Schweizerische Eidgenossenschaft
Confédération suisse
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Federal Department of the Environment,
Transport, Energy and Communications DETEC

Federal Energy Research Commission CORE
Swiss Federal Office of Energy SFOE

ENERGY RESEARCH MASTERPLAN

of the Federal Government

2025–2028

The Confederation's energy research masterplan in Switzerland serves as a planning instrument and aims to shape the country's energy supply for the future by taking into account both technological and social science aspects and their interaction in research.

The behavior of the various actors, their response to policy measures and the way energy markets and the whole socio-technical system function are the **focus of the "Economy, society and political measures"** priority area. Research should provide evidence-based knowledge that enables markets, policies and institutions to be designed in a way that efficiently supports energy efficiency and the transition to renewables, enjoys broad acceptance and facilitates individual well-being.

In the **"Energy Systems" focus area**, the emphasis is on the integration of renewable energies into the existing energy system. The aim is to develop more flexible and resilient energy systems that can better integrate the increasing share of new renewable energies. This includes the development and optimization of flexibility mechanisms, storage technologies and systems relevant to sector coupling.

Innovative solutions for energy-efficient and GHG minimized living, renovation and construction are to be found in the **"Living and working" focus area**. The aim is to ensure that the building stock can be expanded, modified and operated in a climate-neutral and energy-efficient manner. Technological developments for energy storage, supply and demand reduction are analyzed, developed and optimized, both in terms of energy efficiency and GHG emissions. In addition, social science aspects such as user behavior and the acceptance of new developments of energy-efficient buildings and areas are examined.

In the **"Mobility" priority area**, the focus is on promoting sustainable forms of mobility. In addition to the "avoid-shift-improve" principle, technologies and concepts for system integration and energy storage and supply are being researched and tested. Socioeconomic aspects such as the acceptance and use of bi-directional charging and sustainable mobility solutions are also being investigated to ensure that mobility is as energy-efficient and low-emission as possible.

The **"Industrial processes" focus area** is concerned with energy efficiency and the use of renewable energies in industrial processes. Technologies and concepts for the efficient use of energy in industry are developed and tested here. Research is also being conducted into how processes can be designed to conserve resources and how the use of fossil fuels can be reduced.

Overarching topics that are considered in several key areas are flexibility and resilience of the overall system, storage, sector coupling, heating and cooling as well as CO_2 capture and negative emission technologies. This deepens research topics that were already emerging and important in the previous period.

The Confederation's energy research concept thus addresses a wide range of topics and attempts to combine both technological and social science knowledge in order to significantly support the implementation of Energy Strategy 2050, the achievement of climate targets and other federal objectives.

CONTENT

INTRODUCTION

The Federal Administration itself initiates and supports scientific research, the results of which it needs to fulfill its tasks. This research by the Federal Administration is carried out in the context of administrative action in the public interest and is commonly referred to as "departmental research" in German-speaking countries. This includes, for example, the development of scientific foundations for policy development and design in the various policy areas, for enforcement work within the framework of legal requirements, for legislative work or for responding to and implementing parliamentary initiatives. The Federal Administration's research can include practically all forms of scientific research, namely basic and application-oriented research, but also development–, for example in the area of setting up pilot and demonstration plants. It also includes the implementation of accompanying research measures and the transfer of knowledge and technology. The Federal Administration's research is based on clear legal principles. In addition to being based on Art. 64 of the Federal Constitution (SR 101), the Research and Innovation Promotion Act RIPA (SR 420.1) is the framework law for research by the Federal Administration.

In addition to this anchoring in the RIPA, the federal administration's research is based on special legal provisions and the associated ordinances. These specifically stipulate obligations for the implementation of intramuros research and for the granting of contributions (subsidies) to research institutions, programs or projects by the federal government. In addition, international treaties, conventions or memberships also contain or imply obligations for research by the federal administration, meaning that it also plays an important role at the international level.

This federal energy research masterplan[1] serves as a planning instrument for the federal government's decision-making bodies in energy research and as a guide for all other energy research bodies (such as cantonal and communal). Research is forward-looking, but is also shaped by current political decisions.

The framework decree, which includes the revision of the Energy and Electricity Supply Act, is currently setting the course for Switzerland's energy supply of the future. The Federal Council has defined four main objectives for the revision:

- Strengthening the security of electricity supply with a particular focus on the winter situation.
- Aligning the energy system (and the electricity system in particular) with the Federal Council's net-zero climate target for 2050, i.e. creating the right framework conditions so that decarbonization and electrification can take place.
- Driving innovation in the electricity system while improving the efficiency of the system.
- Ensure that customers are active participants in the electricity system.[2]

As a result, the Energy Act will now contain targets for 2035 (and 2050) for electricity generation: Renewable energies (excluding hydropower) 35 TWh (45 TWh) and hydropower 37.9 TWh (39.2 TWh). To this end, approval procedures are to be streamlined and subsidies made possible. Other elements of the blanket decree include consumption targets, "winter reserve", local electricity communities and similar.

With the adoption of the counter-proposal to the glacier initiative "Federal Act on Climate Protection Targets, Innovation and Strengthening Energy Security (KlG)" in June 2023, the Swiss electorate confirmed the move away from fossil fuels. The KlG aims to reduce greenhouse gas emissions, adapt to and protect against the consequences of global warming and direct financial flows towards low-emission development that is resilient to climate change. The KlG is a framework law, i.e. it primarily sets targets and interim targets. How the targets are to be achieved is to be defined in further legislation. The counter-proposal also sets out the following measures, among others: net-zero roadmaps for companies and innovation promotion as well as an incentive program for heating replacement and energy efficiency. Art. 53 of the Energy Act and thus the guidelines for the pilot and demonstration program will be amended via a third-party amendment: Demonstration projects could now be supported with 50% of the eligible costs, and pilot projects with 70% in exceptions to be defined. Further instruments will be developed under the leadership of the FOEN in cooperation with the SFOE.

Based on the IPCC's special report on global warming of 1.5 °C, the Federal Council decided on August 28, 2019 that Switzerland will reduce its greenhouse gas emissions to net zero by 2050[3]. This concretizes and reinforces the decision that Switzerland will contribute to limiting global warming to well below 2 °C compared to pre-industrial times and aim for a maximum warming of 1.5 °C, which it committed to by ratifying the Paris Agreement in October 2017[4]. The net-zero target by 2050 lays the foundation for the long-term Climate Strategy 2050, which the Federal Council adopted on January 27, 2021[5]. The aim of this strategy is for Switzerland to reduce its greenhouse gas emissions by 50% by 2030 (compared to 1990) and achieve net zero by 2050. These targets form the basis for the Energy Perspectives 2050+ (EP2050+), which set out scenarios for achieving the targets and also shed light on the role of CO_2 avoidance and methods for removing CO_2 from the atmosphere[6].

The experience of the winter of 2022/23 with the Winter Energy Saving Initiative and the possible measures in the event of an electricity shortage (see also OSTRAL[7]) – from restrictions on use, bans, quotas to grid shutdowns – shows the importance of a resilient energy supply that is sustainable in all dimensions. Making energy supply and energy consumption more flexible, energy storage and further increases in efficiency are therefore advisable.

This energy research masterplan in the policy area of energy applies to the period 2025–2028. The research priorities were defined by the Federal Energy Research Commission (CORE) and developed in collaboration with other experts and researchers consulted. CORE's most important goal is the interdisciplinary development of new, practicable and accepted energy strategies and technologies. The increasing importance of cross-sectional technologies calls for significantly greater cooperation both among the technical research areas and between the technical sciences and the social sciences and humanities (SSH).

1 – The Federal Administration itself initiates and supports scientific research, the results of which it needs to fulfill its tasks. This research by the Federal Administration is carried out in the context of administrative action in the public interest and is commonly referred to as "departmental research" in German-speaking countries. This includes, for example, the development of scientific foundations for policy development and design in the various policy areas, for enforcement work within the framework of legal requirements, for legislative work or for responding to and implementing parliamentary initiatives. The Federal Administration's research can include practically all forms of scientific research, namely basic and application-oriented research, but also development– , for example in the area of setting up pilot and demonstration plants. It also includes the implementation of accompanying research measures and the transfer of knowledge and technology. The Federal Administration's research is based on clear legal principles. In addition to being based on Art. 64 of the Federal Constitution (SR 101), the Research and Innovation Promotion Act RIPA (SR 420.1) is the framework law for research by the Federal Administration.

2 – Parliament passed the bill in September 2023. A referendum was called against it, and voters will decide on the bill on June 9, 2024

3 – Federal Council wants a climate-neutral Switzerland by 2050 (admin.ch), Bern 28.8.2019

4 – SR 0.814.012 – Paris Agreement of December 12

5 – Switzerland's long-term climate strategy, January 27, 2021

6 – EP2050+ Excursus on negative emission technologies and CCS. Potential, costs and use

7 –OSTRAL is the organization for electricity supply in extraordinary situations. It is subordinate to the federal government's National Economic Supply and becomes active on its instructions when an electricity shortage occurs; www.ostral.ch

OVERVIEW OF POLICY AREA ENERGY

Switzerland's energy policy is facing major challenges. In order to achieve the targets set out in the Federal Council's Energy Strategy 2050, the expansion of "new" renewable energy must be strongly accelerated and energy efficiency in buildings, industry, transport and electrical appliances must be significantly increased. The SFOE's annual brochure "Energy Research and Innovation"[8] provides a good overview of the latest research findings.

In addition to the Energy Strategy 2050, Switzerland's climate targets and all other climate, environmental and sustainability goals are key to energy research.

The SFOE
The SFOE is the central funding agency in the energy sector. The SFOE has its own funding resources for the implementation of this research masterplan with its research programs, its program for pilot and demonstration projects and the SWEET (SWiss Energy research for the Energy Transition) research promotion program (departmental research[9]). The SFOE's research programs aim to coordinate energy research with public sector participation in Switzerland and provide subsidiary support for research projects and pilot and demonstration projects that serve the objectives of the Energy Strategy 2050 as well as the climate targets (especially SWEET).

The SFOE compiles the Confederation's annual energy research statistics[10] which provides information on the expenditure of publicly funded energy research and a detailed compilation of the cash flows. According to the last survey conducted in 2022, the SFOE was the third-largest funding institution after the ETH Domain and EU with a share of 12%, making it one of the most important public funding bodies[11]. With the completion of the NRPs, the capacity expansion at the SCCERs (Swiss Competence Centers for Energy Research) and the new SWEET funding program, the SFOE's importance as a public funding institution in the energy sector is likely to increase.

Energy research: long term focus
New ways of thinking, new approaches and new technologies are needed. Leaving well-trodden paths requires a funding strategy that does not primarily equate the francs invested in research with the kilowatt hours directly saved. Research needs the freedom to take up and try out fundamentally new ideas.

8 – https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/research-and-cleantech.html

9 – Federal administration research is referred to as departmental research. This is research whose results are required by the federal administration or federal policy-makers to fulfill their tasks, or which they initiate because it is in the public interest. Departmental research is described in the RIPA. www.ressortforschung.admin.ch

10 – https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics.html

11 – In addition to the public funding bodies, the universities - above all the ETH Domain - provide most of the funding.

STRATEGIC FOCUS OF ENERGY RESEARCH

"Energy is converted, supplied, stored and used efficiently and in an emission-neutral manner. Swiss energy research makes a decisive contribution to this; it strives for a secure, economically and ecologically sustainable energy supply and thus supports an efficient energy policy". Energy research thus serves to achieve the goals set out in the Energy Act, the Electricity Supply Act and other laws and ordinances relevant to energy supply.

In addition to the energy targets, achieving Switzerland's climate targets is extremely urgent. According to the scenarios of the IPCC, the SFOE and the FOEN, in addition to drastic reductions in CO_2 emissions, the permanent removal of CO_2 from the atmosphere is also necessary[12]. The terms "Carbon Capture, Utilization and/or Storage" (CCS, CCU or CCUS, summarized in this masterplan under CCUS) and "Negative Emission Technologies" (NET) refer to a range of approaches and technologies with which CO_2 emissions can be avoided, stored and even removed from the atmosphere[13]. In the field of CCUS and NET, energy research focuses primarily on energy-related issues. These include both the direct use of CCUS and NET in the energy sector itself and the effects of the wider use of CCUS and NET on energy consumption and GHG emissions in Switzerland as a whole. A SFOE research concept for CCUS and NET is available at www.energieforschung.ch; further information can be found on the FOEN website.

Flexibilization of the energy system, seasonal storage and sustainable fuels will also have to play an important role in the transformation of the energy system. The efficient and sustainable provision of renewable energies and the necessary infrastructure (including grids) as well as energy efficiency must now be implemented quickly and the outstanding research issues must be clarified in a targeted manner.

LEGAL BASIS

The Confederation's commitment to research and research promotion is legitimized by Art. 64 of the Federal Constitution (SR 101), in that the Confederation promotes scientific research and innovation.

Research funding by the SFOE is based on the Energy Act (EnG, SR 730.0). In accordance with Art. 49 of the Energy Act, the Confederation promotes basic research, application-oriented research and the research-related development of new energy technologies, particularly in the areas of economical and efficient energy use, energy transmission and storage, and the use of renewable energy. The Confederation can also support pilot and demonstration projects as well as field studies and analyses that serve to test and assess energy technologies, evaluate energy policy measures or collect the necessary data.

According to Art. 29 para. 2 let. d of the Ordinance on Dams (StAV, 721.101.1), the SFOE also has the mandate to promote research in the field of dams.

The Subsidies Act (SuG, SR 616.1) and the Research and Innovation Promotion Act (RIPA, SR 420.1) apply to funding.

To support research projects within the framework of the EU's European Research Area Networks (ERA-Net), the SFOE also relies on the Riklin motion (10.3142), which instructs the Federal Council to enable Swiss research institutions and Swiss industry to participate on an equal footing in the Strategic Energy Technology Plan (SET Plan) launched by the EU Commission.

According to Art. 86 of the Nuclear Energy Act (KEG, 732.1), the federal government can promote application-oriented research on the peaceful use of nuclear energy, in particular on the safety of nuclear facilities and nuclear waste disposal. Art. 77 of the Nuclear Energy

Ordinance (KEV, 732.11) specifies that the supervisory authorities SFOE and ENSI support application-oriented research projects in the areas of safety and security of nuclear installations and nuclear waste disposal in the form of financial assistance within the scope of approved credits.

Compilation of the basic legal principles:
- Energy Act EnG (SR 730.0), Art. 49;
- Subsidies Act SuG (SR 616.1);
- Research and Innovation Promotion Act RIPA (SR 420.1);
- Ordinance on Dams (StAV, 721.101.1), Art. 29;
- Nuclear Energy Act KEG (SR 732.1), Art. 86.

REVIEW OF THE 2021–2024 PERIOD

Energy shortage

An energy shortage could not be ruled out in the winters of 2022/23 and 2023/24. Due to various measures in Europe, warm weather, calls for savings ("Winter Energy Saving Initiative") and high gas and electricity prices, the shortage was prevented. As a precaution, the federal government has prepared reserve capacities for emergencies: Three reserve power plants were contracted, a hydropower reserve was created and pooled emergency power groups were organized. In addition, the possibility was created to increase transmission capacities on certain power lines if necessary. The sector also procured gas reserves and gas storage capacities abroad.

SWEET

The SFOE has set up the new research funding program SWEET (SWiss Energy research for Energy Transition), which is designed to run for 12 years. The aim of SWEET is to promote innovations that contribute significantly to the successful implementation of the Energy Strategy 2050 and the achievement of the Swiss climate targets. To this end, key topics are put out to tender and worked on in consortia.

Between 2021 and 2024, tenders were invited for the following six key topics:

- Integration of renewable energies
- Living & Working
- Critical infrastructures
- Co-evolution
- Sustainable fuels
- Net zero

Further information on the content, the consortia and initial results can be found on the SFOE's SWEET website[14].

12 – https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/co2-capture-removal-storage.html

13 – The climate impact of these approaches depends on the CO_2 source. If fossil CO2 is captured, CCUS is to be understood as an abatement technology. If biogenic CO2 is captured, it can be attributed to NET, as net removal from the atmosphere is achieved.

14 – www.sweet.admin.ch/

Flagship initiative

The aim of Innosuisse's Flagship Initiative is to stimulate innovation in areas that are relevant to a large part of the economy or society and to promote transdisciplinary projects. The initiative strives to find solutions to current or future challenges that affect several players and/or can only be mastered through their cooperation. Calls for proposals with energy relevance were:

- New materials and processes
- Storage, generation and real-time management of energy
- Energy efficiency and reducing emissions

Further information on other calls for proposals, the content, the consortia and initial results can be found on the Innosuisse flagship website[15].

