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Energy research Masterplan of the Federal Government 2021–2024

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Content

Vision

Energy is transformed, supplied, stored and used efficiently and in an emission-neutral manner. Swiss energy research makes a decisive contribution; it strives to develop an energy supply that is secure and economically and environmentally sustainable, thereby supporting an efficient energy policy.

Research for a successful energy future

The Federal Council and Parliament have decided that Switzerland would phase out nuclear energy in the medium term. 1 January 2018 marked the entry into force of the new Energy Act, for which the Federal Office of Energy developed the ***Energy Strategy 2050***. With this document, Switzerland has set itself ambitious energy efficiency goals for both fossil fuel use and electricity consumption. The production of electricity from renewable sources – photovoltaics, wind, biomass and geothermics – is to be sharply increased and replace the phased-out nuclear energy. Compared with today, the ***Energy Strategy 2050*** implies a doubling of energy efficiency and a 10–20 % reduction of electricity consumption per capita.

According to the Intergovernmental Panel on Climate Change (IPCC), there is an urgent need for a more efficient, more environmentally friendly and low-emission approach to energy. Based on the 2015 Paris Agreement requiring the world's countries to implement climate protection measures in order to limit global warming to significantly less than 2 °C or 1.5 °C above the pre-industrial level, the IPCC produced a special report on the 1.5 °C target. Current plans to reduce greenhouse gases are not sufficient; limiting global warming to a maximum of 1.5 °C would require a radical reduction worldwide, especially by 2030.

The IPCC scenarios cover both accelerated improvements in energy efficiency as well as a threefold or fourfold higher share of carbon-free or low-carbon energy supply from renewable energy, nuclear power and fossil fuels combined with carbon capture and storage (CCS). Switzerland has ratified the Paris Agreement. Swiss climate policy calls for a 50 % reduction by 2030 compared with 1990 levels. The statutory climate target[1] of a 20 % reduction by 2020 has been missed and greater efforts are needed to reduce environmentally harmful gases. In order to reach the climate targets of the 2015 Paris Agreement, the Federal Council adopted in the summer of 2019 a policy of "net zero emissions" by 2050.

Switzerland has also committed to the UN's ***Agenda 2030 for Sustainable Development***. Since 2016, this has constituted the globally valid framework for national and international efforts to find common solutions to such major world challenges as extreme

The Federal Government's energy research Masterplan

The Federal Government's energy research masterplan is a common vision of the Swiss research community with recommendations concerning publicly-funded energy research in Switzerland. It describes the research goals that are key to the achievement of the Energy Strategy 2050 and Agenda 2030.

The Masterplan is a planning tool for all government funding institutions. It also provides guidance for cantonal and communal bodies that have their own funding instruments for energy research.

This concept is for the legislative period of 2021–2024. It was developed by CORE with input from key energy research actors. It is based on current, internationally recognized scientific knowledge and is geared to Switzerland's energy policy goals.

[1] *https://www.bafu.admin.ch/bafu/en/home/topics/climate/publications-studies/publications/klimapolitik-der-schweiz.html*

poverty, climate change, environmental degradation and health crises. Energy research should above all contribute to the achievement of Goal 7, "Ensure access to affordable, reliable, sustainable and modern energy for all", Goal 12, "Ensure sustainable consumption and production patterns", and Goal 13, "Take urgent action to combat climate change and its impacts".

For CORE, the most important goal is the interdisciplinary development of new, viable and accepted energy technologies. The growing importance of cross-cutting technologies requires significantly increased cooperation both among technical research areas and between the technical sciences and the humanities and social sciences.

Energy research and innovation

Switzerland is one of the world's most innovative countries and has for years been at the forefront in various rankings. In the ***Global Innovation Index 2019*** and the EU's ***Innovation Union Scoreboard 2019***, Switzerland is No. 1 in Europe. To determine a country's innovation performance, numerous parameters are measured and compared, including corporate activities and income, human resources, open, excellent and attractive research systems as well as research funding and promotion. In order to maintain Switzerland as a research site – including energy research – at the current high level, further efforts will have to be made.

Knowledge and technology transfers

To maintain its innovative capacity, Switzerland needs open, "symbiotic systems" for research and development. It is necessary to promote cooperation between the Swiss Federal Institutes of Technology, universities of applied sciences and universities as well as with other actors and to establish and further develop networks. These support the transfer of knowledge between research and implementation.

Of critical importance is the transfer of knowledge and technology from universities in practice and back, to ensure that research and the results obtained generate added value in the marketplace. Pilot and demonstration facilities are one means to this end; they should be planned at an early stage in

The Federal Commission for Energy Research (CORE)

The Federal Council established CORE in 1986 as an advisory body for energy research. Among other things, every four years it works out the Federal Government's energy research masterplan, evaluates Swiss energy research and examines the Federal Government's energy-related departmental research. CORE consists of 15 members representing research and science, SMEs and large-scale industry in the energy field. For its current composition, see **www.energieforschung.ch**.

Energy Research

In this masterplan, energy research means the development of the scientific and technical knowledge needed for the economical, environmentally sound and efficient satisfaction of energy needs. Energy research includes basic research, insofar as its goals are related to energy fields, applied research designed to fill present knowledge gaps in order to solve specific practical problems, and development, which evaluates existing knowledge for the creation of marketable new products and processes.

cooperation with economic and other possible actors. These demonstrate the technical feasibility or viability in large-scale facilities with a view to reducing the risk for private investors.

Knowledge must be passed on and used. Consequently, the training of scientific and technical personnel plays a key role.

International integration
International research cooperation helps to enhance the quality of research and the efficiency of the research means employed. The prerequisites for successful cooperation are active participation in international programmes – especially the participation in EU framework programmes – as well as recognized, high-quality contributions of Switzerland.

Top priority is given to the involvement of Swiss researchers in IEA and EU research activities. International cooperation and exchanges of researchers should also go beyond the EU and the circle of industrialized nations to include developing countries.

Through the respective lead Federal bodies – the State Secretariat for Education and Research and the Federal Office of Energy – this cooperation should be established and strengthened. The "Swiss knowledge economy" relies on highly educated foreigners. They are key for ensuring the next generation in academic professions, management and employees in the field of knowledge-based services.

Research priority areas in context

Energy research must be driven by a holistic way of thinking and be geared toward the principle of sustainable development. The Federal Government's energy research masterplan covers the entire value chain of research – innovation – market, using publicly-funded energy research to achieve not only high-quality results but also national economic benefits.

Technology
With all technological solutions for energy supply, transformation, storage and use, priority is given to the closest economically feasible approximation to the respective technological potential. The possibilities offered by digitalization should be explored as cross-cutting topics in all key thematic areas.

Resources
CORE views new and improved technologies and skills to boost energy and resource efficiency and increased use of renewable energies as central elements of energy research. Production cycles should as far as possible be closed in order to avoid harmful emissions and to strive for a circular economy.

Economics and the national economy
The energy research concept is aimed at improving Switzerland's supply security and guaranteeing it over the long term; generating value creation in the form of jobs, know-how or new marketable products for the country; enhancing Switzerland's international competitiveness; and deriving value from its cooperation.

Society
There is a need to answer questions regarding societal needs and policy measures that enable the transformation of the energy sector. Here, for example, research can cover sociological, psychological and political issues concerning energy supply, transformation, storage and use. Last but not least, energy research should contribute to an understanding that neither a national energy policy nor a global climate policy can be replaced by technical measures

alone. In the interest of sustainable energy use, behavioural changes are necessary.

As far as the concept is concerned, research issues on the subject areas of "Economics and the National Economy" as well as "Society" will be assigned to the social and economic sciences and the humanities. They are detailed accordingly in the chapter "Energy, Society and Policies". If they have a clear technical dimension, they are described in the corresponding priority field sections.

The overall energy system

As far as this masterplan is concerned, "energy system" means the transformation, storage, supply and use of energy from natural resources, within the materials cycle and the societal framework. The diagram gives a vastly simplified, schematic overview of the energy system. Natural resources from the environment (water, sun, wind, mineral resources, etc.) are "converted and processed" to provide and produce energy carriers (electricity, heating, fuels and combustibles) and products. They are allocated, stored and transformed or consumed through applications. There are manifold interdependencies and interactions between all actors, conditions and processes. The aim of energy research is to understand this complexity and leverage this knowledge to identify the best possible further development options for the entire system and its components, such as sector coupling.

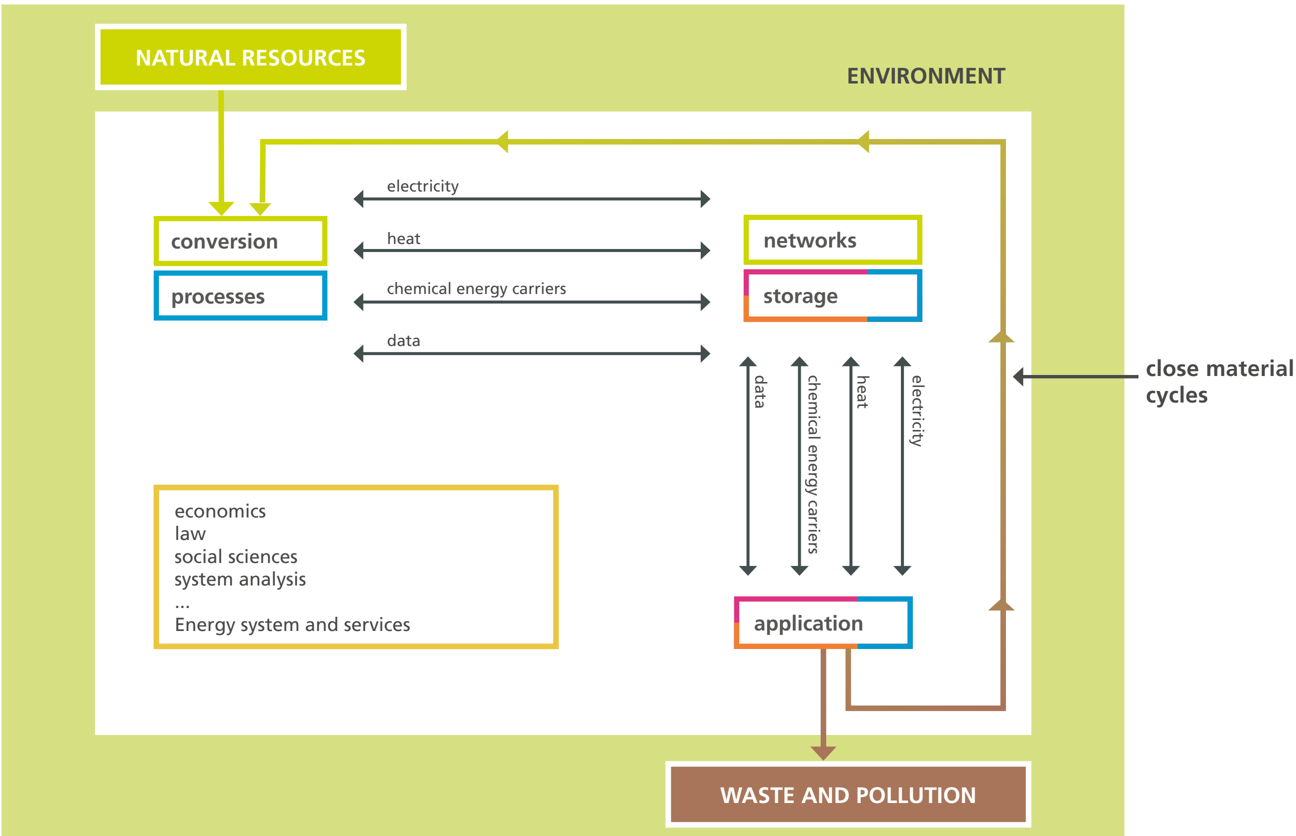


Figure 1: Simplified energy system (CORE based on the ETH domain). © SFOE

CORE has divided the energy system into five priority areas (page 10) covering largely covering all fields of energy research. They reflect everyday life and the related aspects of energy production and consumption, and are illustrated in the diagram using the colours of the priority areas.

