social acceptance of industrial biomass plants in Switzerland

Smart high-capacity networks
- Monitoring and dynamic control methods for transmission and distribution networks
- Integration of multiple connections from alternating current to direct current, transmission and distribution
- Power electronics and switching: new power converter architecture and high voltage and high capacity switching equipment
- Control of large-scale distributed electricity production and storage facilities with the aid of new control theory solutions
- Multiple and polyvalent networks; principles of interactions of multiple networks for planning, operation and control
- Interaction between demand-side response and supplementary and auxiliary services of the distribution networks on the one hand, and the primary, secondary and tertiary reserves of the transmission networks on the other hand
- Standardisation and network control: impacts of grid codes on operating and control procedures
- Components and performance systems: impacts of new monitoring, control and protection equipment on network operation and control
- Control, procedures and design of polyvalent energy networks (natural gas and biogas, low temperature distribution networks, electricity production and distribution, energy hubs)
- Intelligent integration of decentralised electricity production
- Accurate models for short and medium term predictions of electricity production from renewable sources for scenarios for Switzerland's energy systems

Nuclear energy: safety and benefits
Regulatory safety research
- Research into fuels and materials, external occurrences, human factors, system behaviour, accident sequences and protection against radiation; participation in international databases focusing on damage and internal occurrences

Radioactive waste
- Studies of clay rock, design and inventory of a deep geological repository including a pilot storage facility (formation and behaviour of gases in the immediate vicinity of a deep geological repository, as well as further afield)
- Optimisation, prevention and removal of waste

Processes of the future

Resource-optimised and marketable products will be manufactured with new processes and materials that are to be developed under consideration of Life Cycle Assessments. The consumption of energy and materials by production facilities is to be minimised through the use of highly efficient components. Information technologies support process integration all the way to the energy optimisation of products in their use phase. Renewable and readily recyclable raw materials take precedence. The aim is to leave behind as small an ecological footprint as possible.

The development and implementation of improved or new production processes will above all be driven by economic, technological or legal framework conditions. As production factors, the use of energy and consumption of raw materials, as well as the direct and indirect influences on the natural environment, are gaining in importance. Resource efficiency is a target in the sustainability concepts of many companies, and is essential for *Energy Strategy 2050*.

Future processes are to produce consumer and investment goods under competitive conditions; the products are to meet and exceed customers' expectations throughout the entire life cycle with the smallest possible ecological footprint.

Life cycle assessments are to integrated from the early stages of product development. New materials, processes that use energy and materials efficiently, minimised energy consumption in the use phase and appropriate recycling will be critical design factors in meeting the functionality specifications. The fundamental energy and material consumption in the production phase is determined by the manufacturing process. Substantial savings can be made through the development of novel processes.

Processes are implemented in production plants that have to be heated, cooled, powered and controlled. Their ecological footprint can be influenced by choosing the most suitable energy production, energy flow and energy recovery options. Improved components and integrated processes facilitate optimised energy utilisation. Energy consumption during the use phase of goods, and efforts aimed at the suitable recycling of materials, have a significant influence on the ecological footprint as well.

The use of renewable energy sources may require an adaptation of individual processes, For example, an adaptation of process temperatures may be a prerequisite for the use of solar thermal energy. A high degree of supply security is also an important factor in process design. In the case of intermittent power sources, supply security can be improvedwith energy storage devices and smart integration into the supply network p. This calls for greater integration into the energy systems of the future. The use of biomass for energy production competes with its use as a raw material for the production of biogenic materials such as bio-plastics.[26]

For the successful implementation of future processes, regulatory as well as socioeconomic aspects have to be taken into consideration. While legislation can support the implementation of energy efficiency measures, it can also hamper them if processes approved by the regulators can only be adapted at considerable expense. However, economic or other market relevant considerations can also weaken arguments relating to energy or the environment. For this reason, it will be necessary to examine how customers' needs can be developed towards improved market acceptance of products with the smallest possible ecological footprint.

[26] *EU Horizion 2020, Bio-Based Industries Joint Undertaking*

The future processes research priority concerns the industry, services and agriculture sectors, which together account for 36 percent of Switzerland's total energy consumption and 61 percent of its total electricity consumption. These figures do not include the energy required for goods transport and employees' mobility.