National Research Programs (NRP)

The Swiss National Science Foundation (SNSF) has launched two NRPs in the 2022 review round that are potentially related to energy research. Thematic coordination between the NRPs and other European research initiatives (CETP, DUT, see below) has been initiated.

- NRP 81: Baukultur[16]
- NRP 82: Biodiversity and Ecosystem Services[17].

National Centres of Competence in Research (NCCR)

In the fifth series (2020 to 2032), the SNSF is supporting two NCCRs that are relevant to energy research. Further information can be found on the SNSF homepage or on the pages of the NCCRs.

- NCCR Catalysis - sustainable chemistry for a carbon-neutral society[18]
- NCCR Automation - Towards dependable, ubiquitous automation by research, innovation and education[19]

Calls[20]

CETP: The Clean Energy Transition Partnership (CETP) is a transnational initiative of funding programs in the areas of research, technological development and innovation. It supports and accelerates the transformation towards a sustainable energy supply in Europe and beyond. CETP contributes to the EU's goal of becoming the first climate-neutral continent by 2050 by pooling national and regional funding for a wide range of technologies and system solutions. Together with the SNSF, the SFOE has participated in various calls for proposals for different transitions. Further and up-to-date information can be found on the CETP website[21].

DUT: Driving Urban Transitions (DUT)[22] is organized as a European partnership of more than 60 partners from 27 countries, involving national and regional authorities and decision-makers and funding agencies to invest in urban R&I and to create and strengthen a European innovation system for urban transition. To support cities along their specific strategies, the partnership focuses on three critical urban sectors and their interrelationships and has launched several calls for proposals.

ETH Domain (2022): Call for the Joint Activity Energy, Climate & Environment of the ETH Domain[23]. The purpose of this call is the rapid development of solutions in the area of tension between climate, energy and the environment by the ETH Domain in dialog with society.

SFOE: In 2023, the first "Sandbox" (see page 47) on the topic of "Relieving the electricity grid through sensible energy use" was put out to tender. Further calls for proposals were issued, for example, in the SFOE's energy research programs "Energy, Economy, Society", "Grids" - "Mobility"; all SFOE calls for proposals are published on the "Calls for proposals" page[24].

15 – https://www.innosuisse.ch/inno/en/home/promotion-of-national-projects/flagship-initiative/call.html

16 – www.nfp81.ch

17 – www.nfp82.ch

18 – www.nccr-catalysis.ch

19 – https://nccr-automation.ch/

20 – see also SWEET and Flagship Initiative; no claim to completeness

21 – https://cetpartnership.eu/, www.bfe.admin.ch/cetp

22 – https://dutpartnership.eu/, https://www.bfe.admin.ch/dut,

23 – https://ethrat.ch/en/eth-domain/joint-initiatives/; https://www.psi.ch/en/strategic-areas-eth-domain/call-jointinitiatives-jan2022

24 – https://www.bfe.admin.ch/bfe/en/home/news-and-media/calls-for-tenders.html

RESEARCH TOPICS 2025–2028

The following research priorities are aimed at CORE's vision: "Energy is converted, supplied, stored and used efficiently and in an emission-neutral manner. Swiss energy research makes a decisive contribution to this; it strives for a secure, economically and ecologically sustainable energy supply and thus supports an efficient energy policy".

Energy systems overview

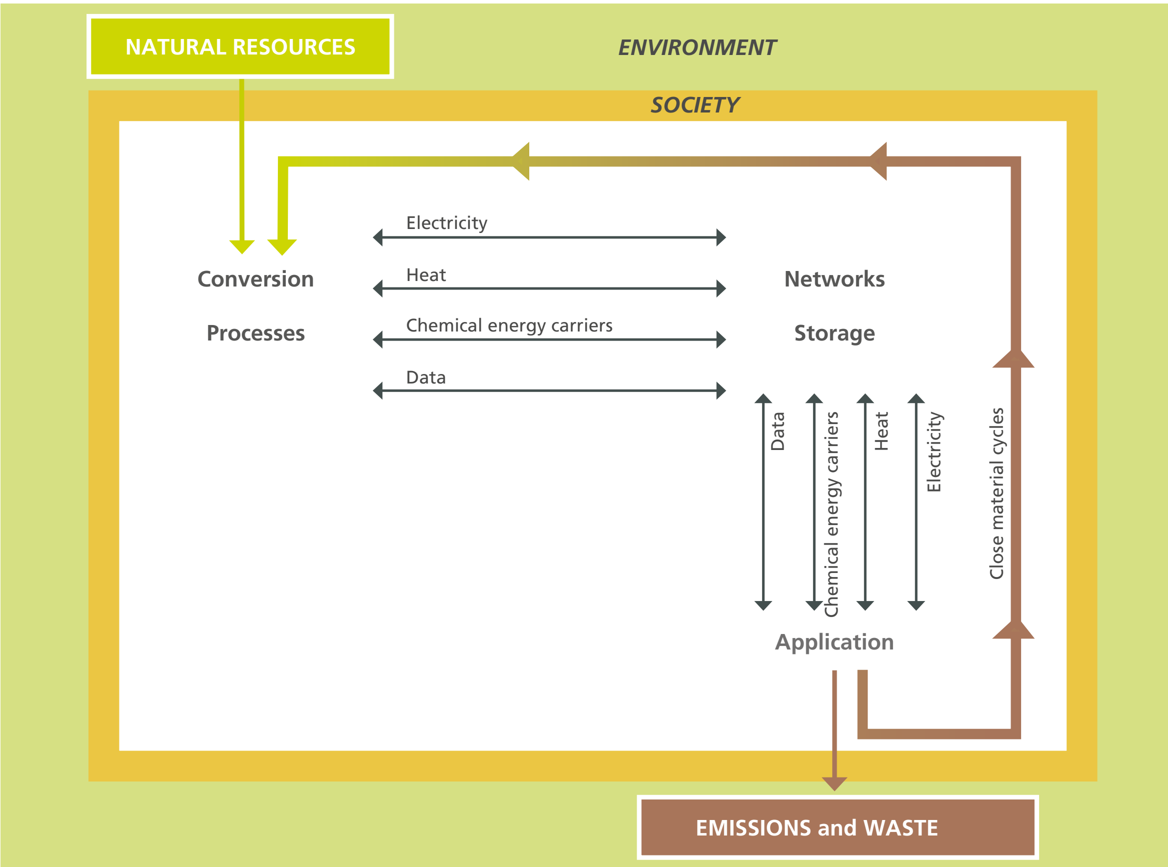

Figure 1: Simplified energy system (CORE based on ETH Domain) ©BFE

The diagram shows the energy system in a highly simplified and schematic form. Energy sources (electricity, heat, fuels and combustibles) and products are provided and manufactured from the environment through the "conversion and processes" of natural resources. They are distributed, stored and converted or consumed by applications. There are manifold dependencies and interactions between all actors, conditions and processes. The aim of energy research is to understand this complexity and to use this knowledge to find the best possible options for further developing the overall system and its components and to contribute to closing the material cycles. Researchers should also strive to take a holistic view when working on specific issues and measure their solution approach against their contribution to these goals.

Flexibility
Flexibility in energy production, distribution and consumption is an important factor for a sustainable and efficient energy system. Some of the most important flexible consumers are electromobility and heat pumps, which can postpone or temporarily reduce their energy consumption in order to balance the grid. By intelligently controlling these consumers, energy can be used more efficiently and costs in the system can be reduced. One example is vehicles with vehicle-to-grid (V2G) technology, which can take up or return surplus energy from the power grid and thus help to balance the system. Industrial processes can also be made more flexible to some extent, especially in interconnected locations. On the other hand, flexible generators are also of great importance. Hydropower plants and power-to-X plants, which can temporarily store surplus energy in the form of hydrogen or synthetic fuels, are important (future) players in the energy system. The integration of these flexible generators can reduce dependence on fossil fuels and help achieve the goals of Energy Strategy 2050. The regulatory framework should allow optimal use of flexibility in the energy system.

Sector coupling
The term "sector coupling" refers to the intelligent connection and interaction of different energy supply systems . The aim is to take a holistic approach to developing solutions to make the overall energy system more efficient and, in particular, to enable the integration of a larger proportion of renewable energy, up to 100%. Examples of this include the use of renewable electricity in electromobility or in combination with heat pumps in the heating sector, or the production of synthetic gases and fuels ("power-to-gas", "power-to-liquid") for use in the transportation, heating or industrial sectors. Coupling brings additional flexibility to the overall system. Furthermore, this approach contributes to security of supply. Various aspects of "sector coupling" can be found in all focus areas.

Energy storage
Energy storage serves to make the energy system more flexible (page 10). Energy can be stored using various technologies - from chemical, mechanical or electrical to thermal storage. Depending on the environment, suitable technologies include accumulators, ultracapacitors, hydrocarbons, hydrogen, dams, biomass, flywheels, springs, compressed air, the subsurface, adsorbents or superconducting coils. Research into storage technologies, including their operation with regard to make the overall system more flexible, is mainly dealt with under "Energy systems". Specific issues relating to the integration of storage in the individual consumption sectors are addressed in the chapters on "Mobility", "Living and working" and "Industrial processes". Regulatory measures, policy measures for optimal integration into the energy system, obstacles from an investor perspective and similar research questions can be found in the focus area "Economy-Society-Policy Measures".

Heat / cold
The provision of heat (heating and hot water in buildings and process heat in industry) currently accounts for around 50% of Switzerland's energy consumption and causes more than 35% of GHG emissions[25]. In order to achieve the net-zero emissions target, heating requirements must be met entirely with renewable energies and have to be GHG emission free by 2050. In addition, future planning and construction practice must be systematically orientated towards low-GHG emission construction methods. The production and distribution of heat is part of the supply side of the energy system and is made possible by various technologies and fuels (see focus on "Energy systems"). A distinction is made here between high-temperature and low-temperature heat, each of which is used for different applications.

The use of heating and cooling takes place primarily in the areas of living and working as well as industrial processes. In residential buildings, heat is mainly used for space heating and hot water, while in industrial processes heat is also used as process heat and steam. Efficient use of heat can help to reduce energy requirements and cut costs in the system. This also involves optimizing the spatial and temporal provision of heat and creating a flexible system that can react to changes in energy demand.

Regulatory framework conditions and political measures are required to ensure a more efficient use of heat and to provide it in line with Switzerland's climate targets (see focus "Economy, society and political measures").

CCUS and negative emission technologies (NET)[26]

Depending on the technology used and the area of application, CCUS and NET belong to different focus areas:

- Economy, society and political measures: Legal issues and regulatory measures, functioning of markets, preferences of stakeholders, etc.;
- Energy systems: distribution and storage of CO_2 and its downstream products, provision of energy for capture, transportation and storage, etc.;
- Living and working: Incorporation of CCU products such as biochar in building materials, accelerated weathering of cement, etc.;
- Mobility: use of synthetic fuels;
- Industrial processes: Improved processes for CO_2 capture and utilization, incl. DACCS, capture at point sources such as cement plants, incl. more efficient conversion of CO_2; etc.;

CO_2 and products made from it can also link the sectors as chemical energy sources.

Excursus: CO_2 and GHG

In addition to CO_2 emissions from the use of fossil fuels and direct CO_2 emissions from industrial processes (see focus) and waste incineration, there are other climate-damaging gases that are reported in the greenhouse gas inventory[27] for Switzerland. These are the greenhouse gases methane (CH4), nitrous oxide (N2O) and synthetic gases from a wide variety of sources. CO_2 accounts for the largest proportion of GHGs in the energy sector, and due to its quantity it also has the most negative impact on the climate. CO_2 reduction is therefore the focus of the reduction of GHGs in this masterplan; if other GHGs are mentioned, they are usually quantified as CO_2 equivalents.

Social Sciences and Humanities (SGW

Research questions in the humanities and social sciences are part of the focus area "Economy, Society and Policy Measures".

In addition to the division's own issues, SHE research contributes to the development and implementation of new technologies. Technical and social progress are closely interdependent and cannot be separated. Technical solutions can make a better contribution to sustainable energy consumption if the social, economic and political environment is given appropriate consideration during their development. For this reason, this research masterplan integrates socio-economic issues directly into the technical priorities if they are inherent to the technology or are of particular importance to it.

25 – SFOE heating strategy: https://www.newsd.admin.ch/newsd/message/attachments/74920.pdf

26 – For definition see page 7: Negative Emission Technologies" (NET)

27 – https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/CO2-capture-removal-storage.html

ECONOMY, SOCIETY AND POLICY MEASURES

The transition towards a renewable, secure and efficient energy system compatible with the net-zero-emissions target will be enabled by behaviors, markets, policies and institutions designed to support energy efficiency and a shift towards renewables in a way that is efficient, broadly accepted, and facilitates individual well-being. Research in the field "Economy, Society and Policies" provides evidence-based knowledge that is necessary to design these markets, policies and institutions.

The 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 a high level of supply security in Switzerland. This requires an increase in energy efficiency and an expansion of energy production from renewable sources, and more generally, a transformation of the Swiss energy system to be compatible with the net-zero-emissions target. Such a transformation includes the efficient management of the growing convergence of energy sectors and the integration of new energy carriers like hydrogen and technologies like NET and CCUS. To achieve these objectives, the development of new technologies will be important[28]. But technological progress on its own will not suffice. Major private investments and substantial changes to energy consumption are needed. Both require behavioral changes, altered incentives, and - possibly - adjustments to governance structures and policies. This transformation of the energy system has to be achieved while sustaining a high level of individual well-being and quality of life and by means that are broadly accepted in society.

The main goal of social sciences and humanities (SSH) energy research is to bring about a better understanding of the behavior of the various actors, of their response to policy measures, and of the way the markets and the whole socio-technical system function. On this basis, the relative potentials and costs of the various measures can be assessed and their design optimized. Furthermore, the SSH research provides a comprehensive view of the transformation of the energy system and a better understanding of the interconnections and interactions of various measures and processes. System-wide assessments support the transformation of the Swiss energy system by providing detailed information on the development of energy consumption and production, their relation to individual behavior, societal and economic developments and their impact on the environment.

The restructuring of the energy system calls for changes in the investment and energy use behavior of the involved actors and for policies, market designs and institutions that enable these changes. Political and regulatory instruments and measures need to be developed and framework conditions have to be created that support the transformation of the energy system. Providing the knowledge required for these tasks is the main contribution of SSH research to the Swiss energy strategy. Particularly, research in the areas of "Energy demand", "Energy supply, grids and storage", "Energy markets and system-wide assessments" and "Energy transition in the wider context" will be needed. In addition to its own research questions, SSH research supports the development and implementation of new technologies.

28 – Please see the other chapters of the document for further details.

PRIORITIES

Energy demand: households, companies and public bodies
In order to successfully implement the energy strategy and the transformation towards a net-zero-compatible energy system, households, companies and public bodies have to change their energy-relevant consumption and investment behavior. The analysis of the determinants of energy demand, including the drivers of increases in energy efficiency and sufficiency and barriers thereof, as well as the development of levers and policies to reduce or shift energy demand are the focus of the first research priority. Specifically, research should improve the understanding and modeling of the behavior of various actors based on psychological, social and microeconomic methods and field experiments and formulate recommendations for action. The purpose is to gain a better understanding of the motives of the respective actors and the effects of specific energy policy instruments.

The targeted phase out of nuclear and the transformation of the energy system towards renewables go hand in hand with an augmented electrification of transport and heating, and call for a reduction and an increased flexibility of energy demand. Consequently, an important research stream is the analysis of the psychological, economic and social determinants of energy demand and energy-relevant behavior in all sectors and of individual decision-making, dynamic group processes and corporate strategies. This facilitates the development of measures that help to reduce energy consumption and to leverage and use demand flexibility. For example, on the household side, further research on the interplay of socioeconomic determinants as well as affective, normative and cognitive factors that influence individual energy consumption is needed in order to design policy measures for a sustainable reduction in energy demand.

In addition, companies and public bodies are important players on the road to the Energy Strategy 2050: their strategies impact, and are also impacted, by consumer behavior and their consumption and investment decisions have a significant influence on energy demand (including embodied energy) and on the development of new infrastructure. Here, research is required into adaptation measures within companies and public bodies and into the development of framework conditions that promote innovation (for example digitalization) and technological changes towards better energy efficiency and renewable energy.