The area marked in yellow (Figure 1, main field **"ENERGY, SOCIETY AND POLICIES"**) comprises the societal components of the energy system and gives the economic and legal framework. The areas of the priority field **"LIVING AND WORKING"** are shown in magenta. Buildings and sites are mostly assigned to the consuming sector but are also "carriers" for storage facilities and "converters" such as photovoltaics or heat and cold storage systems. From an economic perspective, the term "prosumer" has been coined for this. The same applies to the priority area **"MOBILITY"**, a traditional "consumer", which should be regulated in the form of electromobility and should stabilize the power grid as a storage facility.

The priority field **"ENERGY SYSTEMS"** contains the conversion and distribution of energy in all its forms. The last priority area, **"INDUSTRIAL PROCESSES"**, covers the production of not only goods but also fuels, and is therefore shown on the diagram in blue for both applications and processes. It is precisely this priority field that should make a major contribution to the goal of closing the materials loop, whereby waste production and environmental pollution can be minimized and natural resource consumption reduced.

Accordingly, the energy system as such covers the different sectors and their linkage via electricity, heating, fuels and data but goes far beyond this. Moreover, when working on specific questions, researchers should strive for a holistic view and evaluate their solution in terms of their contribution to the energy system.

The research goals of these priority fields should make it possible to derive the key topics for research on a top-down basis and promote both systems thinking and cross-disciplinary research.

The priority areas

ENERGY, SOCIETY AND POLICIES

The transition towards a renewable, secure and efficient energy system will be enabled by 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 understand and design these markets, policies and institutions.

LIVING AND WORKING

In the future, the building stock will be operated on a climate-neutral and energy-efficient basis, thereby helping via a decentralized approach to maintain a balance with regard to supply and demand in energy networks for electricity, heating and cooling. Thus, research is showing socially acceptable technological paths.

MOBILITY

"Emission-free mobility that meets the demands and needs of society and economy"
Facing an increasing mobility demand, mobility research enables the implementation of the necessary technologies, solutions, and knowledge to provide highly efficient, affordable and adequate mobility.

ENERGY SYSTEMS

"Clean, reliable, and affordable energy at a pace and scale that matters."
Decentralized renewable energy systems are rapidly becoming a key part of the future energy system, with new models of integration into energy networks, and facilitated by digital technologies as well as new business models. Advanced research in all components of the energy system, in its integration and in the resilience to external drivers, forms the ground to enable the Energy Strategy in an affordable and secure way.

INDUSTRIAL PROCESSES

Industrial processes will become pillars of a circular economy where products and services leave only minimal energy, materials and emission 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 material use is minimized and the provision of energy relies on renewable sources.

TIMEFRAMES FOR THE RECOMMENDED RESEARCH GOALS

In the following chapters, priorities and goals are defined for the five thematic priority fields. They are geared to two timeframes:

- Medium- to long-term research priorities for the period 2030–2050
- Short-term goals for the scope of application for the existing energy research concept 2021–2024.

Recommendations

CORE recommends that public funding bodies let themselves be guided by the existing energy research masterplan in order to ensure that public funds are utilized in a targeted, coordinated manner.

Research policy background

Within the framework of the Energy Strategy 2050, during the ERI periods[2] of 2013–2016 and 2017–2020, new research groups were formed in eight Swiss Competence Centres for Energy Research (SCCER) as part of the Action Plan for Coordinated Energy Research. The capacity-building planned under the Action Plan was successfully implemented. Now that the current research period has begun, the SCCERs will, as foreseen, not receive any additional support. There is a need to maintain research capacity through the technical colleges and to seek all types of research funding. The two National Research Programmes (NRP) of the Swiss National Sciences Foundation (SNSF) on "Energy strategy" and "Managing Energy Consumption" were also successfully concluded. During the current legislative period, the aim is to determine the additional research needs and ensure optimum use of the knowledge gathered and the research groups established in order to develop further and create innovations.

Funding principles

In the energy field, applied research should be the primary beneficiary of funding. Priority should be given to research fields expected to lead to high value creation for Switzerland and lastingly enhance national supply security. Energy research should make this kind of substantive contribution to the implementation of the national Energy Strategy 2050, the Sustainability Strategy and the achievement of the climate goals. The present masterplan also contains recommendations for energy research that are not directly related to these goals. Here, the prerequisite is the high quality of research, which must be internationally linked and competitive.

The strong public commitment to the networking of research institutions, to the identification of key future areas of technology, to the promotion of international scientific cooperation and to collaboration with universities of applied sciences and the economy is crucial for the implementation of research findings and must be maintained. Efficient, targeted implementation can be promoted through business-friendly regulation of the intellectual property generated with public funding, such as patents or licences.

Reinforcement of energy research

In the eight SCCER established and funded by the Commission for Technology and Innovation (CTI, now Innosuisse) 2013 to 2020, cooperation between universities and disciplines has been firmly grounded. The networks and research capacities created should be preserved in the future, and the universities have agreed to maintain the research centres. The phasing-out of funding for the SCCERs and the NRP 70 and NRP 71 research programmes financed through the SNSF means that significant funding for energy research is no longer available.

The new SFOE funding programme SWEET (Swiss Energy Research for the Energy Transition) will help to close this gap. SWEET promotes interdisciplinary consortia of different types of universities through thematic calls and explicitly requires the participation of implementing partners (e.g. industry, municipalities). Research results must be presented in the form of demonstration projects for implementation. In this way, the best researchers and research groups can continue to be funded, while at the same time providing targeted support for the Energy Strategy 2050.

Federal government research

The government research of the Federal Office of Energy (SFOE) plays an important role in promoting Swiss energy research. With its financial means, it manages to support promising technologies and projects which, in terms of technological maturity, are between basic research and market proximity. By doing so, it acts as a meaningful complement to

[2] ERI: education, research and innovation

promotion by the SNSF and Innosuisse. These efforts also include the derivation of practicable, validated models.

In addition, the SFOE is mandated by the Federal Council to ensure the participation of Swiss researchers in research programmes (Technology Collaboration Programmes, TCP) of the International Energy Agency (IEA). In addition to country-specific contributions, the SFOE also partly finances expenditure for Swiss researchers in conjunction with individual research programmes.

With regard to European research framework programmes, Switzerland participates heavily in the so-called European Research Area Networks (ERA-Net). In this context, the SFOE's government research also plays a special role, given that the financing of energy-related tenders is funded or at least coordinated via the SFOE.

CORE recommends maintaining the volume of government research in the energy field at least at the level of previous years, thereby ensuring the international connection – especially IEA and EU research programmes.

Pilot and demonstration projects

With the funding for pilot and demonstration projects in the energy field, energy policy has been supported via the accelerated introduction of innovative technologies on the market. Demonstrators on a scale of 1:1 have shown how the Energy Strategy 2050 can be implemented. Public confidence is created; new technologies and solutions are subjected to a practical test and made tangible.

At the same time, this raises the profile of Swiss innovations beyond national borders. CORE recommends leaving funding at the present level of some CHF 30 million, continuing to stringently evaluate project proposals and giving special priority to the concerns of the Energy Strategy 2050.

When it comes to testing new technologies, procedures and methods, legal options can be created for field visits and experiments, as long as these are ethically acceptable.

Maintaining know-how in the nuclear energy field

One area requiring special attention is that of nuclear energy specialists. Not only for the remaining life of the Swiss nuclear power plants but also for decommissioning, the phase of dismantling and planned storage – far into the next century – Switzerland needs young talent. Moreover, there is a need to maintain expertise with regard to the assessment of developments in the field of nuclear technology. In order to train these specialized staff members and secure their expertise over the long term, it is necessary to pursue and continue funding the corresponding research in the nuclear field.

Unrestricted access to publications and data

Efforts to date to ensure free access to all publications that are fully or partially publicly funded should be further reinforced. The SNSF's exemplary Open Access Strategy can provide other funding bodies with a guideline, because it also ensures access to publications in journals.

Ensuring that researchers have free access to data is much more difficult than ensuring access to publications. Here, CORE encourages a discussion between data compilers and researchers. There is a need to find the best possible compromise between the necessary data privacy and the desirable free data availability.

In general, CORE recommends supporting the compilation of good data not previously compiled systematically. Of particular value are long-term data rows of over 30 years.

New trends for the research period 2021 to 2024

As far as energy research for 2021–2024 is concerned, CORE is focusing on a holistic energy system approach with special attention to social sciences and humanities. The aim is to ensure efficient sector coupling and an energy system transition to renewable energies. Improved data analysis possibilities should also be utilized in energy research, for example to enable independent learning and optimized, human-centered planning in the energy field.

Energy, Society and Policies: In addition to the long-term reduction in demand, enhancing demand flexibility is in the foreground. Moreover, the optimum integration of renewables into the energy system, along with market design and coordination of actors in a decentralized energy system, offers new approaches. More emphasis is placed on system-wide analyses, which also enable an examination of factors that influence societal transition.