"Internet of Things" and "Industry 4.0"

With the "Internet of Things"[27] revolution,it is not only possible to control and document manufacturing processes from the planning stage through to delivery of the goods, as is understood by the term "Industry 4.0",[28] but thanks to the variety of the collected data the processes can also be optimised in terms of energy efficiency.[29, 30] Furthermore, intelligent sensors and highly integrated mechatronics can monitor and regulate products during their use phase in order to minimise energy consumption. Thus information and communication technology (ICT) will substantially support the improvement of many processes. Together with the services and consumer sectors, ICT is nonetheless a relevant energy consumer in its own right. The benefits of ICT solutions have to be weighed against the additional energy consumption of ICT itself, thus the energy efficiency in the ICT sector has to be greatly increased.

Additive manufacturing processes permit faster production with relatively low consumption of energy and materials, even in the case of complex three-dimensional components. However, the range of suitable materials is still limited.

With new ultra-hard or lightweight materials and low-resistance surface coatings it is possible to develop products that have a longer useful life and a lower energy requirement.[31] The limited availability of

A control system monitors the entire production process and delivers real-time information about energy consumption.
Picture: genkur/Shutterstock

27) Artificial intelligence (computers) is integrated into objects and combined with them, 28) VDMA, Industrie 4.0 konkret- Lösungen für die industrielle Praxis. April 2015, 29) VDI Technologiezentrum. Innovations- und Effizienzsprünge in der chemischen Industrie? Wirkungen und Herausforderungen von Industrie 4.0 und Co. July 2014, 30) VDI Zentrum. Ressourceneffizienz, Material- und Energieeffizienzpotenziale durch den Einsatz von Fertigungsdatenerfassung und –verarbeitung. February 2015, 31) BMBF MatRessource, Materialien für eine ressourceneffiziente Industrie und Gesellschaft. September 2014 raw materials is forcing manufacturers to develop strategies for minimising the use of materials, using alternative materials and recycling materials at the end of the useful life of their products (circular economy). Major potential for resource conservation is anticipated through the use of reneably-based materials such as bio-plastics. In comparison with fossil-based plastics, the formulations of biogenic materials are not always clearly specified, which represents an additional challenge when it comes to their recycling or disposal.[32]

New technologies in the pharmaceuticals and chemicals industries include synthetic biology, the precisely targeted use of active ingredients and advanced chemicals.[33] Advanced manufacturing aims to facilitate the use of continuous processes for a broader range of products.

No standard solutions for optimising processes

The diversity of utilised technologies means there are no standard solutions for the efficient use of energy and materials in industrial processes. The Energy Agency of the Swiss Private Sector has found that energy saving potentials of up to 30 percent are no exception. This figure is aligned with international studies.[34, 35] Over the long term a technical reduction by 50 percent is anticipated via process intensification or next generation manufacturing concepts.

The development of improved or even disruptive technologies will require that companies reorient their production processes. This will provide opportunities to redesign processes based on principles of energy efficiency and resources conservation.

As a study of the Economist Intelligent Unit[36] indicates, 77 percent of the surveyed industry managers named energy efficiency as a critical factor for success in the coming 20 years. Forty-five percent of the responses cited sustainability objectives as the key factor that drives investments in energy efficiency. Numerous national and international programmes focus on resource efficiency, and thus implicitly on reducing energy use, including the European Platform for Resource Efficiency, the Energy Efficiency in Industrial Processes joint programme of the European Commission, the Green Economy Research Agenda of the German Ministry for Education and Research, and the Programme of the Centre for Resource Efficiency of the VDI.[37] In Switzerland, objectives for resource-efficient technologies, processes and products are also defined in the Federal Cleantech[38] Masterplan.