The Energy Strategy 2050 generally requires investments in energy efficiency. Identifying obstacles and formulating recommendations for the establishment of adequate framework conditions to enable these investments is key to its success. Sustainable finance is one of the levers of interest in this context. Limiting rebound effects is also a success condition to reduce energy demand, especially in mobility (also see chapter "mobility"), as well as promoting the circular economy to save material resources and avoid emissions. Finally, improving energy demand modeling to account for individual behavior and social interactions is part of this research priority.

Energy supply, grids and storage: households, companies, public bodies, and energy companies

An energy transition towards a sufficient, diverse, safe, economic, and environmentally sustainable energy supply based on renewable energy requires very significant investments in energy infrastructure at different system levels. The analysis of decision-making affecting energy supply thus stands at the center of the second research priority. On the one hand, this entails the analysis of the determinants of decision-making of households, companies, public bodies and energy companies. On the other hand, a better understanding of existing and the development of novel levers and policies to efficiently increase and shift renewable energy supply and enable its storage and transport are called for, as is prioritizing the use of these resources (the right energy for the right use in the right place).

A successful transition relies on the development of instruments and policies to efficiently integrate renewables in the Swiss energy system as well as of policies for an efficient and effective fossil fuel and nuclear phase out, accounting for the risk of stranded assets. Regulations to leverage supply-side flexibility and sector coupling to achieve this goal should receive particular attention. In this context, the development of the regulation of power networks to provide incentives for an efficient expansion of power grids and the integration of storage will be key.

The analysis of barriers to investments in energy infrastructure (including grids and storage) from the viewpoint of investors and portfolio optimization, and the development of strategies to make these investments more attractive is another important research priority. The role of sustainable finance and new business models in overcoming these barriers is also of interest. The same is true for the promotion of investments and the integration of novel solutions like renewable fuels, CCUS and negative emissions technologies. Generally, the promotion of innovation, particularly digitalization, and community approaches in energy supply are important for a successful energy transition.

Energy markets (domestic and international aspects) and system-wide assessments

In this priority field, the understanding and improvement of the functioning and regulation of the energy markets and system-wide assessments of regulatory measures and policies are the key research areas.

Energy markets coordinate the investment and usage decisions of actors in an energy system. They are thus of central importance to a successful energy strategy and to establishing a secure and resilient energy system. Due to new technological developments that facilitate a close integration of different sectors and energy carriers, the decentralization of the energy system, the integration of intermittent renewables on a large scale, the possible upcoming of new energy carriers like synthetic fuels and the need to be compatible with the net-zero-emission target, future energy markets as well as their underlying regulation have to cope with many challenges. Therefore, a successful energy strategy requires research on market design and regulation, both for existing and upcoming energy markets. For example, the development and analysis of efficient market designs that enable investment in renewables and their integration in the energy system to compensate for fossil and nuclear energy is of high importance. Research has to develop appropriate solutions for the integration of a high share of intermittent renewables and a possible transition towards a more decentralized energy system. This involves new approaches for ensuring security of supply and for coordinating the decisions of actors (e.g., utilities, prosumers, self-consumption communities, network operators) in the system. Opportunities arising from digitalization incl. industry 4.0 in this context are also of interest.

The green energy transition comes with a growing convergence of the different energy supply systems. In order to best exploit opportunities arising from this convergence in terms of efficiency, resilience, social fairness and sustainability, the process itself and the implications of energy policies and regulatory measures at the energy system level need to be better understood and optimized. Further, a good coordination of energy policies, including coordination at the federal, cantonal and communal level, is key. The design of systemic energy-relevant public policies (including incentives and laws) should take into account behavioral insights and reflect the need to integrate the individual perspective with the systemic perspective, instead of considering them separately.

Further, the development of appropriate policies, regulations and market designs has to consider legal and international aspects. International climate and energy policies and market regulations and designs have a major influence on the energy markets in Switzerland, and analyzing this influence, as well as the interactions of domestic and international policy measures is an important area of research, as is Switzerland's positioning on the international markets. This international dimension is for example of high relevance for companies and energy-intensive industries that participate in international value chains, as it impacts supply chain security and competitiveness.

Energy transition in the wider context

To be able to set the framework conditions for a successful energy strategy, the process itself and the implications of energy policies and regulatory measures on the Swiss energy system and economy and society need to be better understood. The same goes for the impact of developments beyond energy policy on the energy transition and vice versa. This is the objective of the fourth priority field. In this context, the analysis of energy policy measures and instruments, e.g. based on macroeconomic tools as well as the investigation of future energy demand, supply and framework conditions via scenarios, energy models and other methods remains an important research field. A deep understanding of the impact of the energy transition and especially various policy options and energy market designs on economic growth, the labor market, consumption and the competitiveness of Swiss industry is a prerequisite for a successful transition. This requires the further improvement of appropriate tools and methods for scenario development and simulation of various energy policy options and their economy-wide implications, as well as the development and enhancement of models and scenarios that describe possible future developments and highlight the key socio-economic factors driving the energy strategy. Techno-economic scenarios are also of interest, but these are addressed in the chapter on energy systems. An important objective is to improve the inclusion of uncertainty and the representation of contextual, behavioral and societal aspects in models and scenarios in order to account for socio-political feasibility of these scenarios.

The energy strategy is a societal as well as a technology strategy. The energy transition should be broadly accepted and facilitate individual well-being. Research about energy justice and the distributional impact of the energy transition itself and of the measures implemented to facilitate the transition are thus of interest. This includes strategies to design an inclusive transition and avoid energy poverty and reductions in quality of life. Further, societal and individual preferences for the design of energy policies need to be investigated, and designs reflecting these preferences developed. As the energy transition is accompanied by a certain decentralization of the energy system, based on renewable energy and increased local energy ownership, the development of strategies to encourage active energy citizenship and citizen participation is an important success factor. The same goes for corporate stakeholder engagement.

Policies, regulations and social factors outside the energy field can significantly hinder or support the energy transition. The political, economic and social framework conditions of scenarios and the interaction of different political measures in policy mixes (policies from different domains, present and new policies etc.) need to be better understood. For example, societal and technological dynamics like digitalization and artificial intelligence influence energy strategy at different level and with different effects. This complex and dynamic interplay of factors driving the energy strategy needs further analysis. In the context of the energy transition and the need to build up new renewable energy production, transport and storage infrastructure, developing options for solving and/or mitigating target conflicts in spatial planning, environmental and energy legislation is of high importance. Options and limitations regarding the acceleration of planning and approval procedures need analysis, as do the ethical dimensions of target conflicts potentially arising between energy supply, environmental protection, agriculture and other land use options. Finally, holistic assessments of the impact of energy market regulation and energy policies are an important research field.

PRIORITY RESEARCH TOPICS 2025–2028

Energy demand: households, businesses, public bodies

Determinants of energy demand: analysis and modeling

- Decision-making affecting energy consumption, including individual (affective, normative and cognitive) and structural (social/societal, cultural, economic, technological, geographical) factors, long-term trends, lifestyles
- Investments into energy efficiency and consumption flexibility, incl. drivers and barriers and response to innovation

Levers and policies to efficiently reduce and shift energy demand: development of new instruments and analysis of existing instruments

- Incentivizing decision-making affecting energy consumption, in particular reducing and shifting energy demand, improving energy efficiency, encouraging low-energy lifestyles and product designs and limiting rebound effects
- Overcoming obstacles to investment in energy efficiency and demand flexibility and innovation, incl. sustainable finance

Energy supply, grids and storage: households, businesses, public bodies, energy companies

Determinants of energy supply: analysis and modeling

- Decision-making affecting energy supply
- Investments into energy infrastructure and supply-side flexibility, incl. drivers and barriers and response to innovation

Levers and policies to efficiently increase and shift renewable energy supply (incl. infrastructure, storage, flexibility, hydrogen, synthetic fuels): development of new instruments and analysis of existing instruments

- Incentivizing decision-making affecting energy supply; in particular integration of renewables and new technologies as well as network regulation
- Overcoming obstacles to investment in energy supply infrastructure and supply flexibility and encouraging the adoption of innovation, incl. sustainable finance

Energy markets (domestic and international aspects) and system-wide assessments

Market organization (incl. integration of decentralized supply and storage, handling intermittency, synfuels): analysis, modeling and market design

- Energy markets' capacity to efficiently integrate new supplies , new demands (e.g., e-mobility), new energy carriers (e.g., synfuels) and new technologies (e.g., digitalization) and to coordinate different actors, while ensuring security of supply and network stability
- Socio-economic components of energy markets' capacity to cope with shocks (e.g., supply interruptions)

Levers and policies to improve market organization: development of new instruments and analysis of existing instruments

- New business models and market designs (e.g., responsibility for system stability, local energy markets) fostering the transition to net-zero-emissions and reduced material consumption (circular economy, urban mining) while ensuring security of supply and resilience of the energy system; efficient design of new energy markets; incl. legal, economic and societal challenges
- Assessing the influence and interaction of foreign energy policy and international climate policy with Swiss instruments and measures; positioning of Switzerland on the international energy markets and assessing the conformity of Swiss policy with international and especially European law

System-wide assessments

- Assessing energy policies at the system-wide level and developing policies to best exploit the convergence of sectors in the energy system, improving the coordination of energy policies

Energy transition in the wider context

Energy transition and the Swiss economy

- Understanding the impacts of the energy transition and specifically various policy options and market designs on the Swiss economy, the labor market, the competitiveness of the Swiss industry and SME, and the environment; improvement of appropriate tools and methods
- In the context of the energy strategy, understanding the complexity and interdependency of different sectors, incl. interactions between technological, societal, political and individual change; analyzing the interplay between different strategies such as efficiency, sufficiency, sharing economy, circular economy, digitalization , etc.

Energy transition and the Swiss society

- Understanding the impact of energy transition scenarios and energy policies on energy justice, identifying strategies to avoid or cushion energy-related poverty and reductions of quality of life, and assessing the socio-political feasibility of these scenarios and policies in general
- Enriching energy scenarios with new scenarios that focus on the key players and society as a whole, e.g. behavior and lifestyles, land use, employment, housing, digitalization , procurement, leisure-time activity, mobility, etc.
- Understanding and analyzing social interactions in different institutional contexts, incl. social learning and social innovations, energy citizenship, consumer movements, grassroot communities, citizen participation processes, acceptance of and resistance to new technologies and policies

Energy transition and policies/societal developments in other fields

- Assessing the consequences of policy interactions (different domains, foreign and domestic, old and new policies) and developing approaches and processes for handling such interactions
- Developing options for solving and/or mitigating target conflicts in spatial planning, environmental and energy legislation; analysis of the interaction of regulations on federal, cantonal and municipal level, options and limitations regarding the acceleration of planning and approval procedures
- Understanding and analyzing spatial interdependencies, incl. niche/regime/landscape interactions, international/national/cantonal/local decision-making and implementation processes in multi-level contexts
- Levers and policies for promoting the deployment of CCUS and NETs
- Investigating links between energy system and environmental impacts of the society's consumption, incl. differences between production-based and consumption-based accounting of emissions

ENERGY SYSTEMS

"Future energy systems will be based on the intelligent interaction of individual technologies and cross-sector media. They thus create the basis for a secure, sustainable and affordable energy supply in line with current energy and climate targets."

An energy system comprises the entirety of all systems for the conversion, distribution or storage of energy in various forms. Depending on the context, an energy system can be organized centrally, decentrally or as a hybrid form. This part of the concept focuses on the supply of energy, while the consumption and thus the use of the energy produced takes place in various areas, which are dealt with in other parts of the masterplan (see the sections on living and working, mobility and industrial processes).

The goals of energy policy are inevitably closely linked to those of climate policy, especially as around three quarters of greenhouse gas emissions in Switzerland are caused by the use of fossil fuels. The net-zero climate target by 2050, which the Federal Council set itself in 2019, and the long-term climate strategy[29] adopted in 2021, with which it intends to achieve the climate target, require a fundamental restructuring of the existing energy system. At the same time, security of supply, which is of central importance for a well-functioning economy and society, must continue to be guaranteed. The diversification of energy sources makes a decisive contribution to this. At the same time, it is important to use the available local resources sustainably and still be well integrated into the European energy system. Strengthening local know-how is also key; this applies to both research and implementation efforts.

The sustainable transformation of the energy system sometimes goes hand in hand with substantial changes in people's habits and behavior (see focus area "Economy, society and political measures"). When using new technologies, for example, it is not just a question of their benefits for the customer, acceptance and sustainability, but also in particular the affordability of the energy supply as a whole or the preservation and creation of long-term jobs.

What do we need for the future?
Objectives up to 2050

The Energy Perspectives 2050+[30] use scenarios to show how the net-zero target can be achieved by 2050. Although the time horizon is very ambitious, it is clearly stated that in principle it is possible to achieve the target with the technologies available today. However, further technological developments could significantly accelerate the transition. Long investment cycles in the energy system increase the pressure to act in all sectors, whereby the distribution of costs and benefits varies greatly depending on the development path and scenario. Exploiting the potential of energy efficiency and renewable energies as well as intelligent and cross-sectoral management of energy flows are fundamental to the net-zero compatible transformation of the energy system. The transformation of the Swiss energy system aims to increase energy efficiency and the share of renewable energies and reduce energy-related greenhouse gas emissions without jeopardizing the high level of security of supply and affordable energy supply. The aim of Energy Strategy 2050[31] is to increase annual electricity production from hydropower to 37.9 terawatt hours (TWh) (2035) and 39.2 TWh (2050) and from other renewable energies to 35 TWh (2035) and 45 TWh (2050)[32]. However, far more ambitious efforts are required to achieve the expansion target for renewable energies (excluding hydropower). The five-year monitoring report on the Energy Strategy 2050 showed in 2022 at[33] that the share of renewable electricity production in national generation had risen to 7.2%. In total, renewable electricity production amounted to 4.7 TWh in 2020. Without new measures as provided for in the Federal Act on a Secure Electricity Supply from Renewable Energies, the rate of expansion of renewable energies is too slow to achieve the medium and long-term targets.

A key element of the future energy system is sector coupling (see section "Sector coupling and digitalization"). Electrical energy in particular will play an important role in the areas of heat generation and mobility. This can be temporarily stored using various technologies or converted into liquid or gaseous energy sources using Power-to-X and thus used flexibly in terms of time and space.

In addition to a supportive legal framework (approval procedures, subsidies), an efficient energy market design and, last but not least, social acceptance plays an important role in accelerating the expansion of renewable energies. Research can make an important contribution to this by achieving technological progress (e.g. increasing efficiency) and scaling up and testing new technologies (P&D systems), as well as demonstrating the added value of these technologies for society and thus also scientifically addressing the issues of social discourse (see focus "Economy, society and political measures"). What is important for the future is a clear approach that technically and economically optimizes the solutions presented and at the same time takes into account the social framework conditions in order to achieve a justifiable balance of interests.

29 – www.admin.ch/gov/en/start/documentation/media-releases.msg-id-82140.html

30 – Energy perspectives 2050+ (admin.ch)

31 – Energy Strategy 2050 (admin.ch)

32 – 21.047 | Secure electricity supply with renewable energies. Federal Act | Business | The Swiss Parliament

33 – SFOE (2022): Energy Strategy 2050: Five-yearly reporting as part of the monitoring process

PRIORITIES

How do we achieve the targets?

Energy grids, system integration, flexibilization

For some time now, research in the field of energy systems has no longer focused exclusively on individual technologies in order to increase conversion efficiency and thus reduce the generation costs for electricity, heat or fuels. Instead, system aspects are increasingly coming to the fore, as the individual generation systems are becoming more and more interconnected and interact with each other. Furthermore, decentralized renewable energy sources will gain in importance in the future, so that the temporal and local variability of supply and demand will come to the fore. In future, research will therefore increasingly focus on the interconnection and integration of the various generation technologies and their intelligent and system-friendly interaction. The aim here is to design the operating mode of the existing infrastructure (electricity, gas, heat) in line with demand and to design it for future use on the basis of models and scenarios. Important research topics in this context are the stability and resilience of the system; both are basic prerequisites for the functioning of the numerous individual components within the system, which are negatively affected by the integration of fluctuating energy sources. The system approach is not limited to the planning and operation of the electricity and gas system; the focus is equally on the thermal grids and their future challenges, e.g., in the area of district heating/cooling system design and their integration. In order for the flexibility options (sector coupling, storage management, demand side management) of its numerous individual components to be utilized in a system, a sustainable and future-oriented market design is required in all dimensions, which deals with regulation as well as the design of policy measures (see focus "Economy, society and policy measures"). In addition to looking at the system as a whole, it is also important to further develop the individual technologies. The focus of research here is on increasing efficiency and optimal and more flexible plant operation.