Living and Working: In the viewing or optimization perimeter, the focus was broadened from the interplay of the building sector with the electricity network to the interaction with all energy networks. This consideration of network permeability (sector coupling) leads in the priority field of Living and Working to a shift of topics from the building level to the site and district level, resulting in new assumptions for the optimization of the building stock as a technical system. However, there is a sharper research focus on humans as users, owners and operators of buildings. This is reflected by new concept approaches and new methods for validating this (living labs).

Mobility: For this priority field, there is more emphasis on studies and an understanding of the mobility system as a whole and the related role of human behaviour. On a technical level, a greater effort is made to tackle the challenge of the decarbonization of air freight and passenger transport.

Energy Systems: Systemic research into the networking of all energy sources and networks with the highest possible share of renewables is receiving greater attention. Energy storage, especially of a long-term nature, remains a relevant topic, along with nuclear safety research.

Industrial Processes: Closing material and energy cycles is the clear long-term goal of this priority field. This leads to a clearer focus on renewable materials and renewable energy provision in industrial processes.

CORE recommends promoting energy research primarily in these fields.

Economy, Society and Policies

The transition towards a renewable, secure and efficient energy system will be enabled by 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 the currently high level of supply security in Switzerland. This requires an increase in energy efficiency and an expansion of energy production from renewable sources. To achieve these objectives, the development of new technologies will be important. But technological progress on its own will not suffice. Major private investments and substantial changes to energy consumption are needed. Both require behavioural 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 goals of social sciences and humanities (SSH) energy research are to bring about a better understanding of the behaviour of the various actors, of their response to policy measures, and of the way the markets function. On this basis, the relative potentials and costs of the various measures can be assessed and their design optimized. Moreover, 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 societal and economic developments and their impact on the environment. Indeed, numerous political instruments and measures have an effect beyond the scope of a single sector, domain or region, and thus need to be examined in a much broader context.

In addition to its own research questions, SSH research supports the development and implementation of new technologies. Technological and societal development are closely tied and cannot be separated. Technological solutions can better contribute towards sustainable energy use, if the social, economic and political environment are appropriately taken into account in their development. For this reason, socio-economic issues are directly integrated into the various technological priorities in this research masterplan, if they are of a technology-specific nature or are of particular relevance to a given technology.

SSH research depends strongly on high quality data. The collection of and the access to such data is not a research priority in itself, but is a prerequisite for excellent research in many fields. This includes the possibility of doing field experiments. The Masterplan addresses this issue in the chapter related to recommendations.

The restructuring of the energy system calls for changes in the investment and energy use behaviour 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 "companies and households", "Markets, regulation and policies" and "Modelling, system-wide assessments and transition process" will be needed.

Medium- to long-term priorities

Companies and households
In order to successfully implement the energy strategy, households and companies have to change their energy-relevant consumption and investment behaviour. The analysis of the behaviour of various actors based on psychological, social and microeconomic methods and the formulation of recommendations for action is the focus of the first medium to long-term priority. The purpose of research is to gain a better understanding of the motives of the respective actors and the effects of specific energy policy instruments. The targeted reduction in energy consumption and the transformation of the energy system towards renewables go hand in hand with both 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 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 are important players on the road to the energy strategy: their strategies impact, and are also impacted, by consumer behaviour and their investment decisions have a significant influence on the development of new infrastructure. Here, research is required into adaptation measures within companies and into the development of framework conditions that promote innovation and technological changes towards better energy efficiency and renewable energy. Finally, the Energy Strategy generally requires investments in energy infrastructure. Identifying obstacles and formulating recommendations for the establishment of adequate framework conditions to enable these investments will be key to its success.

Markets, regulation and policies
In this priority field, the functioning and regulation of the energy markets as well as the design of policies for a renewable, secure, and efficient energy system are key objectives. 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. Due to new technological developments that facilitate a close integration of different energy carriers, the decentralization of the energy system, and the integration of renewables on a large scale, future energy markets as wells as their underlying regulation have to cope with many challenges. Therefore, a successful Energy Strategy requires research on market design and regulation.

For example, the development and analysis of efficient market designs that enable investment in renewables and their integration in the energy system is of high importance. Research has to develop appropriate solutions for the integration of a high share of 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 digitization in this context are also of interest. Furthermore, a cost-efficient and socially accepted Energy Strategy requires well-balanced policy measures and detailed assessments of their effects. Their development has to consider legal and international aspects. Here, the interactions with other (i.e. non-energy-policy) measures have to be taken into account, for example in the areas of spatial planning, climate and transport policy, both at the national and the international level. International climate and energy policies 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. This also applies with respect to Switzerland's positioning on the international energy markets.

Modelling, system-wide assessments and the transition process

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 energy system and the Swiss economy need to be better understood. This is the objective of the third priority field. It requires the development and enhancement of models and scenarios that describe possible future developments and highlight the key factors driving the energy strategy. Technical scenarios are also of interest, but these are addressed in the chapter on energy systems. One important objective is to improve the inclusion of uncertainty and the representation of behavioural and societal aspects in models and scenarios. Second, the political, economic and social framework conditions of scenarios and the interaction of different political measures need to be better understood. This holds in particular as the Energy Strategy is a societal and not only a technology strategy. Drivers of this societal transition and interactions between technological, societal, political and individual change, have to be explored to better understand the success factors of the transition. For example, societal and technological dynamics like digitization influence Energy Strategy at different level and with different effects. This complex and dynamic interplay of factors driving the Energy Strategy needs to be understood.

Finally, 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 priority.

Research will propose solutions for a better integration of renewables into the energy system. In particular, novel approaches for handling the high number and heterogeneity of actors resulting from decentralization will be developed. © Shutterstock

Living and Working

In the future, the building stock will be operated on a climate-neutral and energy-efficient basis, thereby helping via a decentralized approach to maintain a balance with regard to supply and demand in energy networks for electricity, heating and cooling. Research shows socially acceptable technological paths.

In accordance with this vision, in the priority field ***Living and Working***, research focuses on technologies and concepts that reduce energy demand, boost the efficiency of energy conversion and consumption, and reflect their value (exergy). On the whole, human needs in the field of living and working should in the future be met in a resource-saving, socially acceptable way.

To take full account of the building stock's function as a "prosumer", research will focus on decentralized energy storage, local generation of renewable energy for buildings, in sites, neighbourhoods and cities as well as the interplay between energy consumption, decentralized energy generation and storage, and energy infrastructures. Decentralized energy systems must be appropriately integrated into Switzerland's future energy system in order to ensure an environmentally sound, secure, efficient and economical energy supply.

Strategies to boost efficiency and to consequently switch to renewable energy sources are key for ensuring climate-neutral operation in buildings. The optimum amount of efficiency improvements shall be identified in a life cycle assessment with respect to the cost-benefit ratio. Additional efficiency measures should be evaluated in comparison with increased use of renewable energy. In addition, the efficient operation of buildings depends not only on political and regulatory framework conditions but also on the behaviour of owners, operators and users. They have a significant impact on whether energy savings and efficiency possibilities are maximized and the announced goals are reached. Corresponding concepts should be developed, validated (including Living Labs) and demonstrated in practice.

New buildings should not generate any environmentally harmful emissions in operation and should offer a high comfort level in terms of indoor climate, noise/acoustics, lighting and hygiene. Buildings and related materials must be produced on a resource-saving, low-emission and energy-efficient basis. The long-term goal is a circular economy.

To achieve this goal, there is a need to develop technologies and concepts enabling the intelligent generation, transformation, use and storage of energy in the buildings sector including interconnection and exchange possibilities with supply networks (electricity, heating, gas). This covers both technological and social sciences and humanities research aimed at taking user behaviour and needs into consideration. With a view to effective dissemination on the market the resulting knowledge must be made available in suitable form for product and planning, advisory and implementation tools and where needed for energy policy programmes and instruments.

Attention must be paid to the interfaces with the other priority fields of this concept, such as the aspects of sector coupling, mobility and the energy infrastructure or the influence of ICTs and monitoring technologies on the utilization of renewable energy generated on a decentralized basis.

Targets

Buildings account for some 42 % of energy consumption[3] and 26 % of overall CO_2 emissions in Switzerland.[4] Consequently, they are at the heart of the Energy Strategy 2050. On the one hand, the current energy renovation rate[5] of a scant 1 % must be increased urgently and substantially; according to the IEA, this rate should be doubled in the OECD

[3] BFE Gesamtenergiestatistik 2018 — [4] https://www.bafu.admin.ch/bafu/en/home/topics/climate/in-brief.html — [5] Martin Jakob et al., 2014, Energetische Erneuerungsraten im Gebäudebereich Synthesebericht zu Gebäudehülle und Heizanlagen — [6] IEA, 2013, Technology Roadmap Energy efficient building envelopes

countries.[6] At the same time, increasing renovation efficiency via technical and non-technical measures offers an additional means of achieving the goals.

The task of research is to indicate socially acceptable technological paths that lead towards the vision formulated at the beginning. The first stage consists of achieving the Energy Strategy 2050 goals, whereby research must always keep in mind the long-term, significantly more ambitious goals of the 2000-watt Society. A measurable 2050 stage goal for buildings is described in the Efficiency Path Energy guideline from SIA, the Association of Swiss Architects and Engineers.[7] Similar requirements for sites are set out in the 2000-watt society accounting model.[8] Both goal formulations serve as benchmarks that should be significantly exceeded in pilot and demonstration projects.

In addition to efficient energy use, a decarbonized energy supply, resource-saving, low-emission and energy-efficient production of building materials – aiming at a circular economy – as well as societal development that prefers qualitative added value to quantitative material growth, are key to meeting goals. Without pre-empting these developments, the best possible conditions must be created for buildings in order to achieve the above goals.

Building cooling

Owing to rising temperatures in summer and increasing demand for comfort, it will be necessary in the future to factor greater cooling demand into building design. With regard to the development of concepts and technologies for cost-optimized, energy-efficient and resource-saving passive or active space cooling, considerable progress should be made during the current four-year period.

Test bench measurements to determine the cooling capacity of three solar absorbers as part of the project "Heating and cooling via thermally activated external surfaces" at the FHNW. The uncovered solar absorbers function as external heat exchangers that can absorb heat from the environment and by absorbing solar radiation in the heating mode. During the cooling mode at night, they give off heat to the environment. © FHNW IEBau

[7] Merkblatt SIA 2040, Ausgabe 2017. Consequently, the goal is to achieve average power of 2000 watts of non-renewable primary energy and 2 t CO_2-equivalent per person and per year by 2050. Buildings should be allowed to account for about half of the total. In order to situate the energy required for building operation in a more holistic context, the "SIA Energy Efficiency Path" guideline also covers the embodied energy from building materials and building technology components as well as the mobility-related energy consumption linked to the building location. — [8] www.2000watt.swiss, accounting model, 2000-watt-society, as of September 2014.