32) Bio-Based Industries (Public-Private Partnership) der EU, 33) SATW, Technology Outlook, 2015, 34) IEA, Technology Roadmap Energy and GHG Reductions in Chemical Industries via Catalytic Processes, 2013, 35) VDI Zentrum Ressourceneffizienz, Analyse von Ressourceneffizienzpotenzialen in KMU der chemischen Industrie, Okt. 2014, 36) Economist Intelligent Unit, beauftragt durch ABB, Economist Intelligent Unit, Intelligent manufacturing: Targeting better energy efficiency, Sept. 2013, 37) VDI: Verein Deutscher Ingenieure (Association of German Engineers), 38) EVD u. UVEK, Masterplan Cleantech, 2011

Medium to long term priorities

Development process and life cycle assessment (LCA)
In future development processes, the use of materials has to be reduced to the minium required by product functionality, and at the same time, energy use has to be minimised. Consequently, specifications for life cycle assessment have to be incorporated into development tools, LCA data bases for materials and processes have to be broadened, , and the implementation of LCAhas to be accelerated. This also includes integration of LCA into academic curricula.

Processes and materials
As little exergy as possible has to be required for optimal energy-efficient and material-efficient processes, and materials have to be used in a way in which as little waste as possible is produced. Typical xamples are the use of mechanical instead of thermal separation processes, or cold forming instead of casting. For established processes, new solutions for accelerating and improving efficiency in processes need to be researched (paradigm shift, process intensification[39]). These include micro-technical processes that enable more precise product manufacturing, as well as the use of technology alternatives and the development of continuous processes. In addition, biotechnical processes that typically operate at significantly lower temperatures than synthetic-chemical processes, need to be researched. In the long term, new types of processes could give rise to energy savings of up to 50 percent.
Energy research should also be incorporated into the development of novel technologies such as additive manufacturing and nano-processes, and identify their potential benefits and risks for reducing the consumption of resources, as well as validate them in demonstration facilities.

With respect to the development and selection of materials it is essential to include their overall energy balance, from the extraction of the raw materials all the way to recycling. Furthermore, the development of materials produced from biomass for process and manufacturing technology is a research priority.

Energy systems and technology
Integrated and continuous processes will facilitate substantial and long-term improvements in terms of efficient use of energy and materials. There is still a need for research into utilised energy technologies and the optimisation of energy flows, including the availability of fluctuating renewable energy resources. Here the flexibility of production planning and control, as well as the options for integration into smart grids, need to be examined, including the question of the optimal location of the production facilities. Concepts for the integration of low-emission production processes into urban space have a long-term effect: in this way the use of surplus heat can be improved and commuter traffic can be reduced. Research activities in this area have to be coordinated with other research priorities of this masterplan , namely energy systems, housing and employment, and mobility.

"Industry 4.0" concepts, together with improved sensors and simulation models, can support the above-mentioned improvements or even make them feasible in the first place. It is therefore important that energy research incorporates new production processes or forms an integral part of production research.

Information and communication technologies
Despite the ongoing reduction of specific energy requirements (kWh per byte), the sharp increase in the use of information and communication technologies is giving rise to a significant increase in energy consumption. These technologies are becoming interwoven with systems and products to an ever greater extent, thus a wide-ranging optimisation of systems is required. The medium term priority is the development of high-performance computer systems with a more efficient energy supply at the processor level, reduced power loss, improved cooling systems and the utilisation of waste heat for other applications. In the long term, the energy requirement of information and communication technology has to be reduced through the use of fundamentally more efficient systems. Measures to suppress the rebound effect also need to be researched.

[39] *EFCE Working Party on Process Intensification; US Department of Energy, Process Intensification, February 2015*

Product use phase

Energy efficiency during the use phase of investment and consumer goods, has to be incorporated already during their development. In order to obtain the smallest possible ecological footprint, an optimal balance has to be found between the consumption of resources for production and during the use phase. Materials selection plays a significant role with respect to product life time, frictional losses and the energy consumption of moving parts. Through the integration of miniaturised sensors and intelligent mechatronics, products can be designed more efficiently in terms of their actual energy consumption, deviations from intended operating conditions can be detected in real time and and maintenance measures can be triggered at an early stage. Retrofitting methods and the possibilities to carry out repairs make it possible to increase the useful life of products and improve their efficiency during the use phase.