Sector coupling and digitalization

An intelligent connection and interaction of different energy supply systems (sector coupling) increases the flexibility of supply, demand and storage and enables the use of synergies in the future. The technologies required for this are largely available today (combined heat and power, power-to-X), but organizational hurdles (e.g., the infrastructures for different energy sources are usually not in the hands of a single energy supply company) or regulatory hurdles (e.g., spatial planning framework conditions) usually make it difficult to use them and reap the associated benefits for the overall systems.

The heating and mobility sectors are predestined for sector coupling, especially as renewable electrical energy can be used directly in these two areas. If the direct use of renewable electrical energy is not possible, hydrogen and its downstream products (e.g., synthetic methane) can represent a central element in sector coupling as flexible and storable energy carriers. However, these conversion steps are associated with losses and additional costs, meaning that direct use of the electricity is the primary option. The Energy Perspectives 2050+ show that electricity-based energy sources (synthetic liquid or gaseous fuels and hydrogen) are necessary to achieve the targets, but should only be used in areas where there are hardly any alternatives (e.g., international air traffic) for reasons of energy and cost efficiency.

With increasing decentralization and the diversity of players, the complexity of the energy system and thus its control and regulation requirements are growing. In addition to these technical aspects, spatial energy planning aspects also play an important role in countering complexity and making the best possible use of local/regional energy potential. Digitalization, which involves the integration of information and communication technologies, large and complex amounts of data and artificial intelligence, is also an important pioneering technology for the further development of the energy system. In doing so, it is important to harmonize the political design with technical developments and at the same time take into account the security of supply, affordability and sustainability of the energy supply, data protection and also social justice (the latter point is addressed in particular in the focus area "Economy, society and political measures") as central elements[34].

Storage

Furthermore, the issue of storage is inevitably linked to flexibilization. In addition to the further development of individual storage technologies, the focus here must be on their use in the overall system. The increasingly distributed and variable nature of energy supply and storage is creating new opportunities and challenges in terms of planning, operation, flexibility and additional services. In addition to short-term fluctuations in supply and demand, which can be solved with short-term storage and demand management, seasonal differences are more complex and require robust solutions with the help of seasonal storage and sector coupling. Efficient technologies for the recovery, conversion, storage and exchange of chemical, thermal and electrical energy are particularly important for industrial sites (see chapter "Industrial processes").

Transport, storage and use of CO_2 (CC(U)S)

The technologies for CO_2 capture and how they work in the plant context are dealt with in the "Industrial processes" chapter, while the provision of energy for the overall process, the use of CO_2 for other products or the planned future pipeline-based transportation are part of this chapter.

The further use of captured CO_2 can take place in a variety of ways, whereby the CO_2 can be regarded as temporarily or permanently stored depending on the longevity of the resulting products. The use of CO_2 e.g., for the production of synthetic fuels can be regarded as short-term temporary storage, while storage e.g., within building construction materials has a longer time horizon (biogenic building materials several decades, carbonated concrete permanently). CO_2-based fuels will play an important role in the energy sector in the future, as the energy can be stored chemically and the flexibility of electricity production can be supported.[35]

In addition, regulatory and social issues arise in this area that are relevant to energy policy and are part of the focus area "Economy, society and policy measures".

Renewable energies: technologies for flexibility and integration into energy systems

domestic electricity production[36]. The majority of this comes from the use of hydropower. The contribution from the use of solar energy, biomass, biogas, wind and waste amounted to around 8.3% of total electricity production. The renewable share of heat generation was around 25% in 2021. In general, there has been a significant increase in all technologies for both renewable electrical energy and renewable heat production over the last few decades. In addition to further and, above all, accelerated expansion through suitable framework conditions, research efforts are nevertheless needed to scale up new technologies and make them more sustainable and flexible to use, so that the existing infrastructure can be utilized more fully and expanded further if necessary. In addition to storage, new concepts of flexibilization also rely on optimized, combined production from different technologies (e.g., PV on reservoirs). In addition to the production and provision of the various forms of energy (electricity, heat, fuels), their combination will also play a central role in the future.

For an established technology such as *hydropower*, the focus is on increasing annual production and shifting generation to winter, a more detailed understanding of the effects of climate change (changing inflow regimes), compliance with regulations around the operational safety of dams (e.g., increasing sedimentation and consequences on storage and production) and related research topics. This takes place in a changing operating environment, e.g., due to volatile markets, increased environmental regulations, upcoming concession renewals, etc. Increased flexibility, more storage options (on all time scales) and hybridization of hydropower plants (e.g., with photovoltaics) are necessary to support or enable the increasing integration of uncontrollable or conditionally controllable renewable electrical energy generation.

In future *solar energy research*, the focus will be on improving the performance and reducing the costs of systems. The new products to be developed must be designed to be sustainable, reliable and cycle-oriented. Furthermore, quality assurance is an important aspect in order to increase the service life, reliability and also the performance of PV and solar thermal systems. The integration of photovoltaics in various applications such as in buildings, in vehicles or as an agro-photovoltaic system are central aspects of research. The integration of photovoltaics into the energy system forms a cross-sectional topic with other research areas. With regard to balancing feed-in and feed-out, precise generation forecasts in particular will play an increasingly important role in the future. In solar thermal energy, large solar collector arrays are the focus of future low-temperature applications in multi-family houses and heating networks.

Bioenergy is multifunctional with the production of electrical energy, heat, fuels, combustibles and chemicals. The wide variety of conversion technologies coupled with the use of different sustainable source materials and waste resources must be sensibly combined with other generation technologies (in terms of space and time) in the future. In addition, costs can be further reduced through optimized conversion processes and monetization of the resulting added value (services). Especially in the area of negative emission technologies (BECCS and the use of biochar), biomass can play a future role that should not be neglected.

Geoenergy will play an important role in the supply of electrical energy, heating and cooling in the future. In addition, seasonal underground heat storage can contribute to the efficient conversion and stabilization of the future energy system. To this end, research needs to understand and assess the geological subsurface, its geothermal potential and possible forms of development. Geoenergy research also addresses highly developed stimulation and drilling techniques. In addition to these technical aspects, issues relating to safety research, risk assessment and mitigation are important topics for the future use of this form of energy.

The use of *wind energy* is a market-ready technology that nevertheless requires research into issues specific to Switzerland. These include the design of turbines, issues relating to turbines in forested areas, generally improved production forecasts and the reduction of noise and icing. Another key question is the extent to which wind energy can sustainably reduce Switzerland's dependence on imports for electricity in winter.

Models and scenarios

The fundamental transformation of the energy supply in Switzerland is increasing complexity on both the production and consumption side, while security of supply must be guaranteed at all times. It is clear that this transformation requires flexible technologies that can efficiently convert, transport and store energy and make it available as quickly as possible when needed, on timescales ranging from seasonal to second-by-second. In order to map this as realistically and in as much detail as possible, models are needed that show how the ambitious goals can be achieved. Models are important tools for analyzing the influence of technological, economic and regulatory developments on the energy system of the future. By varying different assumptions within the models, scenarios are created that allow us to look into the future as realistically as possible under the given assumptions. In order to be able to answer the resulting open questions in politics, industry and society, it is necessary to compare or link different models or scenario approaches and to check their sensitivities on the basis of differently selected assumptions. The aim of the research is to obtain a digital image of Switzerland's energy system so that, in a next step, social and societal issues can be derived from it that have a positive influence on the transformation of the energy system. Research in this area should include not only questions on policy measures and social developments (both part of the focus area "Economy, society and policy measures") but also continuous benchmarking of the technical and economic progress of various technologies and their impact on the overall system (part of this chapter). Equally important is the question of how systemic risks in the future energy infrastructure can be minimized.

Nuclear energy and nuclear waste

Nuclear energy will continue to make a significant contribution to Swiss electricity production in the coming decades. Maintaining nuclear expertise is therefore essential for the safety of nuclear facilities. Regulatory safety research is concerned, among other things, with the question of how the safe long-term operation of plants can be ensured at the highest level. The focus here is on the ageing of materials and the effects of earthquakes on the structures, systems and components of nuclear facilities, as well as safety-related retrofitting, the introduction of accident-tolerant fuels and load-following operation, and the training of qualified personnel. Research covers the subsequent dismantling of nuclear facilities as well as the conditioning and disposal of radioactive waste, particularly with regard to a deep geological repository and the long-term interim storage of spent fuel elements. Minimizing the radiation exposure of the population and the environment is always of central importance.

Switzerland will continue to play a role in the development of technologies for safe, innovative reactors in the future so that it remains in a position to assess new technologies from other countries and draw appropriate conclusions for the national energy supply. In particular, new Generation IV reactor technologies and their fuel cycles must be examined for their nuclear safety, sustainability and waste reduction strategies. The involvement of research in international organizations such as EURATOM, the OECD's Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), but also in bilateral research cooperation, is of particular importance, as this is the only way Switzerland can safeguard its own interests when establishing international rules and guidelines on the nuclear safety and security regime.

34 – Gährs et al. (2021)

35 – CCS/NET SFOE research concept (www.bfe.admin.ch/bfe/de/home/forschung-und-cleantech/forschungsprogramme/ccus-net.html; German only)

36 – www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/energy-statistics/sector-statistics.html (in German)

PRIORITY RESEARCH TOPICS 2025–2028

Energy networks, system integration, sector coupling: control architecture of network infrastructure, technologies for sector coupling, future use of existing infrastructure, flexibility, integration and resilience of the system

- Power grids: planning & operation tools; integration of renewables » stability effects of grids; resilient protection & fault location systems; innovative materials & technology for grid components; system integration aspects;
- Thermal grids: demand forecasting, cooling technologies, DHC-system design and operation (potential & integration)
- Storage: pumped hydro (hybridization, small scale, retrofitting), compressed air (efficiency, cavern options), long-term storage (advanced concepts; catalytic chemical and electrochemical, CO_2-reduction, storable biofuels, H2-generation), batteries (material availability, manufacturing concepts, costs, recycling), heat storage (thermo-mechanical stability of solid phase, heat transfer degradation PCM, thermochemical storage, underground storage, swarm operations), short-term storage, V2G
- Flexibility vs. storage
- Efficient technologies for the recuperation, transformation, storage and exchange of chemical, thermal and electrical energy (aspects of sector coupling)
- Multi-energy networks to foster synergies and reduce the carbon footprint of heat and power at industrial sites with fluctuating energy sources and dynamic use patterns

Renewable Energy: technologies for flexibility, technology specific energy system integration

- Hydropower: regulatory compliance, shift generation to winter, operational safety research
- PV: performance enhancement & cost reduction; sustainable, reliable, circular; integration of PV (buildings, vehicles, Agro-PV)
- Solar thermal: big size solar collector arrays for future applications in multi family houses, industrial processes and thermal grids
- Bioenergy: Sustainable Feedstock &conversion technologies » energy related products & co-products; integration of bioenergy plants & sector coupling; energy storage & climate control technologies (BECCUS); society aspects
- Efficient and environmentally benign processes for the pre-processing of complex biomass to be used for materials and fuels
- Efficient and environmentally benign processes in the use phase of biobased or synthetic fuels (combustion, fuel cells, etc.)
- Sustainable production, reuse, recycling and disposal of batteries, fuel cells and catalysts at commercial scale
- Geoenergy: prospection, exploration, subsurface resources; safety
- Wind: plant layout, turbines in forests, forecasting, noise reduction, icing

Storage technologies

- Electricity: batteries; capacitors
- Mechanical storage: pumped hydro
- Chemical storage: advanced fuel, biofuels; fuels (liquid, gaseous, solar); solar fuels &materials (redox materials, heat & mass transport); photochemical approaches
- Thermal storage

Nuclear energy & radioactive waste

- NPP long-term operation **»** aging issues
- Impact of earthquakes
- Waste disposal
- Impacts of ionizing radiation on humans
- Advanced & innovative reactor concepts (international aspects, competences)
- Competence and knowledge retention

LIVING AND WORKING

The building stock of the future should produce zero net greenhouse gas emissions. It makes a decentralized contribution to the stable provision of heating, cooling or electricity in energy networks. Operation is energy-efficient and CO_2-free. Unavoidable greenhouse gas emissions from construction, renovation and demolition must be permanently stored. The research shows socially acceptable technological paths as well as social and political instruments for this.

In line with this vision, technologies and concepts that reduce energy requirements, increase the efficiency of energy conversion and use and take their value (exergy) into account are being researched in the *Living and Working* focus area. Overall, human needs in the area of living and working should be met in a climate-neutral, resource-conserving and socially acceptable way in the future.

In order to take account of the function of the building stock as an "energy hub", research is being conducted into decentralized energy storage, the local generation of renewable energy in buildings, areas, districts and cities as well as the interaction of energy consumption, decentralized energy generation, storage and energy infrastructures. Decentralized energy systems must be appropriately integrated into Switzerland's future energy system in order to ensure a climate-friendly, secure, efficient and economical energy supply.

Strategies to increase efficiency and systematically switch to renewable energy sources are key to achieving climate neutrality in the operation of buildings. The optimum extent of efficiency increases must be determined by considering the life cycle in terms of cost-benefit ratio. Additional efficiency measures should be assessed in comparison with the increased use of renewable energy. In addition to political and regulatory framework conditions, the efficient operation of buildings depends on the behavior of owners, operators and users. These have a significant influence on whether the opportunities for savings and efficiency can be exploited and the targets set can be achieved. Appropriate concepts need to be developed, validated (including "living labs" and "sandboxes") and demonstrated in practice.

New buildings should not generate any climate-damaging or environmentally harmful emissions during operation and should achieve a high level of comfort in terms of indoor climate, noise/acoustics, light and hygiene. Buildings and the materials used must be produced in a resource-conserving, low-emission and energy-efficient manner. In the long term, a net-zero balance of greenhouse gas emissions and a circular economy should be aimed for over the entire life cycle (construction, operation, dismantling and disposal).

In order to achieve this, technologies and concepts must be developed that enable the intelligent generation, conversion, use and storage of energy in buildings, taking into account interconnection and exchange options with supply networks (electrical, thermal). This includes both technological and socio-economic research in order to take user behavior and user needs into account. The knowledge gained must be made available in a suitable form for products and planning, consulting and implementation tools and, if necessary, for energy policy programs and instruments in order to diffuse effectively into the market.

The interfaces with the other key topics of this concept must be taken into account, such as the aspects of sector coupling, mobility and energy infrastructure or the influence of ICT and monitoring technologies on the use of decentrally generated renewable energy. There are further points of contact with social science and humanities research, particularly for the analysis of political measures and the behavior of stakeholders. In general, the differentiation from the other focal points of this concept is not made by avoiding thematic overlaps, but rather by focusing the topics in the focal point of living and working on the scope for action to be researched from this specific perspective.

Goals

Buildings are responsible for around 48% of final energy consumption[37] and 33% of Switzerland's total CO_2 emissions (or 26% of GHG emissions)[38]. They are therefore at the heart of ES2050. On the one hand, the energy renovation rate[39] must be urgently and substantially increased from the current level of just 1%; according to the EP2050+, an increase of 50% is conceivable "if the most successful cantons are followed and suitable energy policy instruments are used"[40]. At the same time, increasing renovation efficiency – with technical and non-technical measures – is another important lever for achieving the target. For both new buildings and renovations, the focus is on minimizing the grey emissions caused by the construction of buildings (mainly from building materials). In today's new buildings, these already account for several times the operating emissions[41].

The task of research is to identify socially acceptable technological paths and social and political instruments that lead in the direction of the vision formulated at the beginning. While the Climate Protection Act[42] sets a net-zero target and sectoral reduction paths for Switzerland's territorial emissions by 2050 – 82% reduction for the operation of buildings (Scopes 1 and 2) by 2040, 100% by 2050 – this is not regulated by law for the more comprehensive life cycle assessment of the building sector (including Scope 3 emissions), which extends well beyond 2050. Quantifiable GHG and energy targets over the life cycle of buildings are described in the SIA 390/1 "Climate pathway" standard[43]. The target formulations serve as benchmarks that should be significantly exceeded in pilot and demonstration projects.