Medium- to long-term priorities

Sites and districts
In order to meet Switzerland's future electrical and thermal energy demands as far as possible with locally available, renewable energy carriers, holistic solution approaches are needed. Districts and sites can be developed into decentralized, networked energy systems, thereby taking over energy-related services in the respective districts/sites (incl. electromobility) or for the regions involved in the fields of the supply, transformation, management, storage and distribution. These are not self-sufficient systems; rather, they should be incorporated into energy systems in Switzerland and elsewhere in Europe, as subsystems of the future energy system.

Research questions arise with regard to the load and provision flexibility of a site or its individual buildings for the electrical or thermal grid as well as the distribution of these flexibilities (over time and space) and the extent to which innovative ICT solutions can be applied in this respect.

Further research is necessary to ensure reliable, optimized interaction of electrical, thermal and gas networks, buildings, local energy generation and feed-in, storage and distribution. There is also a need to develop innovative tools for integrated planning and solution evaluation and optimization. These include digital platforms for integrated, multidisciplinary and collaborative planning taking energy-related aspects into consideration, making use of the opportunities offered by georeferenced data as need be.

Existing sustainability strategies like "2000 watt sites" or "Smart Cities and Communities" should be further developed along the lines of climate neutrality at the neighbourhood level. Of special importance is the definition of "grid supportiveness" at the level of sites and districts and the derivation of the resultant improvement assumptions for practice. This approach can help lend substance to the debate on "positive energy districts".[9] Within this framework, concepts, processes, measures and boundary conditions should be analysed, developed and tested.

Also needed are concepts for adaptation to climate change, to enhance the resilience of buildings, sites and districts in relation to global climate developments and local microclimates in urban areas (e.g. "heat island" effect).

Buildings
A significant reduction in the energy consumption and CO_2 emissions of existing buildings poses a major economic challenge requiring the inclusion of all possible optimization measures for buildings. With regard to the energy renovation of building envelopes, costs increase progressively with a certain degree of improvement for every additional energy unit saved (as long as models for the inclusion of external costs are not made binding). If this efficiency increase and the related CO_2 reduction can be achieved in an environmentally friendly manner with other measures, it is more reasonable, from a national economic perspective, to invest in measures with lower marginal costs.

In order to exploit these potentials, there is a need to develop energy-efficient, cost-effective systems for building refurbishment, simple, effective consulting and planning tools and efficient construction processes. Also necessary are inexpensive, robust concepts for residential ventilation and other HVAC technology. In addition, the potentials for digitalized, data-based building modelling throughout the value chain should be researched and demonstrated.

With new buildings, the focus is on research into energy needs as well as emissions of pollutants and greenhouse gases throughout the building's life cycle, including embodied energy needs and the related embodied greenhouse gas emissions. Building Information Modeling (BIM) should enable efficient, precise calculation of these characteristic values, which provide a basis for economic and technical optimization.

[9] *SET-Plan Action 3.2*

With a view to lowering energy consumption during operation, there is a need for research into technologies and systems that not only significantly reduce energy loss but also enable energy generation via building envelopes. Architectural diversity should be guaranteed in this respect. However, concepts for optimum operation are also indispensable in order to avoid an energy performance gap or facilitate operation optimization.

In this respect, one key aspect is the user-friendliness of building systems. This requires new approaches to adequately reflect user behaviour and user needs during building operations. Whereas BIM-related opportunities for facility management should be demonstrated, the application of artificial intelligence (AI) and machine learning (ML) can also shed scientific light on the goal of operation optimization. Research should be conducted to determine whether this knowledge can offer new avenues for building renovation.

Generally speaking, buildings must be adapted to future comfort and spatial needs. This means that they should be made user-flexible and hence resource-efficient, and new technologies and processes can help in this respect. In order to minimize material flows, appropriate performance indicators, strategies and instruments must be developed, with an emphasis on closed material loops.

For all building types, there is a need for research into innovative glazing, window systems and façade elements with improved, modifiable properties like light transmission, heat input and storage as well as energy generation, which enable an optimum indoor climate in winter and summer alike with minimum energy demand. Research should also provide new energy-efficient, environmentally-sound, cost-effective and space-saving thermal insulation solutions that meet architectural and aesthetic needs.

Building technology

Today, buildings are not only energy consumers but are also energy producers and suppliers of renewable energy. As a result, they play a new role within the energy system. When it comes to achieving grid supportive buildings, integrating local heating and electricity storage facilities into the energy system is becoming increasingly important. Whereas electricity storage facilities in buildings are primarily used for the short-term storage of locally produced renewable energy, heat storage facilities for energy storage are suitable for different timescales. Through coupling with different energy sectors, seasonal heat storage facilities can help reduce the load on the power grid, especially during the winter.

The form of energy and storage technology used in buildings should in the future be chosen on a cross-sectoral basis, but also depend to a large extent on the individual application and value of the energy. In any event, forward-looking technologies will be in as much demand as efficient, reliable and inexpensive integration and operational concepts in a life cycle assessment.

Technologies for the generation of renewable (thermal and electric) energy in buildings and the utilization of waste heat should be further developed and made more economical. Architectural integration in buildings as well as the development of active, multifunctional building envelope elements and cost reduction have high priority in this respect. Moreover, there is a need to increase standardization, the corresponding construction processes and the reliability of these technologies.

Local energy supply facilities should be smarter: today, solutions for broad application are lacking for local monitoring, integration in higher-level energy management systems for buildings, districts, sites, cities and regions, function monitoring and automated, standardized diagnosis or error messages to operators. In particular, there is a need to optimize internal consumption (with or without the integration of electromobility) in connection with network needs.[10]

High-performance heat pump technologies for space heating and domestic hot water support the ecological transformation of energy provision in buildings. They are often one of the prerequisites for ensuring that the energy consumption of energy-efficient buildings can be covered by renewable energies. Here, the challenges are linked inter alia to installation in existing buildings as part of energy renovation measures. Likewise, further research should be done on the opportunities and risks linked to the exploitation and use of the subsoil (inter alia in relation to groundwater protection zones) through various energy generation technologies such as geothermal probes, groundwater wells, thermal water, etc. for heating and cooling at different levels (building, district, municipal).

Increased reliance on combined heat and power generation (CHP) systems like fuel cells can facilitate the transition to a climate-neutral building stock. There is a need to highlight solutions that make a cost-effective, emission-neutral contribution to this goal.

Today, domestic hot water systems are subject to more stringent anti-legionella requirements. Innovative energy-efficient systems must comply with such requirements. There is a demand for innovative domestic hot water systems that address both concerns.

Given the upward trend for heat waves, it can be assumed that cooling demands in the building sector will rise in the future. This will lead to a need for more adjustable cooling facilities, implying more stringent requirements for efficient operation in the partial load range. Moreover, cooling demand for residential buildings in urban areas will rise owing to the local climate and specific heat islands effects. To prevent the uncontrolled use of inefficient devices that clutter up the outside space, such as split air-conditioning units, there is a need for research into potentials, concepts and technologies for energy-efficient, resource-saving and cost-optimized passive and active cooling, including the integration of cooling and heating thermal energy storage systems and the use of solar shading systems.

With regard to the monitoring and control of buildings' specific energy consumption, that is, the alignment of internal consumption with the energy generated in and around buildings and in-house technical and structure energy storage as well as cross-building networking, there is a need for research into innovative solutions in the area of ICTs and automation, measurement, control and regulation technologies. Here, cost-effective sensors and controllers represent a strong driver of innovation.

People, markets and policies

In the priority field ***Living and working***, possibilities for accelerating the transformation of the building stock and increasing the renovation rate should be researched. The discussion will focus on the acceptance of new technologies, concepts, processes and models by investors and users as well as opportunities for overcoming possible obstacles.

In addition, there is a need to analyze the drivers and incentives on the part of homeowners and other actors[11] that militate in favour of cross-sectoral energy networking (electricity, heating, gas). Research should also focus on determining how, or according to which criteria, the benefits and profits from networking should be allocated.

As far as the authorities are concerned, research should focus on the development of regional approaches for energy supply to buildings with the inclusion of public goods, for example via shallow geothermics

[10] Please also see "Grid supportiveness" in the section on "Sites and neighborhoods". — [11] In-depth research into the behavior of actors in the field of living and working as well as the relevant influencing factors are discussed in the priority area of "Energy, Economy and Society".

(groundwater, borehole heat exchanger < 500m) and waste heat (waste incineration, waste water treatment, industrial zones, etc.).

The interaction between user behaviour and the technologies utilized should be optimized, with technology promoting rational user behaviour. Here, the focus is on building automation solutions with a high level of acceptance and due consideration for privacy and security, new flexible-use concepts and suitable building-user interfaces.

Implementing renewable, decentralized and integrated energy solutions for sites or districts with multiple owners and actors poses a complex challenge. There is a need to research and evaluate models for promising sponsorships and for (participative) acceptance, procedure and decision-making processes during construction and operation. The findings provide important boundary conditions for planning and advisory processes.

Thought must also be given to socio-economic considerations as to who can most rationally use and operate critical energy infrastructure (network operators, homeowners or energy producers). In particular, there is a need to research common approaches and concepts in a digitalized world,[12] with a view to deriving recommendations for action and policy and developing business models.

[12] Ongoing research into the opportunities offered by digitalization is discussed under the priority field "Energy, Economy and Society".

Mobility

"Emission-free mobility that meets the demands and needs of society and economy"

Facing an increasing mobility demand, mobility research enables the implementation of the necessary technologies, solutions, and knowledge to provide highly efficient, affordable and adequate mobility.

Mobility refers to the physical movement of people and goods through a connected system of transport on land, water and air. When, where and how we move in this transport system is strongly influenced by our society. The challenge for the future is hence to provide a transport system that meets both society's needs and the climate and energy targets that society has set. We are faced with a growing demand for mobility, as access to a comprehensive and affordable transport system for all parts of the public and the economy is requested by society. This leads inevitably to conflicts of interest. For example, if an energy-efficient and emission-free mobility is aspired, then global air travel should contribute to the efforts of reducing harmful environmental emissions, without restricting the general public from using it.