Recycling

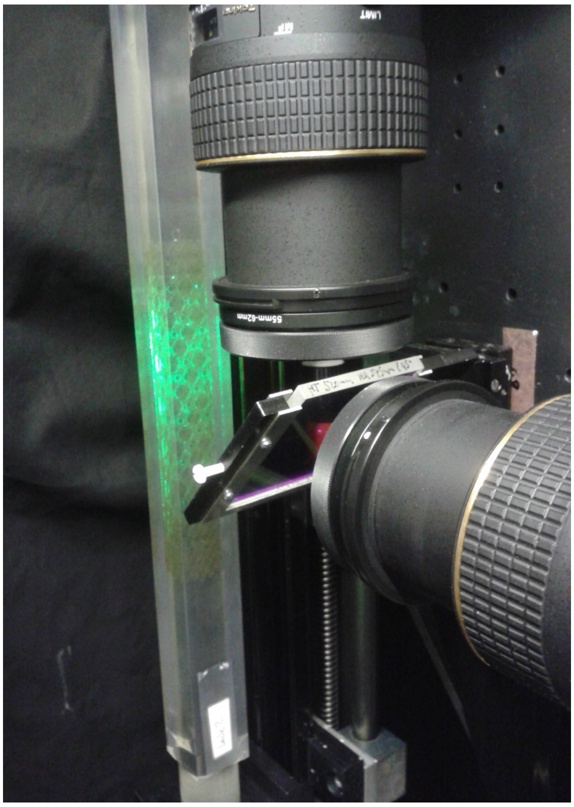
After products have reached the end of their useful life, as many of the resources as possible that were used in their manufacture should be recycled. Here, the availability of the materials, the energy requirements for recycling and the options for obtaining thermal or chemical energy from their recycling are decisive factors. Energy research is pointing to ways in which processes can be designed and operated energy-efficiently while taking account of the maximum possible recovery of resources.

Monitoring of energy consumption

In order to identify energy-efficiency measures and evaluate their potential impact, suitable datasets have to be available. Here, the relevant data include temperatures, waste heat potentials, the potential for energy-related synergies and options for the use of energy-efficient processes.

Behaviour

With respect to the development and implementation of future processes, understanding and support on the part of decision makers, and know-how within the involved companies, are relevant factors. Energy research therefore also has to focus on management tools and education. In addition, research is required into the existing barriers and the potential incentive systems for increasing the demand for products that have been optimised in terms of resource efficiency. The latter may, for example, take the form of price awareness for products that have been improved in terms of their useful life or energy efficiency, but are more expensive. Efficiency measures often give rise to rebound effects, and ways of preventing these also need to be incorporated into behaviour research.



Process intensification: a new type of reactor concept based on porous structures for the continuous and efficient production of chemicals in the chemicals and pharmaceuticals industries. Experimental assembly for the characterisation and optimisation of the new reactor concept in terms of heat and material transport.
Picture: ETHZ, P. Rudolf von Rohr

Areas of research for the period from 2017 to 2020

This section lists a selection of areas of research for the period from 2017 to 2020. The aim is to prioritise a high degree of resource efficiency while taking account of the economic framework conditions. A balance between energy and material efficiency needs to be achieved on a case by case basis. Some research topics are linked with topics in other priority areas.

Development process and life cycle assessment

- Development of datasets for existing and new materials[40]
- Further development of simulation models for selecting more efficient and more economical technology chains, including new processes for reducing energy and material consumption
- Life cycle assessment based on the evaluation of accumulative exergy requirement of products as a function of material selection.
- Demonstration of product concepts with minimal use of energy and materials, especially with regard to materials that are toxic or harmful to the environment
- Exploitation of the potentials of "Industry 4.0" as a method of product development based on the criteria of energy and material efficiency in dynamic procurement markets

Processes and materials

- Further development of detailed analyses of chemical processes, and development of simulation models for researching new resource-efficient process technologies in line with the principle of process intensification; laboratory-scale demonstration
- Research into materials and technologies that facilitate the improvement of energy efficiency in specific applications over the entire life cycle
- Improvement of processes applied on a large scale, e.g. catalytic processes
- Development and improvement of biochemical processes as a substitute for conventional chemical or thermal processes
- Development of datasets and methods for technological, functional or effective material substitution
- Life cycle assessment-based evaluation of resource efficiency of new and biogenic materials, and incorporation into materials research and application