In addition to the efficient use of energy, a decarbonized energy supply, a resource-conserving, low-emission and energy-efficient production of building materials – with the aim of a circular economy – as well as a social development that rewards sufficient behavior, contribute significantly to the achievement of the goals. Without anticipating these developments, the best possible conditions should be created in the building sector in order to achieve the aforementioned goals.

37 – SFOE overall energy statistics 2021, share of households + services in final consumption

37 – FOEN Development of greenhouse gas emissions in Switzerland, 2023, https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/greenhouse-gas-inventory.html

39 – Martin Jakob et al, 2014, Energy renovation rates in the building sector Synthesis report on the building envelope and heating systems, www.bfe.admin.ch/bfe/en/home/news-and-media/publications.html

40 – EP2050+, summary report chapter 2.3.1

41 – Source: Standard SIA 390/1, consultation version 2023.

42 – Draft law: www.fedlex.admin.ch/eli/fga/2022/2403/de

43 – Standard SIA 390/1, edition 2024.

PRIORITIES

Areas and neighborhoods

In order to cover Switzerland's future electrical and thermal energy requirements largely with locally available, renewable energy sources, holistic solutions are required. These should support security of supply in winter in particular. Neighbourhoods or areas can be developed into decentralized, networked energy systems and take over energy services within the respective neighbourhood/area (incl. electromobility) or for the associated region in the areas of supply, conversion, management, storage and distribution. They are not self-sufficient systems, but should be integrated as active elements in the energy system of Switzerland or Europe, as subsystems in the future energy system.

Research questions arise regarding the load and supply flexibility of an area or its individual buildings for the electrical or thermal grid, as well as the allocation of these flexibilities (in terms of location and time). Further research is also needed to ensure reliable and optimized interaction between electrical and thermal grids, buildings, local energy generation and feed-in, storage and distribution.

Existing sustainability strategies such as "Net-zero GHG emissions buildings[44]" or "Smart Cities and Communities[45]" are to be examined and further developed in the direction of climate neutrality at district level. To this end, concepts, processes, measures and framework conditions are to be analyzed, developed and tested. Of particular importance is the network[46] usefulness at the level of areas and districts and the derivation of resulting optimization premises for practice.

Building

A far-reaching reduction in the energy consumption and CO_2 emissions of existing buildings is a major economic challenge that requires the inclusion of various optimization measures on the building. From an economic point of view, however, it will not be possible to comprehensively upgrade the building stock by 2050 by renewing the building envelopes in terms of energy technology. Consequently, this increase in efficiency and the associated reduction in CO_2 must be achieved with further measures that enable a switch to CO_2- and fossil-free operation.

In order to exploit this potential, energy- and cost-efficient approaches, technologies and systems must be developed for building renovation. Innovative building elements must be developed for all building types (window systems and façade elements with improved and variable properties such as light transmission, heat input and storage, and energy generation). Research should also provide new environmentally and climate-friendly, cost-effective and space-saving thermal insulation solutions that meet architectural and aesthetic requirements.

For new buildings, the focus of research is on reducing energy requirements and greenhouse gas emissions to net zero over the entire life cycle of the building, including construction, operation, renovation, demolition, reuse and disposal at the end of life. The question "refurbishment or replacement?" is of central importance in order to make better use of the existing stock of materials in buildings. To answer this question holistically, basic principles and decision-making aids must be created at the building/plot level and in the overall economic context.

In general, buildings must be adapted to future comfort and space requirements, i.e. designed to be flexible in terms of use and therefore resource-efficient, to which new technologies and processes can contribute. Suitable key figures, strategies and instruments must be developed to minimize material flows. The aim is to achieve closed material cycles and increase recyclability in the direction of a circular economy.

Building technology

Today, buildings are not only energy consumers but also energy producers and provide renewable energy. This gives them a new role within the energy system. "Whereas previously they mainly consumed energy, they are gradually becoming an energy hub. They produce electricity and heat, they store energy, they become a filling station for our vehicles. In short, buildings are becoming an energy hub and thus contributing to the implementation of the Swiss government's Energy Strategy 2050."[47] The integration of local heat and electricity storage systems into the energy system is becoming increasingly important in order to achieve grid-friendly building behavior. While electricity storage systems in buildings are primarily used for the short-term storage of locally produced renewable energy, heat storage systems are suitable for storing energy on different time scales. By linking different sectors, seasonal heat storage systems can help to relieve the pressure on the electricity grid, especially in winter.

Which form of energy and storage technology is used in buildings will be determined across all sectors in the future, but is also heavily dependent on the application and the value of the energy. In any case, future-oriented technologies are just as important as efficient, reliable and cost-effective integration and operating concepts in a life cycle perspective. Particular attention should be paid to reducing electricity demand in winter through storage and local energy supply. Accordingly, the technologies for generating renewable energy (thermal and electrical) in buildings and for using waste heat are to be further developed and made even more economical.

Local energy supply systems should become "smarter": Solutions ranging from local monitoring to integration into higher-level energy management systems at building, district, area and city level Function monitoring and automated, standardized diagnostics or error messages to operators are currently lacking for widespread use.

Highly efficient heat pump technologies for space heating and domestic hot water heating are one of the prerequisites for covering the energy consumption of energy-efficient buildings with renewable energies. The opportunities and risks of tapping into and using the subsurface (including groundwater protection areas) with various energy production technologies, such as geothermal probe systems, groundwater wells, thermal water, etc. for heating and cooling at various levels (buildings, districts, cities) require in-depth investigation.

Due to the trend towards an increasing number of hot spells, it can be assumed that cooling requirements in buildings will increase in the future. As a result, cooling systems will need to be more controllable, which will also place greater demands on efficient operation in the partial load range. Due to local climate effects, residential buildings in urban areas are particularly affected. In order to prevent the uncontrolled use of inefficient devices that pollute the outdoor space, such as split air conditioning units, potentials, concepts and technologies for energy-efficient, resource-saving and cost-optimized passive and active cooling, including the integration of thermal storage (cold/warm) and the inclusion of sun protection systems, must be investigated.

Building technology plays an important role in the life cycle assessment of buildings. At the same time, only incomplete LCA data exists for technical building elements and systems. These are to be processed in a targeted manner and made available as directly applicable data sets.

Innovative ICT-based solutions for automation, measurement, control and regulation technologies must be developed to monitor and regulate the building's own energy consumption, i.e. to coordinate internal consumption and energy produced in the building with in-house technical and structural storage and cross-building networking. In particular, aspects of grid serviceability must be taken into account.

People, market, politics
In the focus area of *living and working*, the possibilities for accelerating the transformation of the building stock and increasing the renovation rate are to be researched. The acceptance of new technologies, concepts, processes and models by investors and users as well as ways of overcoming any obstacles should be discussed. The current dynamic regulatory developments in the EU and their repercussions for Switzerland (in particular the extension of the EPBD as part of the Green Deal) must also be taken into account.

On the other hand, the drivers and incentives that speak in favor of cross-sectoral energy networking (electricity, heat) on the part of homeowners and other stakeholders[48] must be analyzed. Furthermore, it is necessary to examine how the benefits and profits of networking are distributed and according to which criteria they should be distributed. At the level of the public sector, the development of regional approaches to the energy supply of buildings with the involvement of public goods should be investigated, e.g. for shallow geothermal energy (groundwater, EWS < 500m) and waste heat (MSWI, WWTP, industrial zones, etc.).

The implementation of renewable, decentralized energy network solutions for areas or districts with several owners and stakeholders is a complex challenge. Models for promising sponsorships and for (participative) acceptance-finding, procedural and decision-making processes during construction and operation are to be examined and evaluated. The results represent important boundary conditions for planning and consulting processes.

44 – Net-zero greenhouse gas emissions in the building sector - Issues F0_F1_F3_F4 and overall coordination KO - Texts (admin.ch)

45 – What is a smart city? (local-energy.swiss)

46 – Single or multiple electrical installations (generators, consumers or storages) which contribute to reduce grid costs (e.g. reduction of grid bottlenecks, grid expansion demand or optimized grid operation) are grid-saving. Source: What means grid-serving? - FfE

47 – EnFK, 2023, Homepage - Energiehub (energiehub-gebaeude.ch)

48 – An in-depth examination of the behavior of actors in the area of living and working and its influencing factors is addressed in the focus area "Energy, Economy, Society"

PRIORITY RESEARCH TOPICS 2025–2028

Areas and neighborhoods

- Reliability of energy systems with local renewable energy sources, as well as energy-efficient measures to increase security of supply, especially in winter
- Buildings and sites (incl. electromobility) as energy service providers: What load and supply flexibility can a building or site offer the electrical or thermal grid and at what price? Allocation of these flexibilities (building, site, neighborhood)?
- From building energy management to site/neighborhood energy management: concepts, planning, operation.
- Further development of existing sustainability strategies such as "net-zero GHG emissions buildings" or "smart cities and communities" towards climate neutrality at neighborhood level, as well as demonstration of these new approaches. Based on this, analyze, develop and test concepts, processes, measures, framework conditions and incentives.
- Investigation of the scope for action with regard to thermal networks from the perspective of buildings, areas and districts: typologies, storage, integration of renewables, innovative concepts for supplying heat consumers with high flow temperatures for space heating.

Building

- Energy- and cost-efficient systems for building renovation. New concepts, approaches and technologies, both for the building envelope and for energy-efficient refurbishment solutions that do not require external thermal insulation.
- Refurbishment or replacement building? Basic principles and decision-making aids for answering this question holistically at the building/plot level and in an overall economic context.
- Thermal insulation: New materials and constructions that are energy-efficient, environmentally friendly, cost-effective and space-saving.
- Minimizing material flows, LCA and increasing recyclability towards a circular economy

Building technology

Decentralized technology

- New cost-efficient heat storage technologies and materials (thermo-chemical, latent).
- LCA, of technical building elements and systems.
- New approaches for intelligent control and self-learning, automated operational optimization of building technology systems for flawless and efficient operation (incl. monitoring, fault diagnosis, maintenance notification, etc.).

Thermal and electrical use of local, renewable energy

- Smart solar/solar thermal systems (integration into energy management systems, function monitoring, automated error messages to installers, self-consumption control for hybrid systems)
- Reduction of electricity demand in winter through storage and local energy supply (solar, combined heat and power generation, avoidance through substitution of waste heat, geothermal energy, etc.)
- Efficient cooling, including resource-saving room cooling in urban areas, integration of thermal storage (cold/warm) Resource and cost-optimized solutions for active and passive building cooling

I*nformation and communication technologies (ICT)*

- innovative solutions with ICT for building automation, measurement, control and regulation technologies.

People, market, politics

- Investigate the possibilities (new approaches to incentives, standards, regulations) for accelerating the transformation of the building stock and increasing the renovation rate.
- Investigation of influencing factors, drivers and obstacles as well as possible incentives that encourage building owners to network and join an energy network (new participatory processes and business models for all stakeholders, including tenants)

MOBILITY

A diverse and integrated range of emission-free means of transportation enables efficient and socially acceptable mobility that takes all aspects of sustainability into account.

The mobility sector includes the transportation of people and goods using various means of transport. In Switzerland, transportation (excluding international aviation) is the largest source of greenhouse gas emissions with a share of 31%.[49] The transportation sector also takes the top spot in terms of energy consumption with a share of 32%.[50] Apart from a short-term, pandemic-related reduction in the years 2020–2022, consumption and emissions have only decreased slightly since 1990, and the previous reduction targets in the transport sector have clearly not been met.[51]

In the meantime, new drive technologies based on renewable energy sources have become established, above all electromobility. Thanks to the rapid transformation of the automotive industry and regulatory adjustments, it can now be expected that half of all cars in Switzerland will be electric by the middle of the next decade.[52] Even in heavy goods road transport, the electrification of drive systems seems to be gaining ground, with hydrogen/fuel cells and synthetic fuels providing further renewable alternatives. According to the IEA, electromobility alongside photovoltaics is the decisive technology for reducing emissions quickly and economically in the medium term.[53] With the emerging electrification of almost all road traffic, the domestic reduction targets are within reach. Aviation, ocean shipping and special applications (e.g. non-road, agricultural technology) are more difficult to electrify and will therefore remain, at least partially, dependent on chemical energy carriers in the future. New types of sustainable fuels that are obtained from biomass or generated using renewable electricity or heat are an option here.

Owing to significantly shorter investment cycles for vehicles compared to real estate and energy infrastructure, the decarbonization of land transport can progress rapidly. From a technical point of view, it must primarily be ensured that renewable energy is available to the appropriate extent. This requires significantly greater integration into the energy system, especially for electromobility. In an efficient system, the key technologies of photovoltaics and electromobility should complement each other ideally in terms of the temporal and spatial availability of energy, as well as with regard to convergent grid expansion and the optimal integration of renewable energies.

Mobility remains a basic human need and a prerequisite for a prosperous economy. Electromobility locally enables largely “emission-free” transportation - at least in terms of CO_2 and other exhaust gases. Noise emissions are also lower at low speeds. Other traffic-related externalities such as space requirements, strain on infrastructure and the effects of traffic jams remain unchanged. With a view to a sustainable, efficient and socially acceptable transportation system, further systemic transformations are therefore absolutely necessary. In Switzerland, the car will remain the most important mode of transportation for the foreseeable future.[54] Of all modes of transport, however, it is the most inefficient in terms of space requirements and energy consumption per passenger kilometer. With regard to greater energy efficiency and the reduction of transport-related externalities, the main focus is on avoiding traffic and shifting to more sustainable modes of transport. The rebound effects of electromobility and changes in work and leisure behavior pose major challenges for public transport. At the same time, the pandemic has led to a veritable boom in cycling in recent years. In addition to an increased awareness of sustainability and the joy of movement, the e-bike is a particularly strong driver of this development. More sustainable transport behavior with targeted promotion of active mobility[55] and the necessary infrastructure as well as increased use of public transport and micromobility can transform passenger transport more cost-effectively and sustainably than electromobility alone.

Interfaces to the other key topics of this concept arise via sector coupling and integration into the energy system, in particular electromobility as a flexible consumer and storage system. In addition, there is the influence of behavioral changes and regulatory adjustments. (See chapter "Energy systems and SSH)

Goals

Switzerland's long-term climate strategy sets net-zero greenhouse gas emissions as the target for 2050 for both land transportation and international aviation. The transformation of aviation is a global challenge and is also being tackled as such internationally. There is a broad consensus that operations must switch to 100% sustainable aviation fuels (SAF) in the medium term.[56]

With a few exceptions, land transport should no longer cause any greenhouse gas emissions. Several scenarios in the EP2050+ show how this goal can be achieved. The scenarios differ primarily in terms of the degree of electrification and the proportion of synthetic and biogenic fuels. However, it is already becoming apparent that electrification in road traffic will increase significantly faster than assumed in the EP2050+.[57] As early as 2035, a 60% share of electric vehicles is expected for passenger cars. This means that the electricity demand for electromobility will also increase to around 7 TWh by this time. The rapid expansion of the charging infrastructure and the comprehensive integration of electromobility into the energy system will become all the more urgent. Road traffic accounted for 97% of land transport emissions in 2021.[44] With the right measures, it will therefore be possible to reduce local emissions from land transport by more than half by the middle of the next decade.

The rapid progress of electrification poses a major challenge for the development of the charging infrastructure. Electric vehicles are flexible consumers with substantial storage capacity. Practical solutions are urgently needed to integrate electromobility into the energy system in a grid- and system-friendly and cost-efficient manner. The now massive use of batteries requires an even greater focus on their resource-efficient production, as well as secondary use and recycling. For the remaining applications that are difficult to electrify, climate-neutral alternatives, primarily based on biogenic and synthetic energy sources, must be developed in the medium term.

In a constantly changing world of living and working, mobility needs are also changing. Working from home in particular, but also other forms of digitalization and sustainable spatial planning, offer opportunities to avoid mobility. New mobility options and improved integration of multimodality should substantially increase the share of efficient and sustainable modes of transport such as rail, bus and micromobility, as well as active mobility. It is essential to consider other aspects of sustainability in addition to climate and efficiency targets.

49 – Greenhouse gas inventory of Switzerland, FOEN 2023: Greenhouse gas inventory of Switzerland (admin.ch)

50 – SFOE overall energy statistics 2021

51 – Switzerland's long-term climate strategy, FOEN 2021

52 – Understanding charging infrastructure 2050 - How will Switzerland charge in the future, SFOE 2023

53 – Net Zero by 2050: a roadmap for the global energy sector, IEA 2021: Net Zero by 2050 - Analysis - IEA

54 – Transport perspectives 2050, ARE 2021

55 – Active mobility here refers to walking and cycling.