Mobility, even on a mere national level, is a highly complex system of demand and supply. In order to realise the vision of an emission-free mobility that meets the needs and demands of society, a comprehensive understanding of the interdependencies is necessary. A stronger systemic approach to mobility research, taking into account the various interests of different stakeholders, is therefore needed, complementing efforts to improve technical components and subsystems. A balanced strategy in designing a future mobility system is crucial. This also requires a more interdisciplinary view, as mobility relates not only to the topic of energy, but also to questions of climate, urban and spatial development, as well as other areas of research. An increased consideration of non-technical aspects, i.e., the social sciences and humanities (SSH), is hence required in mobility research, especially when it comes to the in-depth understanding of the behaviour of mobility users.

The options to reduce CO_2 and other emissions from mobility are on the one side to reduce and optimize the energy intensity of mobility on a technical and SSH level. Technical aspects generally address the supply side of mobility, for example through reducing the fossil energy consumption in heavy-duty road transport and air travel, while SSH measures usually have an effect on the demand side, for instance by providing adequate modal choices for mobility users. In any case, these options at the supply and demand sides need to be implemented in practice (systematic aspect). These three fundamental focal points, a more systematic approach, a stronger consideration of SSH aspects, and ongoing improvements of technical solutions, have been identified for the future orientation of mobility research.

Systematic view of mobility

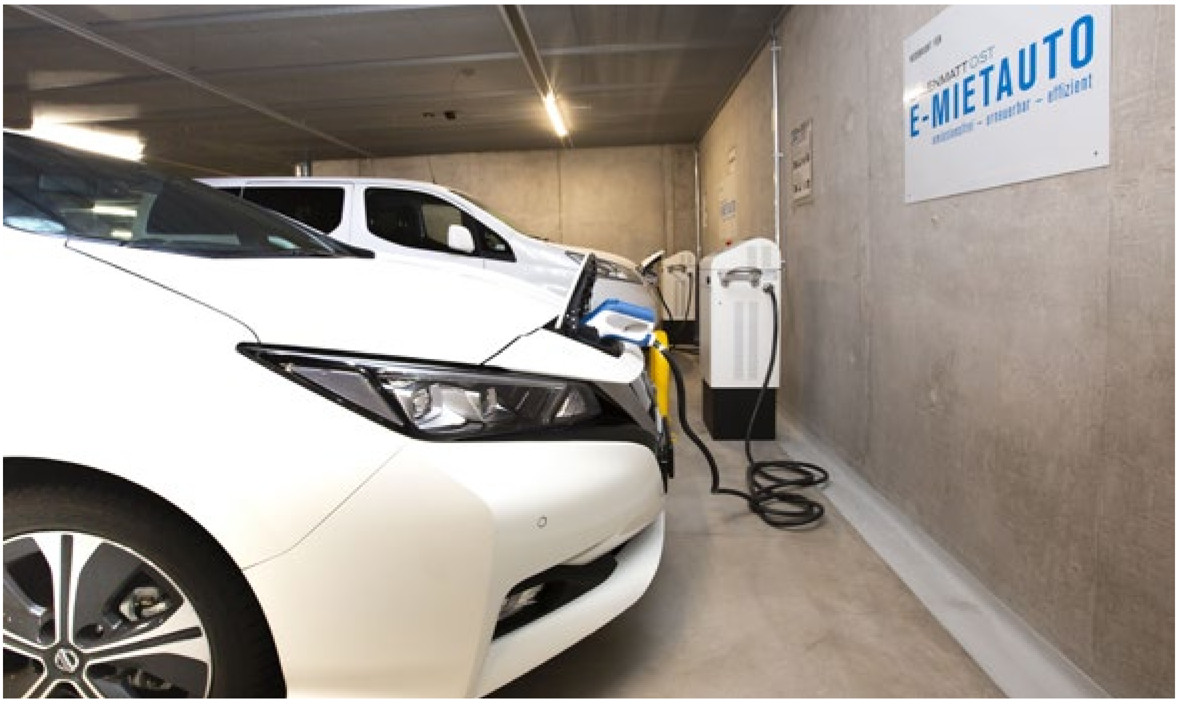
An interdisciplinary approach requires considering various research areas that touch the topic of mobility, for example by examining mobility in the context of modern-day civilisation and thus in the context of the other priorities, such as climate policy, spatial planning or the digitalization of society and the economy. A holistic view can help identify entirely new solutions that are needed to achieve the ambitious energy and climate goals in the mobility sector, for instance through a combined approach for passenger transportation and freight logistics rather than optimizing them separately. A systematic view can provide insights on possible risks of unwanted side effects, such as rebound effects and grey emissions, accounting for technical and SSH aspects and their interactions. To maximize the impact of mobility research, international coordination as well as dialogue with the industry and local public entities shall be increased in the development, piloting and roll-out of new solutions. Specifically, mobility research on the system level should primarily support the domestic economy in order to generate solutions that are tailored for Switzerland and can have an impact on the mobility system at large. Increased dialogue can bring the consequences and benefits of introducing potentially disruptive new technologies and solutions, such as electromobility, automated driving or "mobility as a service" concepts, to the attention of industry and local authorities.

Importance of SSH aspects

On the demand side of the mobility sector, i.e. societal behaviour and attitude towards mobility, lies a substantial potential for resource efficiency that has not yet been fully exploited. The SSH aspects of mobility should therefore be more comprehensively included in the investigation of research topics. For instance, increased data availability can advance the understanding of microeconomic factors, such as user behaviour, and how mobility choices can be influenced without causing rebound effects. With the available data, strategies and business models for alternative mobility offerings, such as mobility as a service concepts, can be derived, together with the appropriate technical and SSH requirements for their implementation. Researchers in the field of social sciences and humanities are further referred to the priorities in the chapter "Economy, Society and Policies", many of which are relevant for mobility.

Sustained technological progress

In order to put novel mobility concepts that are the result of a systematic approach and SSH considerations into practice, adequate technical solutions are required. Solutions need to be developed increasingly in an interdisciplinary fashion. For instance, the integration of a growing mobility demand in the Swiss energy strategy, driven by the decarbonization of the



Sector coupling represents a major pathway to exploit the potential of renewable electricity production and energy efficiency in various domains, such as the transport sector. In this context, mobility research is expected to provide the necessary technical solutions and adequate business models so that electric vehicles are connected with buildings and the electricity grid and provide added value in all three sectors. © novatlantis manufacturing and power generating industry, will require concepts for sector coupling and high-performance energy storage systems. In order to implement alternative mobility offerings and new business models, ICT technologies are needed to take advantage of the opportunities offered by the growing digitalization. Solutions for the widespread use of renewable fuels for fuel cells and conventional internal combustion engines, particularly in heavy-duty applications, shipping traffic and aviation, need to be found, for both the infrastructure and the vehicle side of the value chain. Due to its large multiplication potential, increasing the efficiency of the drivetrain is still a major lever to reduce environmental emissions. The same is true for the vehicle itself, where advances in lightweight construction, material science, aerodynamics or rolling resistance can greatly contribute to reducing the energy consumption of vehicles. Technical questions arising from new vehicle concepts, such as drones, are also to be addressed.

Medium- to long-term priorities

Under the premise of the three fundamental focal points, a more systematic and SSH approach as well as ongoing technological developments, relevant mobility research areas can be identified that will play an important role.

Mobility as a comprehensive system

A larger focus is required on viewing mobility as a large, comprehensive system with interdependencies to various other domains of our economy and society. Mobility encompasses all modes of transport, both for people and cargo, be it on the road, on rails or in the air. These modes of transport are not to be regarded independently, but as parts of one large system that are interconnected. Relevant touching points, for example to the electrical power system and the building sector or issues concerning spatial planning, need to be considered. In this regard, the energy potential of sector coupling is to be exploited and adequate technical solutions and business models, e.g. for "mobility as a service" concepts, are needed. A holistic approach can lead to new and improved mobility concepts, by combining transport solutions for people and cargo. Recognizing how new technologies, such as automated vehicles, interact with existing technologies will become increasingly relevant. As is the in-depth understanding of the required infrastructure and its design, for instance the requirements for a nationwide smart and fast charging system for electric vehicles. The transformation of the mobility system will require an appropriate regulatory framework. Mobility research shall therefore also provide the necessary theoretical and practical foundation, on which policy instruments, such as incentives or taxes, can be designed. Such basic information includes, for example, the assessment of the ecological and economic benefits of innovations on a system or component level.

New and intelligent mobility concepts through ICT technologies

Modern ICT technologies and the digitalization in general can be a significant enabler for new and intelligent mobility concepts, especially those that are driven by technical advances. For instance, automated road vehicles could potentially trigger a major revolution in the mobility sector. Research should therefore focus on the development of the required technical solutions and on the analysis of the potential impact of automated vehicles on viable business models, possible rebound effects or the necessary regulatory framework. The possibilities of digitalization can also enable other kinds of novel mobility systems where user behaviour and traffic management are important factors. ICT technologies are needed to process big data to model and predict such factors and to generate detailed information on resource consumption. In additions, from in-depth analyses, problems with the nature of new large-scale mobility systems can be identified and priorities for future designs can be deduced. In this context, the legal aspects of data acquisition and ownership will also become more relevant in the coming years.

User behaviour, social change, spatial planning, economic and regulatory aspects
In addition to the technical prerequisites, a deeper understanding of user behaviour is crucial for the successful implementation of new comprehensive mobility systems. The application of technological innovations should therefore go hand in hand with an in-depth monitoring of mobility patterns for a representative part of the population. From this data, predictions on the needs and the behaviour of the user can be made and the most adequate means of transportation for people and cargo can be offered, and information on these modal choices can be generated. In the public transport segment, ways of attaining a more balanced distribution of passengers by partially shifting traffic flows from peak periods to off-peak periods or new concepts for door-to-door transport need to be investigated. Aspects of spatial planning shall also be considered in these investigations, as they represent a crucial boundary condition to the mobility sector, which is connected with other relevant domains, such as the built environment that includes buildings and infrastructure.

Energy storage and substitution of fossil fuels
In order to achieve a substantial decarbonization of the mobility sector, its successful integration in the changing Swiss energy landscape with increasing sector coupling is a critical factor. Hence technically and economically viable solutions for short- and long-term energy storage, particularly to manage the fluctuating production of renewable electricity, and the substitution of fossil fuels with renewable energy carriers are needed. For electromobility, low-cost and high-performance solutions for the storage of electricity is needed, in the vehicles and possibly on the infrastructure end, too. It is important to increase the energy and power density as well as the service life of batteries, while simultaneously lowering the total cost. In addition, measures to assess and reduce the ecological impact of batteries, for instance through life cycle analyses and second life concepts, need to be investigated. Research can contribute to achieve these goals together with the industry. In addition, adequate concepts for alternative chemical energy carriers need to be derived. In the area of freight transportation (on land, water and air) as well as in general aviation, renewable gaseous and liquid fuels are needed for the foreseeable future. Solutions for the energy-related and ecologically reasonable production, distribution and use of these kinds of fuels need to be developed and implemented.