Production facilities and energy technology

Production facilities

- Use of improved or new materials and manufacturing processes for the energy optimisation of production facilities
- Development of numeric simulation models for minimising energy requirement
- Demonstration of the potentials of new sensors and mechatronics for energy-optimised monitoring, control and maintenance of production facilities

[40] *Today there are around 40,000 metallic and 40,000 non-metallic alternative materials (VDI, Ressourceneffizienz durch Werkstoffsubstitution. December 2013)*

- Development of methods and programmes for exploiting the potentials of “Industry 4.0” concepts to improve resource efficiency; integration into the development paths of “Industry 4.0” technologies
- Development of concepts and control algorithms for the optimal harmonisation of energy flows in process chains, taking account of new types of components for energy recovery and storage
- Integration of intermittently produced renewable energy and interaction with energy networks, especially the electricity grid in smart grid concepts

Energy technology

- Increase in the efficiency of electric drive systems, including improvement of demand-based control and options for energy recovery; research into the substitution of strategic raw materials
- Increase in the efficiency of combustion engines and hybrid drive systems in machines; harmonisation with research projects relating to future mobility
- Improvement of the energy efficiency of fluid-dynamic systems such as pumps, ventilators and valves
- Further development of highly efficient and robust storage systems for heat, electricity and kinetic energy in industrial applications
- Improvement of technologies for the recovery of thermal, electric, chemical or kinetic energy, including their use at low temperatures and in widely dispersed energy flows
- Improvement of the energy efficiency, and demonstration of the flexibility of use, of combined heat and power (cogeneration) systems in relation to energy demand for production, supply from variable energy sources, and the electricity grid
- Improvement of the efficiency of cooling machines by 20 percent versus the present-day status of technology
- Development and demonstration of heat pump technologies for utilising process waste heat, e.g. temperatures from 80 °C to above 120 °C

Information and communication technologies (ICT)

- New approach to processor design, with integrated cooling, more efficient 3D processor packaging and lower energy consumption
- Further development of improved cooling systems, especially options for energy recovery (use of waste heat) in ICT systems
- Development of software with energy efficiency as a criterion (energy-aware computing)
- Development of planning tools for implementing the energy efficiency criteria for ICT concepts (introduction of energy efficiency as standard in addition to computing power)
- Identification of energy efficiency potentials in new types of ICT systems and components, and implementation of energy research in their development phase

Product use phase

- Development of intelligent (self-regulating) products equipped with sensors and mechatronic systems in order to minimise the energy requirement during the utilisation phase itself

- Demonstration of tools for web-based monitoring and control of the nominal vs. actual operating status of products, including self-diagnosis and maintenance monitoring
- Development of retrofitting concepts for improving the resource efficiency of products

Monitoring of energy consumption

- Assessment of resource efficiency of production systems, taking account of upstream and downstream processes
- Use of the "Internet of Things" as an opportunity for real-time energy monitoring and management

Recycling and disposal

- Modelling and analysis of the disposal chain, based on material and energy balances
- Examination of the resilience of raw material supply chains for production systems
- Development of energy- and material-efficient recycling and disposal concepts for complex products
- Improved use of waste for energy purposes, including waste heat and CO_2 separation

Behaviour

- Research into barriers to energy-optimised production planning and implementation, and development of suitable solutions, including management models and education
- Examination of economic and regulatory barriers, and identification of options for improvement
- Analysis of the marketability of processes and products that have been optimised in terms of material and energy efficiency, and derivation of marketing strategies, including measures to prevent rebound effects
- Review and improvement of communication tools for informing users about the resource-efficiency of products, for example through labelling

Research policy recommendations

CORE recommends that public sector research bodies should align themselves with the Federal Energy Research Masterplan in order to ensure that public funding is utilised in agreement with the declared objectives.