56 – FOCA report on promoting the development and use of sustainable aviation fuels: Climate protection in aviation

57 – Understanding charging infrastructure 2050, SFOE 2023: Understanding charging infrastructure 2050 (laden-punkt.ch)

PRIORITIES

The extremely dynamic development of mobility in recent years and the rapidly changing framework conditions require increased flexibility and agility from researchers. The long-term goal of emission-free, sustainable and socially acceptable mobility must always be kept in mind. The rapidly advancing drive transition requires the rapid and adequate provision and distribution of the necessary energy. There is an urgent need for research and action here. At the same time, a holistic transformation of the transport system must be driven forward at a systemic level. The "avoid-shift-improve" principle for a holistic mobility strategy remains unchanged.

Energy supply and comprehensive system integration
The rapidly advancing electrification of road traffic must not be hindered by an inadequate charging infrastructure or energy supply. The increasing share of photovoltaics and other intermittent renewables requires greater flexibility from consumers. The bidirectional integration of electric vehicles into the electricity grid (vehicle-to-grid, V2G) enables flexible charging and feeding energy back into the grid. In terms of grid convergence, electromobility should be integrated in such a way that grid expansion can be minimized. In particular, this means that local, renewable energy is used for charging and part of the vehicle battery is also available for storage in order to increase self-consumption in buildings, areas and energy communities. Practicable and efficient technical solutions and functioning business models for this are still lacking.

Integrating electromobility into the grid and system should increase the overall stability and flexibility of the electricity grid and, thanks to intermediate storage, also enable the optimal integration of renewables, particularly photovoltaics. Privately owned vehicles are particularly suitable for V2G due to the short daily distances. However, this requires the vehicle to be connected to the grid as often as possible and a partial delegation of vehicle control to an external entity. This extension of the vehicle's use must be designed in such a way that it is attractive to vehicle owners. The charging management of commercial vehicles (trucks and buses) is much more demanding. Here, range and performance typically correspond to the usage profile. Charging strategies must be developed in such way that vehicle operation, battery capacity and energy availability are optimally coordinated. Batteries will play a central role in the future transportation system. Their production is responsible for a large proportion of the emissions associated with the manufacture of electric vehicles. More sustainable production and the reuse of batteries and components (2nd life, recycling) are essential for a resource-efficient circular economy.

Ultimately, the transformation of sectors that are difficult to electrify, in particular aviation and ocean shipping, but also special vehicles, must also be driven forward in order to achieve the emission targets. Hydrogen and its vector products (ammonia, methanol) as well as sustainable fuels on a synthetic or biogenic basis are considered particularly promising here. Their use is to be investigated from a technological, systemic and economic perspective.

Vehicle development and optimization
As electromobility reaches market maturity, its industrial development is also progressing rapidly. There is still a need for optimization, particularly in charging technologies, power electronics, battery storage and the consumption of auxiliary units, primarily air conditioning. In the context of urban mobility, there is certainly potential for new forms of efficient micromobility and for (partially) autonomous electric vehicles. In agriculture and the construction sector, there are numerous specific applications for which sustainable drive technologies need to be developed. In addition to direct electrification, the use of sustainable fuels should also be examined here.

The transport system as a whole

In a modern transportation system, different transport tools are available for both freight and passenger transport, depending on the purpose of the journey and the route. Such a complex system requires continuous holistic optimization with regard to important parameters such as emissions, energy consumption, accessibility, comfort and resilience. Changing transport demand and the availability of energy sources and means of transport must also be taken into account.

In passenger transportation, the car is still the most comfortable and fastest means of transport in many cases. Electromobility and increasing automation are making the car even more attractive. Due to the high external costs of private transport, a shift to more sustainable means of transportation is desirable from an ecological and social perspective. New business models and mobility services, in particular shared mobility and MaaS (Mobility as a Service), could increasingly represent attractive alternatives to car ownership. The comprehensive availability of mobility data enables the combined and efficient use of different modes of transport in terms of multimodal mobility. New forms of micromobility and the e-bike enable efficient access to the "last mile" and connections to mobility hubs. Social changes, in particular new flexible forms of work, but also changes in leisure behavior are influencing mobility behavior. The need for mobility can also be significantly influenced by spatial planning measures, such as the 15-minute city and "induced mobility".

Freight transport must also be taken into account in a holistic view, as it shares the transport infrastructure with passenger transport in many cases. A rapid electrification of road freight transport is emerging, particularly in Switzerland. Together with efficient urban logistics and new forms of unaccompanied combined transport involving rail, new multi- and intermodal approaches are emerging here. A clear basis for decision-making requires periodic evaluation of the effects of new technologies and holistic transport concepts in terms of their economic opportunities and ecological impact.

People, market and politics

The behavior of the players in passenger and freight transport is fundamentally different. Freight transport is strongly cost-driven and rationally controlled. Accordingly, the transformation here can be controlled by cost-efficient modes of transport and regulatory framework conditions (HVF, road pricing). New opportunities may arise in conjunction with new technologies, in particular (partially) autonomous vehicles and the changing transportation system as a whole. In freight transport, the high investment costs and sometimes long life cycles must be taken into account.

In contrast to freight transport, individuals only act rationally to a limited extent in passenger transport. A detailed understanding of individual needs and changing mobility behavior is essential in order to guide decisions regarding the choice of means of transport towards sustainable mobility. Social trends and ongoing urbanization must also be taken into account. Electromobility and the emergence of autonomous driving harbor great potential for rebound effects. These need to be identified at an early stage and, if necessary, countered with suitable measures. The erosion of the mineral oil tax requires a fundamental refinancing of the transport infrastructure, for example in the direction of "road or mobility pricing". In public transport, too, demand should be better distributed and the high investment and operating costs offset by means of suitable tariff systems. There is a need for research into the acceptance and impact of such regulatory measures, also in connection with the creation of new incentives.

With regard to the integration of electromobility as flexible storage in the energy market, it must be investigated whether adjustments to regulation or market design are necessary to make new, sustainable business models profitable.

PRIORITY RESEARCH TOPICS 2025–2028

Energy supply, conversion, consumption and system integration

- Optimal use/integration of renewable energy sources
- Flexible and efficient system integration of mobility
- Charging infrastructure, bidirectional charging, use of flexibility and storage
- Requirements for grid expansion – grid convergence
- Sustainability of raw materials and resources for mobility, circular economy
- Increased efficiency of the drive and energy distribution/storage
- Increased efficiency of auxiliary units and other components, aerodynamics and weight reduction
- Sustainable, biogenic and synthetic fuels: production, use.

Mobility system: concepts, analyses

- Influence of new technologies and offerings in the overall system
- Modeling/optimization of the overall system, taking into account the availability of various energy sources and other resources
- Increasing the attractiveness of sustainable means of transport: active mobility and public transport, and prioritizing them in spatial planning
- Efficient logistics: new concepts, intermodal and multimodal freight transport
- Holistic and comprehensive assessment of the transportation system, as well as various transport and energy sources, both techno-economically and in terms of sustainability and social acceptance.

People, market and politics

- Understanding individual mobility needs, mobility behavior and choice of means of transport
- Interaction with changing mobility options and expansion of infrastructure (rebound effects)
- Mobility pricing, dynamic tariffs: Acceptance, incentives, opportunities, impacts and costs.

INDUSTRIAL PROCESSES

"Industrial processes will become pillars of a circular economy where products and services leave no energy, materials and emissions footprints throughout their entire life cycle. Research enables the development of innovative process technologies and intelligent management practices that advance industrial resource efficiency to a level where the remaining energy demand is covered from renewable sources and Switzerland's net-zero climate target[58] is achieved."

Climate protection

Switzerland's long-term climate strategy sets an ambitious target for the industrial sector: its GHG emissions are to be reduced by 90% by 2050 compared to the reference value of 13.6 million tons of CO_2 equivalents (Mt CO_2eq) from 1990. In the referendum on the "Climate and Innovation Act" (i.e. the indirect counter-proposal to the Glacier Initiative) on June 18, 2023, Swiss voters confirmed these targets and demanded that all companies have net-zero emissions by 2050. To this end, the law provides financial incentives to companies that are early adopters of innovative technologies and processes. Simultaneously, it obliges the federal government to hedge the risks associated with investments in public infrastructure required to achieve the net-zero target.

The pressure to act is enormous, as the most recently reported figures from 2021[59] are still a long way from this target: in 2021, the sector emitted 10.7 Mt CO_2eq, which corresponded to 23.6% of total Swiss GHG emissions. Of this, 2.9 Mt CO_2eq were attributable to waste incineration, the rest to industrial plants and, to a lesser extent, to industrial and construction machinery. At 73%, the majority of industrial GHG emissions were attributable to fossil fuels.

Here, energy efficiency and the use of renewable energy are key levers for reducing GHG emissions. However, these approaches are not effective for process-related CO_2 emissions, which are inevitably released in chemical reactions such as cement production. At large industrial point sources, the direct capture of CO_2 for further use or long-term storage (carbon capture and utilization or storage, CCUS) is required. Due to the high cost of capture and the limited capacity for CO_2 storage, these technical approaches must be reserved for GHG emissions that are difficult to avoid. Where they are not an option, nature-based negative emission technologies (NET) remain the last option for offsetting the remaining GHG emissions.

Circular economy

In the circular economy[60], products and materials are kept in circulation in order to minimize environmental impacts and the consumption of limited primary raw materials. The hierarchy of principles often summarized as the "10 Rs" serves as a guide: "Refuse - Rethink – Reduce" for efficiency in product design and manufacture, "Reuse - Repair – Refurbish - Remanufacture - Repurpose" to extend the service life of products and "Recycle – Recover" for material or energy reuse at the end of a product's life.

As a rule of thumb, measures to increase resource efficiency also have a positive impact on energy efficiency, as smaller quantities of materials have to be processed, transported and stored. When closing material cycles, it is important that the effort associated with recycling is lower than the effort that comes with producing from virgin materials. The circular economy also includes the use of renewable energy. Energy should be used as efficiently as possible, since the provision of renewable energy also consumes natural resources. The same applies to the provision of renewable raw materials or CO_2 from separation plants. Ultimately, it takes holistic life cycle assessments to identify the most beneficial options for product design, production, use and disposal.

58 – www.bafu.admin.ch/dam/bafu/de/dokumente/klima/fachinfo-daten/langfristige-klimastrategie-der-schweiz.pdf.download.pdf/Langfristige%20Klimastrategie%20der%20Schweiz.pdf

59 – https://www.bafu.admin.ch/bafu/de/home/themen/klima/zustand/daten/treibhausgasinventar.html

60 – https://circular-economy-switzerland.ch/wp-content/uploads/2022/11/Nachhaltige-Kreislaufwirtschaft-als-Schluessel-element-zu-Netto-Null.pdf

PRIORITIES

The Energy Perspectives 2050+[61] describe transformation paths towards the net-zero target of the long-term climate strategy with technologies that are already known today. Further innovations should make the transition faster, more efficient and more socially acceptable.

The transformation to a climate-friendly circular economy offers industry promising opportunities with new products, new business models and new markets. The success of manufacturing companies stands and falls with a secure energy supply and resilient supply chains. Long planning cycles and high investment costs in industry require stable, predictable framework conditions. In the "Economy, society and policy measures" chapter, research priorities are formulated for entrepreneurial decisions, the design of adequate framework conditions for innovation and investment, and the effects of energy and climate policy on competitiveness, whereas the following sections of this chapter focus on technology innovations. The order of the sections reflects the hierarchy of measures: efficiency before substitution before NET technologies.

Efficiency

The circular economy with its requirements for economical consumption and durable goods offers a wide range of benefits: Savings in energy, materials, operating costs, environmental impact, etc. and can be realized at all levels of industrial systems: Systems, devices and their components as well as process steps, production lines, locations and supply chains. So far, the efficiency potential of industrial processes is far from exhausted. What is needed are disruptive innovations for novel processes as well as pragmatic, easy-to-implement solutions for retrofitting existing processes.

Substitution

The remaining energy demand after efficiency improvements should be covered from renewable sources. Industrial companies can contribute to renewable energy production with photovoltaics, solar thermal energy, geothermal energy or bioenergy with combined heat and power generation at their own site. The electrification of heating and cooling by means of heat pumps allows the provision of process heat of up to 200 °C from waste heat or ambient heat. However, there is still little experience with the integration of fluctuating renewable heat sources in production processes. In addition, upcoming restrictions on the use of synthetic refrigerants require new solutions. Innovative energy storage technologies and alternative process routes at lower temperature levels are needed to further expand the use range of renewable heat sources.

Fossil-free fuels from biomass or synthetic gases are scarce and valuable. They should therefore only be used very purposefully where there are no practicable alternatives. Accordingly, they should be reserved for high-temperature processes in the industrial sector that are difficult to electrify. Leaps of innovation are still required to advance the sustainability, cost-effectiveness and availability of these chemical energy carriers to a point where they can replace their fossil predecessors as fuels and feedstocks on an industrial scale.

Depending on the fossil, geogenic or biogenic origin of the CO_2 molecules, CO_2 capture directly at the industrial site offers the possibility of reducing GHG emissions in the atmosphere, if not even generating negative GHG emissions. However, today's processes to capture CO_2 at point sources or from the atmosphere require high energy and financial expenditures. Significant improvements in this area would have a positive impact on GHG savings in the entire energy system.

Because the formation of new molecules from the captured CO_2 is thermodynamically unfavorable, disruptive innovations are needed to increase the yield and productivity of these conversions to the point of economic feasibility. Other CCU processes, such as the accelerated mineralization (carbonation) of building materials, also require innovation to improve their competitiveness versus conventional products with a higher GHG footprint. There is similar competitive pressure in terms of quality, price and sustainability for bio-based materials and secondary raw materials from recycling processes.

Flexibility
Whenever energy sources or materials are substituted, supply chains must be restructured. To ensure the smooth operation of industrial processes even in a circular economy with renewable energy and secondary raw materials from smaller, decentralized plants, the new supply chains must be able to deal with variable energy supplies and fluctuating quality of input materials. This results in challenging tasks not only in logistics and procurement, but also in technology development for industrial plants and infrastructures.

The "Energy systems" chapter describes solutions based on sector coupling. In industry, the linking of electricity, heating and cooling is particularly necessary. In these areas, industrial processes can act as both consumers and producers. In order for them to play this "prosumer" role in a way that benefits the system, large storage systems with high charging and discharging capacities as well as intelligent concepts for controlling industrial energy consumption while ensuring production reliability will be prerequisites. A further degree of freedom in balancing production, consumption and storage arises when chemical energy carriers (e.g. hydrogen H2, methane CH4, methanol CH3OH, ammonia NH3) also serve as raw materials for the chemical and pharmaceutical industry, which is of great importance in Switzerland.

Integration
Synergies from the intelligent integration of industrial processes can arise at every level of the energy system. At the same time, however, the additional complexity associated with integration also creates new chal-

lenges. Models, analyses, simulations and scenarios at the various system levels should help to explain the interrelationships and identify synergies and risks more clearly.

Process integration aims at the economically viable exchange and cascading use of material and energy flows and is therefore a key prerequisite for the circular economy. Research should create the scientific basis for the technologies and instruments that are required for the development, management and operation of highly integrated industrial systems. It is important to keep the bigger picture in mind, especially to prevent that scarce and sought-after resources such as domestic biomass or temporary surpluses from photovoltaic production are allocated more than once.

Industrial symbiosis concepts at site level are intended to identify synergies from the networking of processes, the coupling of materials and waste management and the local use of renewable energy resources. Biorefineries for the co-production of materials, fuels, heat, electricity and negative emissions are a prime example of this approach. Whether and to what extent symbiosis can be extended beyond the immediate industrial cluster will depend heavily on access to CCUS and multi-energy infrastructures. Therefore, industrial symbiosis models should be designed in a way that they can also be used in the planning of new infrastructures such as grids and storage for CO_2, hydrogen or other chemical energy carriers.

Due to the long investment cycles in industry, prudent planning is essential. Models and scenarios from the energy system level down to individual industrial processes can provide valuable decision-making support for companies and stakeholders alike. Digitalization offers great opportunities for data-based planning, monitoring, control and optimization of industrial value chains. The earlier such methods are integrated into innovation processes, the more targeted technical developments can be aligned with criteria of performance and all dimensions of sustainability.