Vehicle efficiency
Efforts on improving the efficiency of vehicles (including vessels, aircrafts, self-propelled machines, etc.) remain a priority, both on the level of the vehicle as a whole as well as its drivetrain and auxiliary equipment. Through multiplication of new generations of vehicles, a large impact on fuel consumption reduction can be achieved by improving existing technologies and implementing technological innovations. At the forefront of these efforts, both from a short-term and long-term perspective, are solutions to completely electrify all possible vehicles. In applications where full electrification appears difficult to achieve (e.g. aviation or maritime transport), hybridization should be pursued and further improvements in efficiency and environmental emissions are necessary. Regardless of the drivetrain technology, solutions for reducing the vehicle weight through lightweight construction and the use of novel materials with reduced ecological impact should also be investigated. While technological improvements are generally implemented on new vehicles, adequate solutions will also needed to reduce the energy consumption and environmental emissions of the large existing vehicle fleet, which will remain for the years to come.

Energy Systems

"Clean, reliable, and affordable energy at a pace and scale that matters."[13]

Decentralized renewable energy systems are rapidly becoming a key part of the future energy landscape, with new models of integration into energy networks, facilitated by digital technologies and new business models. Advanced research in all components of energy systems, including integration and resilience to external drivers, forms the necessary ground to realize the Energy Strategy in an afforda-ble and secure way.

Fundamental changes are currently taking place in modern energy systems, since energy infrastructures have to satisfy conflicting requirements: providing reliable and secure services to an increasing number of customers, taking into account the rational use of energy and the protection of climate and environment. This last requirement drives major changes in energy systems, where renewable energy sources need to be increasingly deployed. It is generally acknowledged that these sources need to be significant and distributed, in order to provide a major part of the energy needs. It is also generally agreed that such integration of renewables into existing energy supply infrastructures depends on the successful combination of specific processes, new technologies and adequate solutions. Currently, there is a major effort from different research communities, to propose, discuss and validate new methodologies for the planning, operation and control of future energy systems.

It is also worth identifying the main factors promoting the evolution of modern energy systems: increased societal participation, policies aimed at encouraging lower carbon generation, large integration of renewables into energy grids, ageing assets of the energy infrastructure, and progress in technology, including information and communication.

Although the term "energy systems" may generally be applied to the whole, many system components are described in this document – including buildings, mobility and industry. This chapter will focus on the supply side, respective technologies and the interactions between different energy carriers, transformations and networks.

The contents described in this chapter are by definition strongly linked to all other chapters, in particular the demand side aspects of buildings, mobility and industry as well as socio-economic, regulatory and policy-related topics.

Targets

The Energy Strategy 2050 provides clear guidelines for the electricity sector: By the year 2035, the present target to be achieved by renewable energies excluding hydropower is 11.4 TWh whereas the target for hydropower is set at 37.4 TWh. While the intermediate target by 2020 of 4.4 TWh by renewable energies excluding hydropower will likely be superseded, the target of 2035 represents close to three times that amount to be reached in 15 years. The dominant contribution to this target will have to rely on photovoltaics, based on technologies that are largely available today.

The research described in this chapter shall prepare the ground for much higher contributions of clean power, heat and fuels, with the potential to contribute to a 100 % fossil-free energy system in the longer term and fulfilling the targets of the UNFCCC Paris Climate Agreement of 2015.

Finally, energy research in the system dimension is not to be seen in isolation and within the national context only. Advanced research in energy systems traditionally also has the vocation of international research excellence, thereby contributing to Switzerland's high ranking in the global research and innovation landscape. The latter contributes to strengthen Switzerland's economy and role as an exporter of high added-value products and services.

[13] NREL, Energy System Integration Facility (ESIF), https://www.nrel.gov/esif/

Medium- and long-term priorities

Energy system integration

For a long time, energy system research has focused on individual technologies, increasing their conversion efficiencies and lowering their generation costs, be it for power, heat or fuels. As many new energy conversion technologies have strongly progressed over the past decade, efficiency and cost are no longer the single indicators to be paid attention to. On the technology side, availability, versatility of use and sustainability have become additional key indicators.

More importantly, the ongoing transformation of the energy system as a whole is much more complex and challenging than the switch of generation technologies alone. In particular, as distributed renewable energies are becoming more important and will in the long term represent the backbone of the entire energy system, variability in time and location, both of supply and demand, become much more relevant.

This general trend poses new challenges to power grids, heat and gas networks and – particularly – their interaction, as well as their storage in all possible forms and at different scales in time and amounts. The increasingly distributed and variable nature of energy generation and storage brings along new opportunities and challenges for network planning, operation, flexibility and ancillary services. Whereas day and night differences in energy supply and demand can be addressed by short-term storage technologies and demand side management, seasonal variations in supply and demand are more complex to address and will require coupling of different sectors, namely between power, heat and gas (including hydrogen). Switching to an increasingly electrified mobility system will accentuate these challenges.

As a consequence, the needs for research in power grids and heating networks, energy system integration, sector coupling and storage are strongly increasing, thereby shifting the focus from individual technologies to a system view. Many different solutions are possible and need to be developed and assessed in an appropriate systems analysis.

Digitalization

Smart energy systems are not a new topic per se. However, new digitalization technologies and their widespread use offer many new opportunities but also some challenges for the development, operation and management of future energy systems and networks.

The expected benefits from the digitalization of the energy sector, as far as energy systems are concerned, are projected to affect the efficient management and secure operation of future, strongly distributed energy systems, from generation to storage, transformation and use.

Many of the current digitalization trends such as big data, data-driven models and management, digital platforms, artificial intelligence, machine learning, etc., offer new technical, business and market-related opportunities for energy systems and their stakeholders.

The concrete solution paths and impacts of the ongoing digitalization on the planning, development, operation and management of future energy systems is, however, a broad field where much research is still needed.

Cyber security of energy systems and data privacy aspects are further subjects of critical relevance and focus of research.

Finally, digitalization and increasing, massive data volumes have large impacts in terms of their accompanying energy consumption. This needs to be continuously assessed and strategies for reduction developed.

Scenario modelling and systems analysis

The ongoing fundamental changes of the entire energy system bring numerous changes how energy is generated, transformed, transported and used. Many different pathways are technically feasible and need to be well understood from a systems perspective. In this complex landscape, research in scenario modelling and systems analysis, taking into account resource-related, technical, social and economic aspects on the different time and spatial scales plays an increasingly important role in defining optimized pathways and options for the future energy system. Comparing different models and scenario approaches and analysing their sensitivity to various assumptions forms an important base to solidify their outcomes. Such research activities should include a continuous benchmarking of the techno-economic progress of the various technologies and its impact on the energy system. Moreover, systematically assessing the risks of different technologies and possible disruptive changes of the energy system should form part of this analysis.

Sustainability aspects

The ongoing transformation of the energy system involves massive deployment of new generation and storage technologies as well as the increased coupling of the various sectors. The sustainability aspects of these important changes need to be assessed and optimized in all dimensions, namely concerning resources, materials, processes, products, embedded energy and associated GHG emissions as well as regarding social and economic impacts or related spatial planning issues.

Renewable energy

Renewable energy, although already an important pillar of the Swiss energy system, both in the electricity and the heating sector, will have to play a much larger role in the future energy supply. Besides hydropower, photovoltaics will by far be the dominant new contributor to the electricity supply.

Strong dedicated research in the different renewable energy technologies must continue in order to enable an optimized and cost-effective mix of the various contributions to the generation of power, heat and – in the longer term – fuels.

For hydropower, which presently is a mature technology, research should aim at maintaining and increasing the electricity production while addressing the changing operational environment regarding the water regime (e.g. legal boundary conditions, deglaciation, precipitation patterns), the short-term flexibility needs with increased component wear, as well as the shift of the generation to winter months. Assessing the consequences of these operational changes of hydropower systems for water quality and flow regimes form relevant broader considerations.

Research in photovoltaics needs to continue on the technology front regarding new highest efficiency solar cells and modules, but equally on the product and system level in order to foster the tremendous potential of solar photovoltaics and its integration into buildings, infrastructure, mobility and the energy system at large. In addition to efficiency and cost, aesthetics and multifunctionality are important aspects to further develop. Advanced industrial processes and manufacturing continue to form important goals of research in photovoltaics. Integration of photovoltaics in the electricity grid and – at high penetration levels – also the energy system form crosscutting issues with other research areas. Life cycle assessment and improved solar resource forecasting are relevant areas of accompanying research.

Bioenergy offers a large variety of transformation processes using different feedstocks and waste resources enabling broad end uses for heat, power, gas and other fuels as well as chemicals. Developing and improving selected value chains involving microbiological and thermochemical processes, or a combination of both, should lead to higher conversion efficiencies and better feedstock utilization. Research should also be strengthened regarding the future role of biomass for energy storage, climate control and sector coupling.

Geoenergy can play an important role in the supply of heating and cooling, thermal networks, power and storage. Assessing and understanding the geological subsurface, its geothermal potentials and how to explore it, form key research areas. Research in geoenergy also addresses advanced technologies for stimulation and drilling. Risk assessment and mitigation as well as safety research form particularly relevant research aspects regarding the future utilization of geoenergy.

Wind energy represents a rather mature technology. Nevertheless, specific aspects of wind energy use in Switzerland, e.g. regarding icing, as well as alternative wind-turbine concepts are subjects where further research is needed. Furthermore, advanced power forecasting and control strategies will help to optimize plant performance.

Besides photovoltaics, solar energy offers large application potentials, both with low temperature heat for heat supply as well as high temperature heat for power generation and industrial processes and – in the longer term – fuels. In this area, solar thermochemistry, photo-electrochemistry and electrochemical fuel synthesis form subjects of more fundamental research.
Energy storage aspects become relevant when large amounts of solar and wind energy contribute to the energy system. The flexible energy consumption in combination with flexible energy generation is only possible if today's rigid energy system is reinforced with energy storage elements to provide the required flexibility. At the moment, the available short-term storage technologies serve the needs of peak shaving and summertime heat supply. In order to make the installation of short-term storage more attractive, cost and reliability questions need to be addressed. For the future, long-term large-scale storage systems are required (for Switzerland) to improve the dependency on energy imports and electricity costs in winter times. Such storage systems, like power-to-X (e.g. power-to-gas or large thermal storage systems combined with large heat pumps), are in an early stage of development, but will be essential to meet the climate goals. A strong storage backbone increases independence and resilience of the energy system.