Criteria for the promotion of energy research
In the energy sector it is primarily application-oriented research that is to be promoted. Priority is to be given to areas of research that have a high potential for value creation in Switzerland and can be expected to make a sustainable contribution towards the security of the domestic energy supply. In other words, energy research should make a significant contribution towards the implementation of Switzerland's *Energy Strategy 2050*. This Masterplan also contains recommendations for energy research that is not directly associated with *Energy Strategy 2050*.

The high quality of the research community, which must be internationally integrated and competitive, is a prerequisite. The strong commitment of the public sector to the networking of research institutions, the identification of important future areas of technology, the promotion of international academic cooperation and cooperation between universities and the industry sector, are of central importance for the implementation of the research results and must be maintained. An efficient and target-oriented implementation is to be supported via a business-friendly regulation of the intellectual property that is developed with the aid of public funding, for example patents and licences.

Promotion of energy research at the Federal Institutes of Technology and at universities and colleges of technology
The launch of the eight Swiss competence centres for energy research[41] supported by the Commission for Technology and Innovation (CTI) and the two research programmes financed via the Swiss National Science Foundation (SNSF) – NRP 70[42] and NRP 71[43] – has been successfully completed. The creation of the Swiss Competence Centres for Energy Research enables universities to increase their personnel capacities in the area of energy research, including sponsored professorships (financed by the SNSF) and financial contributions towards research infrastructure.

CORE supports this policy and recommends continuing the expansion of the competence centres (in line with the procedure adopted by Parliament for the period from 2012 to 2016) in the 2017–2020 legislature. After 2020, the expanded capacity is to be financed and sustainably secured by the colleges of technology and universities, as originally planned.

Federal sectoral research
The sectoral research of the Swiss Federal Office of Energy (SFOE) has an important function in the promotion of Swiss energy research. With its financial resources, it is able to support promising new technologies and projects that are positioned in terms of technological advancement between basic research and market proximity. It is therefore a valuable complement to the research activity of the SNSF and the CTI.

The SFOE has also been mandated by the Federal Council to secure the involvement of Swiss researchers in the research programmes of the International Energy Agency (IEA). In addition to Switzerland's contributions, the SFOE also finances the activities of Swiss researchers within the framework of individual research programmes (implementing agreements).

Despite Switzerland's classification as a third country within the scope of the framework programmes for research, the country is able to actively participate in the European Research Area Network (ERA-Net). Here the sectoral research of the SFOE also plays a special role in that the financing of energy-related calls for tenders is provided by the SFOE.

CORE recommends that the extent of energy-related sectoral research should at least be maintained at the same level as in the previous years, so that in particular it will be possible to secure international integration, especially in the research programmes of the IEA and the EU.

41) SCCER, cf. Swiss Coordinated Energy Research action plan, 42) Energy Tournaround, 43) Management of Energy Consumption

Pilot, demonstration and flagship projects

Through the funding for energy-related pilot, demonstration and flagship projects, energy policy is being supported by the accelerated introduction of innovative technologies into the market. At the same time the attractiveness of Swiss cleantech innovations is being enhanced outside the country. CORE recommends that this funding should be maintained at the current level of 35 million Swiss francs, applications for project support should be as stringently evaluated as before, and in particular the objectives and targets of *Energy Strategy 2050* should be taken into account.

Geothermal energy is allocated a significant role in *Energy Strategy 2050* with a share of the specified expansion targets of 4.4 TWh. However, to date no production facilities have been put into operation. Comprehensive geological knowledge is essential in order to be able to make reliable predictions regarding suitable sites. This means that a number of special drillings and stimulation tests below the ground have to be carried out. Given the geothermal electricity target in the *Energy Strategy 2050* CORE recommends providing the necessary financial resources for a nationwide campaign.

Preservation of know-how in the nuclear energy sector

One area that requires special attention is the availability of specialists in the field of nuclear energy. Switzerland urgently needs to recruit young professionals, not only for the remaining period of operation of its nuclear power plants, but also for the 3 or 4 decades during which the existing power plants are to be decommissioned. It also needs these professionals as experts to help with the avoidance, reduction and disposal of radioactive waste. Furthermore, it is essential to retain the acquired expertise that will be required for assessing developments in the area of nuclear technology.

In order to educate these specialists and secure their expertise over the long term, a minimum of corresponding research in the nuclear sector will be required.