61 – https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html

PRIORITY RESEARCH TOPICS 2025–2028

Materials and products in closed resource loops

- Materials and product design for extended lifetime and integrated end-of-life management
- Efficient processes to refurbish or remanufacture products, recycle materials and treat residual waste at the appropriate scale
- Substitution of fossil raw materials with bio-based or recycled materials;
- Sustainable carbon capture, utilization (CCU) processes to close the carbon cycle
- Approaches for equipment and product management in line with the principles of the circular economy
- Barriers and opportunities for the introduction of resource-efficient products

Innovative, optimized production processes

- Process intensification for the more efficient use of energy and other resources
- Advanced separation processes with high yield and selectivity at minimal energy consumption
- Electrification of process heat, especially via flexible high temperature heat pumps with natural refrigerants
- Flexible process designs to accommodate the variability and heterogeneity of material inputs from a circular economy
- Integration of fluctuating renewable energy sources with storage at process and site level
- Monitoring, control and optimization for efficiency, flexibility and resilience in highly integrated processes
- Solutions to overcome persistent barriers to energy optimized production planning and operations
- Pragmatic solutions to retrofit production plants, apparatuses and components for improved energy efficiency and longer life times

Systems perspectives in planning and development

- Industrial symbiosis to reduce and flexibilize energy demand and create business opportunities from the local exchange of heat, power, material resources and equipment;
- Integration of predictive LCA methods into product design and process development to promote energy and resource efficiency throughout the entire product life cycle;
- Generic process models and virtual production plants for holistic scenario analyses in early development and planning stages;
- Multi-criteria optimization methods to accelerate the development of processes with improved performance in all aspects of sustainability;
- Science-based design and optimization methods with the capability to assess the performance of integrated process networks at site and supply chain level;
- Practical tools to develop and compare transformation paths towards net-zero targets at plant and site level

PRINCIPLES OF ENERGY RESEARCH

Application-oriented research should be promoted primarily in the field of energy. Priority should be given to research areas that are expected to generate high added value for Switzerland and make a sustainable contribution to national security of supply. Energy research should thus make a significant contribution to the implementation of the national Energy Strategy 2050, the sustainability strategy (see p. 48) and compliance with climate targets. A holistic approach should also be taken when researching specific issues and the solution approach should be measured against the contribution to the energy system and the aforementioned goals. This concept also contains recommendations for energy research that is not directly related to these goals. The prerequisite for this is the high quality of research, which must be internationally integrated and competitive. The strong commitment of the public sector to networking research institutions, identifying important future technology areas, promoting international scientific cooperation and cooperation between universities and industry is central to the implementation of research results and should be continued. Efficient and targeted implementation is promoted by business-friendly regulation of intellectual property developed with public funding, such as patents or licenses.

Unrestricted access to publications and data
Efforts to date to make all publications that have been financed in whole or in part with public funding freely accessible should be further strengthened. The SNSF's exemplary open access strategy can serve as a guideline for other funding bodies, as it also ensures access to publications in journals. Free access to data for researchers is far more difficult to achieve than access to publications. Here, CORE encourages a discussion between data collectors and researchers. The aim is to find the best possible compromise between the necessary data protection and the desirable free availability of data. In general, CORE recommends supporting the collection of good and previously unsystematic data; long-term data series of more than 30 years are particularly valuable.

Coordination between the funding organizations

Good coordination between the various funding institutions in Switzerland increases their effectiveness. An improvement was recommended in the last in-depth review of Switzerland by the IEA[62]. Early, mutual information between the funding agencies is also provided for in the Federal Act on the Promotion of Research and Innovation RIPA[63] (see also p. 45). This is particularly important for planned calls for proposals.

Sustainability strategy

In its Sustainable Development Strategy 2030 (SDS 2030[64]), the Federal Council outlines the priorities it intends to set for the implementation of the "2030 Agenda for Sustainable Development" over the next ten years and has defined three priorities:

- **1.** sustainable consumption and production: promoting and enabling sustainable consumption patterns, ensuring prosperity and well-being while conserving natural resources, driving forward the transformation towards sustainable food systems at home and abroad, strengthening corporate responsibility at home and abroad.

- **2.** climate, energy and biodiversity: reducing greenhouse gas emissions and managing climate-related impacts, reducing energy consumption, using energy more efficiently and expanding renewable energies, conserving, sustainably using, promoting and restoring biodiversity.

- **3.** equal opportunities and social cohesion: promoting the self-determination of each and every individual, ensuring social cohesion, guaranteeing real equality between women and men.

All three priorities relate to energy research, most directly to the second priority. The SDS 2030 sets out in more detail the interactions and mutual influences between the areas of climate, energy and biodiversity and calls for the transparent handling of conflicting objectives; this is precisely where energy research can make a decisive contribution:

Resources: New and improved technologies and findings to increase energy and resource efficiency and the increased use of renewable energy are key elements of energy research. Production cycles should be closed as far as possible, harmful emissions avoided and a circular economy pursued.

Energy infrastructures: Develop assessments of the design, necessary incentives and possible obstacles to investment in new energy infrastructure (energy generation from renewable sources only). Develop strategies to increase the attractiveness of such investments to help optimize them towards sustainability.

Technology: For all technical solutions that serve to provide, convert, store and use energy, the greatest possible sustainable - ecological, economic, social - approximation to the respective technical potential is sought.

Economy and national economy: The energy research concept aims to maintain, improve and secure Switzerland's security of supply in the long term, to generate added value for the country in the form of jobs, know-how or new marketable products and to maintain and increase Switzerland's international competitiveness and maintain its value for cooperation.

Society: Questions on societal needs and policy measures that enable a transformation of the energy sector are to be answered. For example, sociological, psychological and political issues relating to energy supply, conversion, storage and use are examined. Last but not least, energy research should contribute to the understanding that neither a national energy policy nor a global climate policy can be implemented with technical measures alone. In the interest of sustainable energy use, behavioral changes are required.

62 – https://www.iea.org/reports/switzerland-2023

63 – SR 420.1 - Federal Act of December 14, 2012 on the Promotion of Research and Innovation (RIPA) (admin.ch)

64 – https://www.eda.admin.ch/agenda2030/de/home/strategie/strategie-nachhaltige-entwicklung.html

IMPLEMENTATION IN THE SFOE

RESEARCH PROGRAMS

The SFOE's research programs are grouped into three areas: "Energy efficiency", "Renewable energy" and "Humanities and social science issues". Other SFOE funding instruments are the Pilot and Demonstration Program (see p. 50) and the SWEET research funding instrument (see p. 50). SFOE funding is based on the "Principles of energy research" and the implementation directive[65].

«Efficiency»
— Buildings and cities
— Mobility
— Electricity technologies
— Grids
— Heat pumps and refrigeration technology
— Combustion-based energy systems
— Fuel cells
— Industrial processes
— Batteries

«Renewable energies»
— Solar heat and heat storage
— Photovoltaics
— Solar high-temperature energy
— Hydrogen
— Bioenergy
— Hydropower
— Geoenergy
— Wind energy
— Dam safety

«Society and economy»
— Energy - Economy - Society (EES)

Detailed information on the individual research programs and the respective research priorities, which are based on this concept, can be found on the SFOE website6. The relevant contact persons are also listed there.

All criteria for funding can be found in the implementation instructions at www.energieforschung.ch

65 – https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/research-and-cleantech.html

Pilot and demonstration projects
The testing of technical innovations or new business models under real conditions through pilot and demonstration projects (P+D), but also field studies, are essential in order to successfully bring them from the laboratory to the market and to obtain information on their feasibility, technical functionality, applicability or economic viability. Particularly in the case of long and costly technical developments in the energy sector, private investment in this crucial phase is limited as it is based on strict performance criteria. This brings the development of many technologies to a standstill. The P+D program closes this gap by providing subsidiary support and can thus facilitate investment decisions by the private sector.

The programme covers the entire spectrum of energy technologies: the use of renewable energy, energy efficiency, storage technologies or optimizing national electricity grids. P+D projects are characterized by a substantial innovation content and a high energy and market potential.

Sandbox
The SFOE has now made research in "sandboxes" possible: within a regulated framework, projects can be approved that partially deviate from the applicable legal framework (limited in terms of time and location). Only Art. 6, Art. 8 and Art. 10 - 20a. StromVG. may be deviated from. Applications can be submitted to the SFOE using the usual application form, which has been expanded to include "sandboxes". After a positive assessment, the sandbox is regulated in an ad hoc ordinance. Approval for a "sandbox" does not a priori include any financial support. If financial assistance is required, this must also be applied for via an existing funding instrument.

SWEET/ER
SWEET – *"SWiss Energy research for the Energy Transition"* – aims to promote innovations that contribute significantly to the successful implementation of the Energy Strategy 2050 and the achievement of Switzerland's climate targets. SWEET is essentially based on the existing rules of departmental research. While the SFOE's research programs are designed to support individual projects across the entire spectrum of energy efficiency and renewable energy, SWEET exclusively promotes consortium projects in competitive calls for proposals and on selected research topics. Preference is given to cooperation between different types of universities and between academia, research institutions, the private sector, the public sector and companies close to the federal government (SBB, Swiss Post, etc.). The aim is to promote inter- and transdisciplinary consortia. Special attention is paid to energy research in the humanities and social sciences.

In June 2023, the Federal Council opened the consultation on an additional commitment credit for the current SWEET research funding instrument. This is intended to expand SWEET to SWEETER (SWiss research for the EnErgy Transition and Emissions Reduction) and intensify cooperation with the Federal Office for the Environment. SWEETER is intended to provide rapid and targeted answers to new, urgent questions regarding Switzerland's energy supply security, particularly in relation to the summer-winter issue (storage), as well as the decarbonization of the economy. Financing for the years 2025 to 2036 is to be provided via an additional commitment credit of 135 million. The additional credit is expected to be used to finance eight further calls for proposals on topics such as energy storage and grids, underground energy generation and storage, spatial planning, digitalization and smart grids, local energy markets and grid convergence, the circular economy and industrial processes, smart cities and social innovations. The consultation process was completed in September 2023. The bill is expected to go before parliament in spring 2024.

Further and up-to-date information can be found at www.bfe.admin.ch/sweet.

Research in the field of nuclear energy

One area that requires particular attention is that of specialists in the field of nuclear energy. Switzerland needs young professionals not only for the remaining lifetime of the Swiss nuclear power plants, but also for the post-operational phase, the dismantling phase and the planned storage - well into the next century. In addition, the expertise needed to assess developments in the field of nuclear technology must be retained. In order to train these specialists and secure their expertise in the long term, the corresponding research in the nuclear sector is still necessary and should be promoted. However, the SFOE does not run its own research programs in the field of nuclear energy, but it does support selective research activities that serve to promote international cooperation in the field of nuclear safety and the maintenance of expertise (e.g. IAEA or OECD) and those that involve the monitoring of advanced nuclear technologies abroad. Research activities in the field of nuclear fission are carried out by the Paul Scherrer Institute (PSI) and the ETHZ, those in the field of fusion by the EPFL and regulatory safety research by the Swiss Federal Nuclear Safety Inspectorate (ENSI). Information on the relevant research can be obtained from the responsible bodies:

- Fusion: EPFL, Swiss Plasma Center (SPC), www.epfl.ch/research/domains/swiss-plasma-center/
- Nuclear technology and nuclear safety:
  » Paul-Scherrer-Institute (PSI), www.psi.ch/nes
  » ETH Zurich, «nuclear engineering»
- Regulatory safety research: Swiss Federal Nuclear Safety Inspectorate (ENSI), www.ensi.ch/de/sicherheitsforschung/

FINANCING

EXPENDITURE BY THE PUBLIC SECTOR

From 2005 to 2020, public funding for energy research increased continuously, as shown in Figure 2. Since 2014 in particular, there has been a significant increase as part of the Energy Strategy 2050 and the "Coordinated Energy Research Switzerland" action plan. The development and establishment of the national competence centers in energy research (SCCER) by Innosuisse, new national research programs in the energy sector (NRP 70 and 71, NRP Energy) of the Swiss National Science Foundation and a targeted expansion of the SFOE's pilot, demonstration and lighthouse projects contributed significantly to the expansion. The decline compared to previous years is due to the expiry of the energy funding program (SCCER): The ETH Domain and Innosuisse therefore contributed less to energy research in Switzerland; the NRP Energy expired in 2020. As the SWEET funding program and the energy-oriented Flagship calls for proposals are less endowed than the previous Energy funding program, it is unlikely that the decline can be fully compensated for in the future.

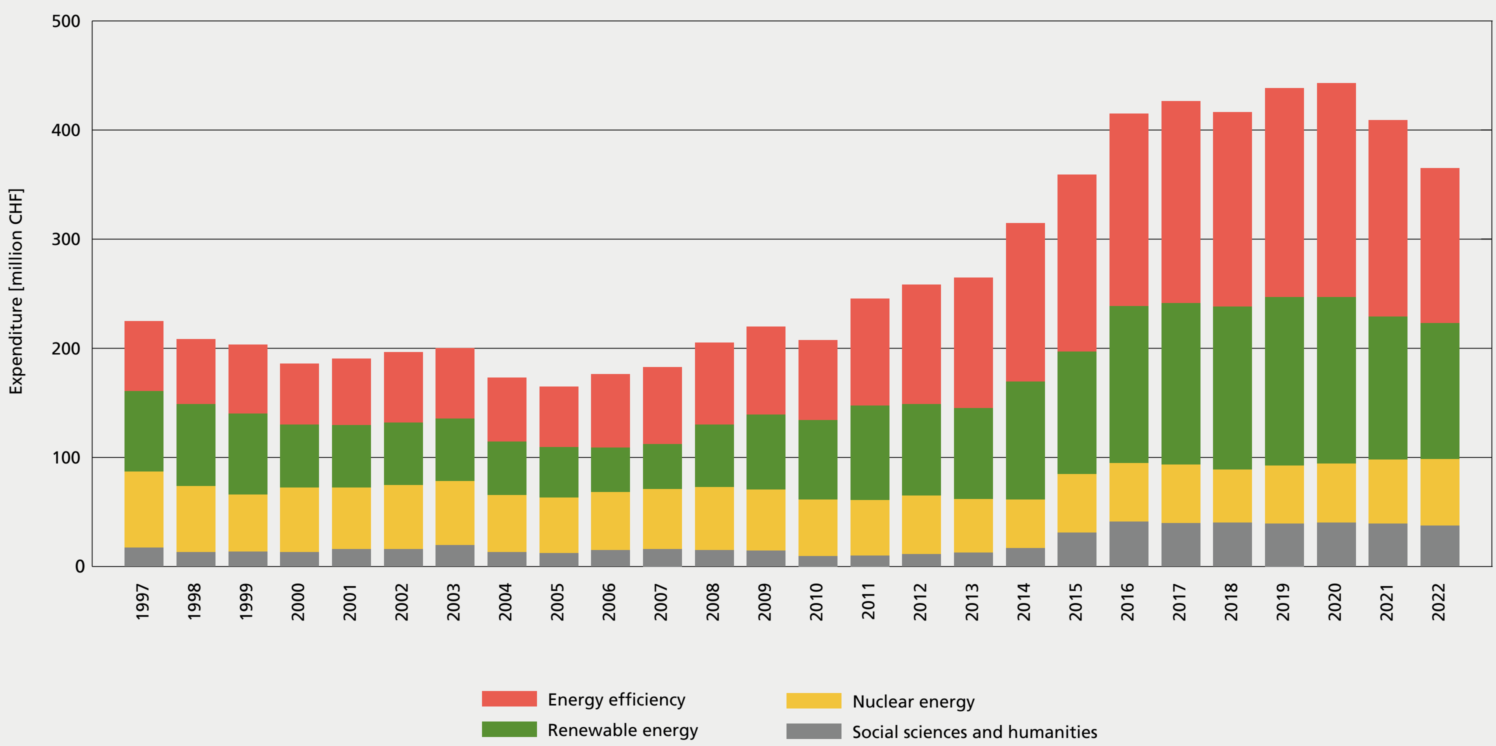

Figure 2: Development of public funding for energy research. (Source: SFOE, without inflation correction)

RESOURCES OF THE SFOE

Planned funds 2025 to 2028
Table 1 shows the budgets planned for the SFOE's research, pilot and demonstration projects for the period 2025–2028, as well as for the SWEET funding program. The figures are assumptions and not budgeted funds. The budgets for the individual years must be approved by the councils.