Nuclear energy and radioactive waste
Independent regulatory research needs to be continued at the state-of-the-art of science and technology, in order to maintain the highest safety standards for Switzerland's fleet of nuclear power plants (NPP) in the long term. With the anticipated lifetime extension of Swiss NPP to 60+ years of operation, ageing mechanisms will increasingly challenge the plants' safety performance, which calls for supporting evidence that the NPP will remain able to cope with all design-based accidents with sufficient safety margin. In addition, the Fukushima accident and the European stress tests have triggered a wide range of activities on severe accident management, retrofitting of safety systems, and accident-tolerant fuel types. All these measures necessitate continued research efforts to prove their safety efficiency, including the maintenance of critical nuclear research facilities in Switzerland.

Regardless of the future role of nuclear energy in the Swiss energy mix, the issue of a safe disposal for radioactive waste has to be further advanced towards full implementation of a deep geological repository. With the advent of phase 3 of the Sectoral Plan (Sachplan Geologische Tiefenlager), a definite disposal site must be found until the end of the next decade. This will require scientific infrastructures to accompany the geological investigations, as well as sophisticated computer modelling techniques to understand the complex geochemical and rock-mechanical processes in the host rock formations. A transparent conduction of the entire siting process, including a careful assessment of social and psychological criteria, is crucial to reaching a widely accepted solution.

Switzerland is to continue playing its part in the development of technologies for safe and innovative reactors, to the extent that it remains able to make its own expert judgements of advanced nuclear technologies emerging elsewhere. Consequently, new Generation-IV reactor technologies and their related fuel cycles have to be continuously evaluated from the point of view of nuclear safety, sustainability, and waste minimization strategies. Continued

Generation-IV research activities, embedded within supranational organizations like EURATOM, the OECD Nuclear Energy Agency (NEA), and the International Atomic Energy Agency (IAEA) enable Switzerland to advocate its national interests in the building of international rules and guidelines in the nuclear safety and security regime, and are therefore the best guarantee to maintain a strong voice on the international stage.

Fusion research is to be continued to the extent to which it can be financed within the framework of multilateral research activities and does not interfere with research funding for other energy technologies.

All these measures contribute to the overarching goal of maintaining and securing the high level of domestic nuclear competence that is needed to ensure the safest operation of the Swiss power plants well into the 2040s and the proficient management of the nuclear legacies for the decades to come.

Research in the energy system scale has never been as relevant as it needs to be in the coming decade: Advanced energy network management, system integration, sector coupling and storage will play a decisive role in extending the limits of renewable power penetration. Extensive research in these areas will advance the penetration limits well beyond 100 % of the present distribution grid capacity.
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Industrial Processes

Industrial processes will become pillars of a circular economy where products and services leave only minimal energy, materials and emission 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 material use is minimized and the provision of energy relies on renewable sources.

In the transition towards this vision, industrial processes face challenges and opportunities alike:

Circular economy

Closing material loops begins with smart product design, striving to minimize energy and material use not only during manufacturing and use phases of products, but also at their end of life. Material reuse, recycling or conversion at industrial scale provide new opportunities for the coupling of waste management and materials supply chains. Sustainable biomass production or carbon capture and utilization from CO_2 emitting processes offer further alternatives to fossil-based carbon feedstocks and fuels.

Whenever incumbent feedstock materials are replaced, existing supply chains have to be redesigned. In many instances, this may involve a shift away from commodity production with large volumes of materials in centralized processing facilities towards smaller decentral facilities, be it for the recovery of materials right at their point of use or for the processing of locally grown biomass. Besides the availability of local, renewable feedstocks, the proximity to customers is another driver for decentralized manufacturing, especially since the digitalization of supply chains enables the manufacture of customized products in smaller lot sizes with reduced inventory and agile delivery.

To be economically viable and environmentally sound, material recovery processes at the end of product life have to compete with the production of virgin materials in terms of quality, price and efficiency. As closed material loops come with more constraints in material quality and availability than commodity sourcing, the receiving processes need to be highly resilient in order to deliver consistent product output even when the sourcing situation changes. Likewise, the trend towards more flexible supply chains calls for more adaptable industrial facilities that are well connected into virtual manufacturing networks.

Renewable energy

Currently, the share of renewable energy in this sector is low, because the requirements that many industrial processes impose on their energy supply present serious hurdles towards the integration of renewables. Reliability is essential, since disruptions in energy supply not only affect asset productivity, but also put facility safety and product quality at risk. When it comes to process heat, it is not only local availability that matters, but the industrial process also dictates the required temperature level.

Such demand-side constraints are in juxtaposition to the intermittent and seasonal generation patterns of wind and solar energy, as well as to the location-specific availability and quality of bioenergy and geothermal or ambient heat sources. Consequently, matching industrial energy demand with renewable sources often requires complex and customized solutions, be it in terms of technology selection, operational management or business model design. The inclusion of energy efficiency measures upfront usually renders any of these approaches more affordable.

System approaches to efficiency and flexibility

Energy and material efficiency are interconnected since the bulk of energy consumed in industrial value chains is used to process materials in the manufacture of goods. As a rule of thumb, reducing the material consumption of a given process corresponds to decreasing energy expenditures, as well as reduced amounts of emissions and waste.

Further efficiency gains and flexibility benefits can be expected from the local integration of energy and material flows, or their broader exchange in decentralized energy hubs that connect industrial sites with surrounding commercial or residential buildings. Sophisticated process integration methods play an essential role in achieving optimal solutions, be it at the site level or in large-scale systems. In a multi-energy grid, electricity, district heating/cooling, fuel, water and sewage grids are operated jointly. In such a combined network, energy shall be stored, converted and re-released in a coordinated manner.

Integration at the highest system level leads to sector coupling, where the provision and use of energy are linked via a variety of conversion and storage technologies. Here industrial processes play a pivotal role as producers and consumers trading electricity and heat as well as platform chemicals and fuels. Ultimately, the most impactful solutions will not only generate efficiency gains and open up more industrial applications for the use of renewable energy, but simultaneously create new degrees of operational freedom that allow industry to offer flexibility services and therefore better exploit their assets.

Digitalization as a transformative force in the industrial sector

In the internet of things, inexpensive, zero energy consumption sensors generate a wealth of data on process parameters, equipment performance and material quality that can be transmitted in real time around the globe, even under demanding circumstances. Such remote monitoring is invaluable for dynamic and predictive process control, predictive maintenance or agile supply chain planning, with immediate benefits in terms of resource efficiency, process safety, product quality, asset productivity and cost.

The fast and reliable calibration of process models with real life data collected under well-defined circumstances rather than hypothetical assumptions facilitates more robust process designs and avoids the resource and cost penalty of over-engineering and redundancies for safety margins. Once a design is implemented, frequently updated models can serve as optimization tools in day-to-day operations as well as for scenario analysis in support of business decisions. Shaped into digital twins of a selected facility, such a model also lends itself for training and educational purposes, reducing inefficiencies from shutdown times for maintenance or retrofits.

As computing power increases and artificial intelligence methods evolve, process models can expand in scope from unit operations over production lines to integrated industrial sites. With smart monitoring at different system levels, it will become easier to find an optimum and stay close to it even when circumstances change. Swarm logic allows for the coordinated remote control of "cloud factories", i.e. distributed plants in virtual networks.

Energy management is taken to new levels as real-time data on energy generation and consumption can be exploited to optimize industrial energy efficiency or offer grid flexibility services on demand. Combined with time dependent information on the cost and environmental footprint of the energy mix, even complex energy systems with high shares of renewables can be guided towards robust, economically viable and environmentally sustainable operations.

Medium- to long-term priorities

Process technologies enhancing material and energy efficiency
Currently available, cost-effective best practices still provide a sizable potential for further improvements in resource efficiency, especially in existing installations and retrofits. However, disruptive technology innovations could offer even more significant efficiency gains.

Product design aiming at minimal material consumption and maximal recyclability leads to smaller waste streams of higher value. Intelligent processes that transform such wastes or sustainably sourced biomass into industrial raw materials and energy resources will be essential for the circular economy. While their lower temperature levels prohibit the direct use of waste or ambient heat sources in many conventional processes, novel bioprocesses or innovative catalytic conversions could accommodate this constraint without undue compromise in yield, selectivity or speed. Innovative technologies to efficiently lift temperature levels and minimize heat transfer losses expand the use of renewable heat even further.

Process intensification is another research area to boost resource efficiency. Whether optimizing process designs for accelerated heat and mass transfer, enhancing reaction speed and separation efficiency, driving towards higher selectivity and yield at more benign conditions, identifying synergistic combinations of unit operations or shifting processes from batch to continuous modes – all these strategies can help reduce energy consumption and minimize material losses.

Novel process equipment with improved heat and mass transfer in optimized flow fields (e.g. micro reactors, pipeless heat exchangers) is a key enabler of process intensification. Breakthroughs in material science and additive manufacturing technologies shall give more freedom in the design of 3D structures and thus permit the tailoring of critical equipment components to specific process needs at affordable cost. Artificial intelligence methods could expedite the design process with rapid automated screening of variants. Ultimately, modular, compact and versatile pieces of equipment suitable for retrofits as well as for greenfield facilities of various scales, shall give more flexibility to industrial process developers and supply chain planners in a circular economy.

Process integration methods at site and system level
Process integration aims at the economically viable exchange and cascaded use of material and energy flows at facility, site or regional level, and is as such a key enabler of the circular economy. Research is challenged to generate the scientific basis for the technologies and tools that are required to develop, manage and operate highly integrated industrial systems.

At the unit operations level, it takes models that adequately describe the physical conditions of energy and material flows and their conversion processes, not only to assess resource consumption patterns, but also the ability of processes to integrate themselves into process networks with cascaded use of heat and materials. Novel industrial symbiosis concepts at the site level shall create synergies from interconnecting processes, coupling material and waste management and integrating renewable energy resources. Biorefineries for the co-production of materials, fuels, heat and power are a prime example of this approach. The integration of industrial clusters at the level of multi-energy grids poses new challenges due to daily and seasonal variations in supply and demand. Although advanced process control schemes could mitigate these fluctuations to some degree, further research into efficient and affordable technologies for short- and long-term industrial energy storage seems warranted. In light of the longevity of industrial assets, retrofitting existing production and infrastructure facilities is a particular challenge.