	2025	2026	2027	2028**
Pilot and demonstration projects	22'884'400	23'344'200	23'571'500	
Research programs	17'752'400	17'744'900	18'076'300	
SWEET funding program	17'784'000	19'760'000	19'760'000	
Coordination*	2'644'000	2'634'000	2'689'000	
Total	**61'064'800**	**63'483'100**	**64'096'800**	

Table 1: Budgets planned by the SFOE for the period 2025–2027
This is based on the 2025-2028 financial plan, which must be approved by the councils.
** Including external management of research programs and experts SWEET*
*** no planned budgets are available yet*

Funds deployed 2021 to 2024
Table 2 shows the budgets set for the 2021-2024 period for SFOE research, pilot and demonstration projects, as well as for the SWEET funding program. 2021 and 2022 are "actual values"; the budget for 2024 still requires the approval of the Councils. The figures for 2023 and 2024 are assumptions and not budgeted funds. The budgets for the individual years must be approved by the councils.

	2021	2022	2023	2024
Pilot and demonstration projects	13'253'035	14'109'547	20'272'400	17'500'000
Research programs	25'491'054	17'757'400	17'783'800	17'916'000
SWEET funding program	9'940'000	7'783'810	13'832'000	13'832'000
Coordination*	2'087'879	2'028'379	2'444'000	2'178'500
Total	**50'771'968**	**41'679'136**	**54'332'200**	**55'035'600**

Table 2: Budgets 2021 and 2022 used by the SFOE, budget set for 2023 and budget according to the 2024 estimate.
** Including external management of research programs and experts SWEET*

PLAYERS AND INTERFACES

The broad scope of energy research gives rise to a variety of thematic and organizational interfaces. One of the SFOE's central tasks is to network the national players within Switzerland and with the international research community. To this end, the SFOE has built up an extensive network of contacts over the last few decades, encompassing the entire university sector as well as private research institutions. All SFOE-funded research projects are supervised by the heads of the SFOE's research programs, which ensures an intensive exchange of knowledge with the most important players in the Swiss research community. The SFOE represents Switzerland in all committees of the International Energy Agency (IEA) that are relevant to energy research.

NATIONAL PLAYERS AND INTERFACES

The following overview provides a simplified overview of the energy research landscape in Switzerland.

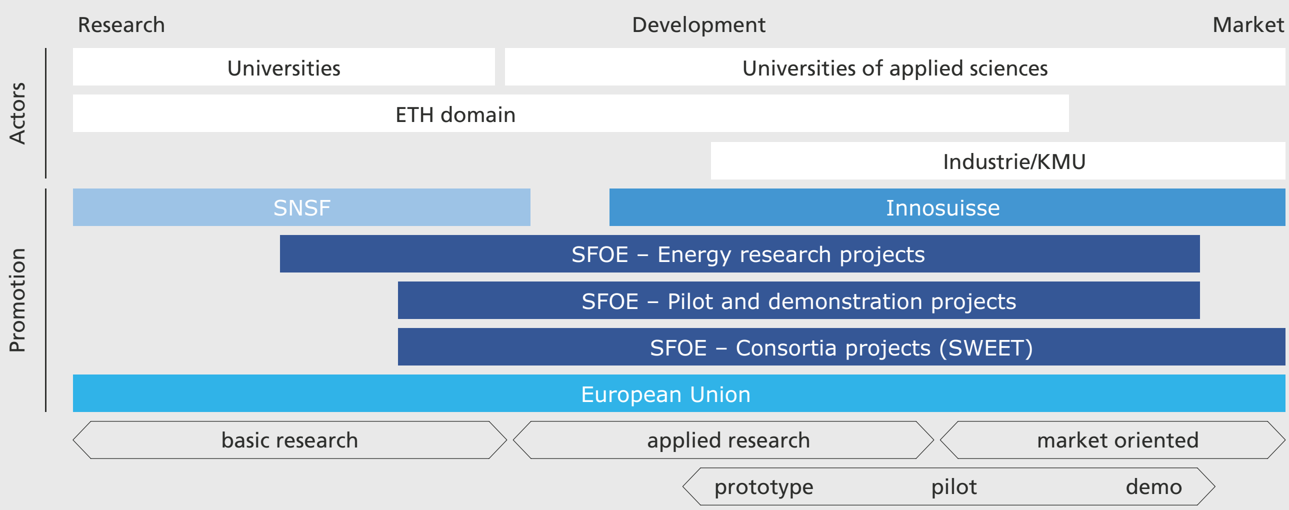

Figure 3: There are thematic interfaces with Innosuisse and the SNSF, especially if these organizations call for tenders for programmes or projects in the field of energy research.

In the case of private organizations, the contacts cover both large companies with pronounced research activities of their own, such as ABB or IBM, as well as a large number of innovative SMEs such as Indeotec or Awtec, through to start-ups and engineering firms. There are also collaborations with partners that have great multiplication potential, such as Swiss Post, SBB or electricity supply companies such as Axpo, BKW and various municipal utilities.

INTERFACES TO RESEARCH FUNDING INSTITUTIONS

Through its research programs, the SFOE's energy research is closely networked with all research institutes at Swiss universities that are involved in energy research. The following map, which is updated in the annual report "Energy Research and Innovation" (see: www.energieforschung.ch), provides a good overview.

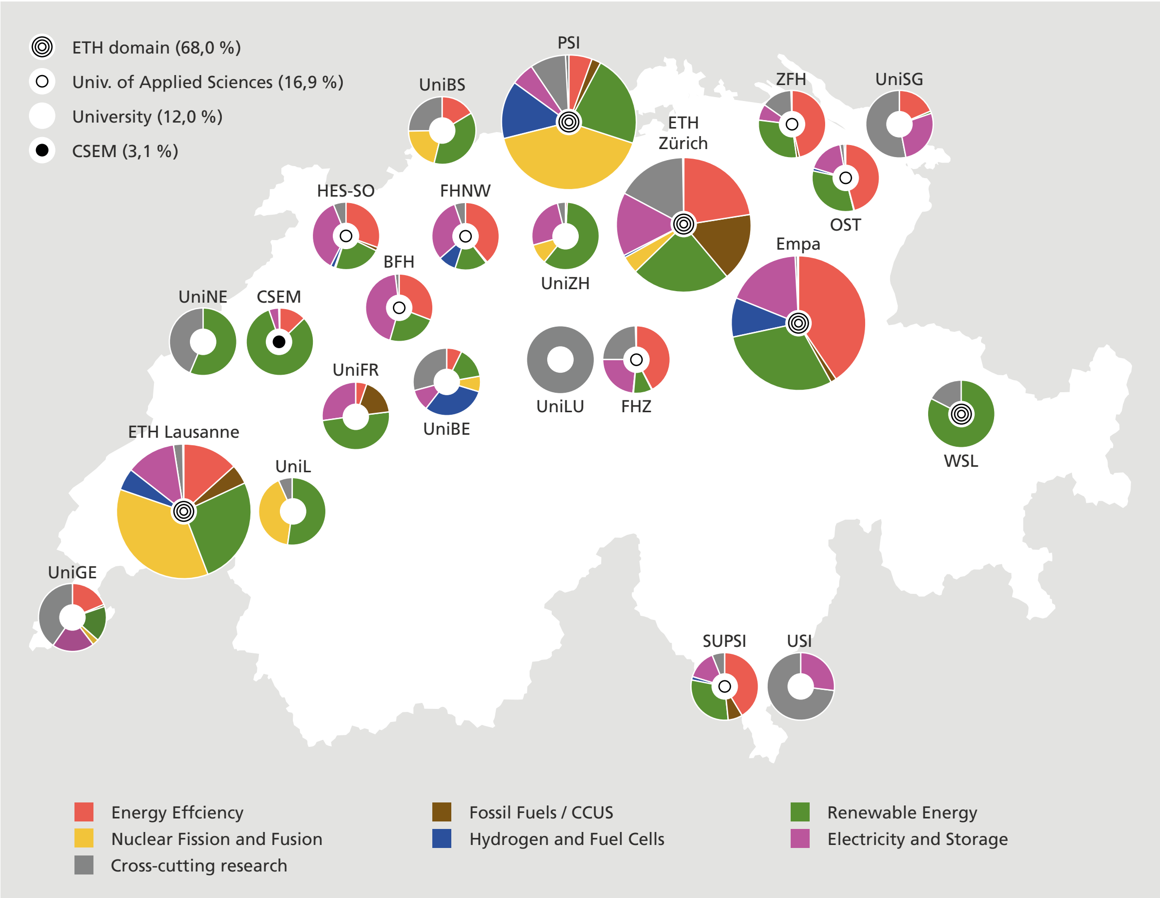

Figure 4: Energy research topics at Swiss universities (2022). The topics are broken down according to the classification of the International Energy Agency (IEA). The majority of public energy research (68 % of the public funds used) takes place in the ETH Domain. BFH: Bern University of Applied Sciences, CSEM: Centre suisse d'éléctronique et de microtechnque, EMPA: Swiss Federal Laboratories for Materials Science and Technology, EPFL: Swiss Federal Institute of Technology Lausanne, ETHZ: Swiss Federal Institute of Technology Zurich, FHGR: University of Applied Sciences Grisons, FHNW: University of Applied Sciences Northwestern Switzerland, FHO: University of Applied Sciences Eastern Switzerland, FHZ: University of Applied Sciences Central Switzerland, HES-SO: University of Applied Sciences Western Switzerland, PSI: Paul Scherrer Institute, SUPSI: University of Applied Sciences and Arts of Italian-speaking Switzerland, UniBE: University of Bern, UniBS: University of Basel, UniFR: University of Fribourg, UniGE: University of Geneva, UniLS: University of Lausanne, UniLU: University of Lucerne, UniNE: University of Neuchâtel, UniSG: University of St. Gallen, UniZH: University of Zurich, USI: University of Italian-speaking Switzerland, ZFH: Zurich University of Applied Sciences (the size of the circle serves to distinguish the ETH Domain from other universities)

INTERFACES TO FEDERAL OFFICES

The Federal Council has defined four guidelines for the 2023–2027 legislative planning period[66]: Safeguarding and promoting prosperity, cohesion, security and natural resources. Based on this and on numerous federal strategies and associated action plans, the federal agencies with departmental research[67] defined common challenges in 2022. The aim for all federal agencies is to create awareness of the challenges and promote the participation of all interested federal agencies.

Cross-cutting topics such as the use of resources, international relations, digital transformation, education and innovation support the management of thematic challenges.

As a trans- and interdisciplinary field of research, energy research has interfaces and points of contact with other policy areas in many sub-areas. Examples of this are

- Climate: CO_2 emissions from combustion-based processes in transportation, buildings and industry; effects of climate heating on energy production
- Health: Particulate matter from wood firing; noise
- Land use: energy systems in areas and neighborhoods; planning of energy infrastructures; mobility,
- Meteorology: Forecast optimization for wind and PV systems
- Environment: noise, residual water, landscape

The "National Center for Climate Services" (NCCS www.nccs.admin.ch) is a successful example of how challenges in departmental research can be tackled together. As a federal network for climate services, the NCCS is currently an association of nine federal units (MeteoSwiss, FOEN, FOAG, FOPH, FOCP, FSVO, SFOE, ETHZ, WSL). As a national coordination and innovation body and knowledge hub, the NCCS supports climate-compatible decision-making in order to minimize risks, maximize opportunities and optimize costs.

INTERNATIONAL INTEGRATION

Successful research always has an international focus: international cooperation increases the efficiency of the resources used and enables an effective exchange of knowledge between researchers. A prerequisite for successful collaboration – especially within the framework of IEA and EU projects – is scientifically recognized and high-quality contributions from Switzerland. The national and international networking of Swiss researchers is therefore an important element of energy research, in addition to actively supporting economically high-risk research projects and closing gaps in the innovation chain.

Participation in energy-related cooperation in the European Research Area (ERA) of the EU is currently only possible for Switzerland as a "non-associated third country". Up-to-date information can be found on the SERI website[68]. Under these circumstances, it is only possible to help shape the content in certain areas, but Swiss researchers can participate in most of the ERA. For current calls for proposals, see page 10.

Switzerland is involved in the IEA's most important research programs via the SFOE. The Technology Collaboration Programs (TCP) are the main focus here. Switzerland is involved in the TCPs that are essential for energy research[69].

66 – https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-92499.html

67 – https://www.ressortforschung.admin.ch/rsf/de/home.html

68 – https://www.sbfi.admin.ch/sbfi/en/home/research-and-innovation/international-cooperation-r-and-i/eu-framework-programmes-for-research/european-research-area.html

69 – https://www.bfe.admin.ch/bfe/en/home/research-and-cleantech/international-cooperation.html

SCIENTIFIC ADVISORY COMMITTEES AND QUALITY ASSURANCE

The SFOE covers practically the entire spectrum of energy research. It does not limit itself to awarding funding, but also closely supports the individual research projects and actively represents the research programs in national and international committees. The necessary expertise is either available within the SFOE or is provided by external persons (external mandated program managers).

MONITORING COMMISSIONS

The SFOE is supported by the extra-parliamentary Federal Energy Research Commission (CORE), an advisory body for strategic issues. Among other things, CORE sets the priorities for the present masterplan every four years and prescribes recommendations and topics for the SWEET funding program. All of CORE's activities are published in the Commission's annual reports at: www.bfe.admin.ch/core.

The members of CORE are elected by the Federal Council and represent the most important players in Swiss energy research, such as industry, SMEs, the energy industry, the ETH Domain, universities of applied sciences and universities. In addition to the SFOE, the FOEN, SERI, swissuniversities, Innosuisse and the SNSF have a seat as observers. The complete and updated list of CORE members can also be viewed on its website.

The secretariat of CORE is provided by the SFOE. As a rule, CORE meets for four half-days each year and holds a two-day retreat in the summer.

The SFOE's research programs have subject-specific support groups on a case-by-case basis.

QUALITY ASSURANCE

The SFOE bases its research funding on the guidelines for quality assurance in federal res sort research: The interdepartmental coordination committee for federal departmental research issues guidelines for quality assurance in federal administration research.[70] The quality assurance concept comprises the three main pillars of research management, reporting and effectiveness testing. Strategic planning, transparent award procedures, project information in the ARAMIS database, publication of research results and research monitoring play a central role. The guidelines are aimed in particular at people from federal agencies who are directly involved in research to fulfill the tasks of the Federal Administration. The federal offices involved in research are instructed to apply the guidelines when designing their own office-specific quality assurance concepts and guidelines.

As part of its internal control system (ICS), the SFOE has a three-stage procedure for awarding research contracts: at least two experts review the submitted project proposal according to a predefined project evaluation form with regard to its relevance, contribution to the objectives of energy research, the scientific quality of the procedure and the competencies of the researchers and, if applicable, other parties involved. The financial and procurement-related aspects undergo a review process in the finance section and a final review of the content is carried out by the professional line with a double signature.

Research management

Project applications for research and development (R&D) are evaluated by the research program managers with the involvement of at least one other expert. Pilot and demonstration projects (P+D) are evaluated in specialist ad hoc groups (with the involvement of specialists from the SFOE who are close to the market). SWEET consortia are evaluated by an external expert group.

The strategic relevance, implementation and multiplication potential, sustainability criteria and possible risks of a planned project are queried in the applications and are included in the evaluation alongside the actual content (see application and implementation instructions www.energieforschung.ch).

Reporting

All research, pilot and demonstration projects involving the SFOE are stored in the federal government's publicly accessible database ARAMIS[71]. Selected P+D projects supported by the SFOE are shown on the SFOE's cleantech map[72]. In addition, the SFOE's research programmes regularly organize specialist meetings and conferences at which the findings from the research projects supported by the SFOE are presented and discussed. Finally, the SFOE publishes the public expenditure on energy research annually (www.energieforschung.ch).

Evaluation of energy research

The CORE Research Commission is tasked with commenting on the SFOE's energy research. External evaluations were carried out in the 2017–2020 period for both the program for pilot and demonstration projects (2018) and energy research (2019)[73]. The SFAO regularly audits the proper allocation of funds.

Knowledge and technology transfer

The SFOE promotes knowledge and technology transfer (KTT) in the energy sector with various instruments and measures:

- Creation of a KTT position;
- Publication of specialist articles;
- Active exchange with implementation stakeholders and SwissEnergy;
- Meetings and conferences;
- Support groups.

70 – "Quality assurance in federal departmental research", Guidelines of the interdepartmental coordination committee for departmental research, March 26, 2014

71 – The ARAMIS information system contains information on research projects and evaluations carried out or (co-)financed by the Confederation. www.aramis.admin.ch

72 – https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/geoinformation.html

73 – https://www.bfe.admin.ch/bfe/en/home/news-and-media/evaluations.html

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