As process networks are not easily represented in design and optimization tools, engineering research is required to propose methods for the accelerated screening of integration options based on their performance at site and supply chain level. Since sustainable symbiosis relies on exchanges with mutual benefit to all partners involved, research shall not only address the feasibility and environmental impacts of technical designs but also the economic viability of innovative business models and the cultural changes that facilitate collaborative approaches.

Multi-criteria assessments for decision support in industry and policy

Due to the progressing integration of industrial processes into larger physical and virtual networks, the reach of technology, business and policy decisions keeps expanding far beyond a decision-maker's immediate sphere of influence. To address future challenges without unintended consequences of rebound effects and burden shifting, decision-makers will rely more and more on tools that elucidate possible positive and negative impacts of the options at hand. Research is challenged to address the increasing complexity with models that examine the options in a scientifically sound manner, yet can be translated into effective tools for stakeholder engagement and decision support.

To avoid the optimization of a sub-system at the expense of the overarching goals, product variants and process alternatives need to be assessed in a life cycle perspective. The boundaries for life cycle assessments (LCAs) have to be defined carefully; they often range from the sourcing of raw materials and primary energy all the way through product use and

Advanced process technologies and management practices that enhance energy efficiency and enable the integration of renewable energy sources in networks that span facilities, sites and value chains. © Shutterstock loop-closing at its end of life. In particular, efficiency gains from cascaded use or network exchanges are easily overlooked when the analysis is limited to a core process or a single manufacturing site.

Comprehensive methods for multi-criteria assessments are required not only to pinpoint potential issues across a broad range of impact categories, but also to highlight multiple benefits beyond energy savings and greenhouse gas reductions, such as cost advantages or intangibles in the areas of quality, safety, supply security, resilience, productivity, or reputation. In highly integrated systems, impacts and benefits can rarely be traced back to single measures, which raises research questions around tracking, monetarization and allocation methods that satisfy the needs of business partners, regulators and other constituents alike.

The earlier the assessment is integrated into product design and process development, the better. However, insufficient data quality and availability are common obstacles in the evaluation of cutting-edge technologies. To avoid that future scenarios for business and policy decisions rely on outdated information, researchers need to find ways to describe disruptive innovations in terms that are compatible with multi-criteria assessments.

Close collaborations with industry and broader stakeholder engagement from scope definition though critical reviews and finally the dissemination of results is essential to ensure the relevance and credibility of an assessment. However, the complexity and technical content of the analysis often discourage broader participation. Research shall facilitate well-informed conversations beyond the inner circles of experts and thus empower decision makers in industry, policy and society at large to rely on the results of multi-criteria assessments.

Appendix
Areas of research 2021–2024

This section lists a selection of areas of research that are to be focused on in the period from 2021 to 2024. In most cases, the listed research topics are of relevance to several priority fields. For example, a better understanding of the factors that influence individual energy consumption is of importance in the future in the areas of mobility as well as living and working.

ENERGY, SOCIETY AND POLICIES

Companies and households

Energy consumption and individual behaviour
— Modelling of individual decision-making including both rational (risk versus return) and "bounded rationality" influences;
— Analysis of the interplay of socioeconomic determinants as well as affective, normative and cognitive factors influencing individual energy consumption;
— Analysis of the impact of social innovation in the energy sector and analysis of the behaviour of households when faced with innovations in the energy sector.

Finding leverage for demand reductions from households and companies
— Analysis of structural aspects of household energy demand: Lifestyles, where and how people live;
— Analysis of societal and economic developments: Long-term trends altering energy demand;
— Analysis of behaviour change during windows of opportunity (from technological, societal, economic change, in particular digitization);
— Development of price signals that include the real cost of energy related services (including transport);
— Analysis of the impact and design of non-price interventions to reduce energy consumption;
— Analysis of rebound effects and development of targeted reduction strategies.

How to leverage and use demand flexibility from households and companies
— Development of business models to enhance flexibility in the energy system, accounting for the influence and opportunities provided by digitization;
— Development and analysis of pricing schemes for network use and energy that use demand flexibility;
— Experimental evaluation of novel instruments for demand-side flexibility.

Investment behaviour, corporate strategy and organization
— Analysis of the attractiveness of investments in energy infrastructure from the viewpoint of investors and portfolio optimization, development of strategies to make these investments more attractive;
— Development of strategies for smart energy systems (including data protection law barriers);
— Analysis of obstacles to investment in energy efficiency and renewable energy;
— Analysis of the energy sector as an innovation system: functionality and determinants of and incentives and obstacles to innovation; diffusion of new products;
— Analysis of the behaviour of actors in organizations and solutions to reduce obstacles to the spread of energy related innovation;
— Assessment of ways in which companies can influence the energy-related behaviour of employees, and vice versa (including labour law barriers);
— Opportunities for collaboration between actors from different industries or sectors;
— Integration of new technologies (e.g. storage): analysis of the opportunities and benefits for firms and other actors.

Markets, regulation and policies

Market design and market regulation

— Assessing different designs for energy markets in Switzerland and development of novel and efficient market designs with a focus on their ability to
  › integrate renewables on a large scale;
  › foster sector coupling;
  › support an efficient investment in and deployment of storage and demand-side management technologies;
  › harness the potential of new technologies (e.g. arising from digitization) and new societal developments (e.g., circular economy, urban mining);
— Developing decision support tools for sector coupling;
— Analyzing the effects of market liberalization, in particular w.r.t. electricity and gas markets;
— Assessing market regulation options;
— Analyzing the legal implications of energy as a service;
— Analyzing the legal implementation of investment incentives in new market designs;
— Analyzing the stringency of use of legal instruments in a holistic perspective on the energy system.

Integration of renewables and decentralization

— Analyzing the legal and societal challenges and opportunities of the transition to a more decentralized and intermittent energy (e.g., distributional aspects, responsibility for system stability, new regulatory instruments);
— Developing approaches (e.g. market designs, business models) for handling the high number and heterogeneity of actors resulting from decentralization, in particular with regard to coordinating their investment, deployment and usage decisions. Opportunities arising from digitization in this regard;
— Assessing the contributions of self-consumption communities and of the transition from consumers to prosumers for the energy strategy;
— Developing approaches towards handling intermittency and ensuring security of supply in a strongly decentralized energy system;
— Developing decision support tools for assessing the evolution of a decentralized energy system.

Analysis of policy instruments and measures

— Developing novel policy measures and approaches for
  › Reducing energy demand and improving energy efficiency that account for the determinants and obstacles found in research domain 1 ("companies and households") and new prospects arising from digitization;
  › Increasing investments in energy technologies and infrastructure that account for the obstacles found in research domain 1 ("companies and households") as well as financial risks;
  › Using spatial planning as a platform to realize new energy projects (in the built environment, process of construction permits);
  › Improving the distributional effects of policy measures (e.g. social cushioning).
— Assessing the consequences of policy interactions (different domains, old and new policies) and developing approaches and processes for handling such interactions;
— Ex-post analysis of the impact of policies/instruments to promote efficiency and the dissemination of renewable energy and lessons learned for Switzerland.

Legal and international aspects

— Positioning of Switzerland on the international energy markets and options for integrating Switzerland into the European energy (electricity) market, including pump storage plants in the European network
— Assessing the influence and interaction of foreign energy policy and international climate policy with Swiss instruments and measures;
— Assessing the conformity of Swiss instruments and measures with international and especially European law;
— Developing options for solving and/or mitigating target conflicts in spatial planning, environmental and energy legislation; options and limitations regarding the acceleration of planning and approval procedures
— Analysis and normative evaluation of legal framework conditions in the case of long-term investments.

Modelling, system-wide assessments and the transition process

Energy modelling and scenarios for decision making

- Improving and developing new energy models and scenarios for covering distributional aspects, disruptive change, and uncertainty;
- Improving and developing appropriate tools and methods (e.g., macroeconomic models) for scenario development and simulation of various energy policy options;
- Enriching energy scenarios with new scenarios that focus on the key players and society as a whole, e.g. behaviour and lifestyles, land use, employment, housing, digitization, procurement, leisure-time activity, mobility, etc.;
- Improving energy demand modelling to account for individual behaviour and social interactions;
- Developing appropriate modelling tools for holistic analyses of the highly dynamic and digitized energy system, including model comparison standards and improved handling of uncertainty.

System-wide assessments

- Assessing policies for decarbonizing the Swiss mobility and heating systems at the system-wide level;
- Simulating the impacts of various policy options and market designs on the energy supply, the competitiveness of the Swiss industry, and the environment;
- Evaluating mechanisms aimed at further separating energy and economic growth;
- Developing and assessing strategies for adapting to climate change in the energy sector (e.g. cooling or availability of water).

The transition process

- In the context of the energy strategy, understanding and analyzing the complexity and interdependency
  - › of different sectors, including interactions between technological, societal, political and individual change;
  - › of the interplay between different strategies such as efficiency, sharing economy, digitization etc.
- Understanding and analyzing social interactions in different institutional contexts, including social learning and social innovations, governance, movements, grassroots, communities, collaboration and citizen participation processes, acceptance of and resistance to new technologies and policies;
- Understanding and analyzing spatial interdependencies, including niche/regime/landscape interactions, international/national/cantonal/local decision-making and implementation processes in multi-level contexts;
- Development of strategies to avoid reductions in quality of life during the energy system transformation.

LIVING AND WORKING

Sites and districts

- Reliability of energy systems with local renewable energy sources as well as energy-efficiency measures to boost supply security;
- Buildings and sites (incl. electromobility) as energy service providers: What load and supply flexibility can a building or site offer the electricity or thermal network and at what price? Allocation of these flexibilities by building, site or district? Role of innovative ICT approaches?
- From building energy management to site/district energy management: concepts, planning, operation
- Development of planning tools for better system integration of renewable heat, gas and electricity (incl. biogenous, synthetic CHP systems);
- Digital platforms for integrative, multidisciplinary and collaborative planning with the inclusion of energy aspects, using georeferenced data as need be;
- Further development of existing sustainability strategies like "2000-watt sites" or "Smart Cities and Communities" along the line of climate neutrality at the district level as well as demonstrations of these new approaches. Analyze, develop and test the concepts, processes, measures and boundary conditions based thereupon;
- Concepts for climate adaptation for enhancing the resilience of buildings, sites and cities in relation to global climate development and urban and local microclimates (including the "heat island" effect).

Buildings

- Lean retrofit: Cost savings through simple, robust or scalable renovation solutions that are less complex and highly effective, including digitalized, data- and model-based energy renovation of buildings;
- Energy-efficient and cost-effective systems for building envelope renovation. New concepts, approaches, technologies (e.g. membranes);
- Reduction of energy performance gaps on the basis of user-friendly buildings (inter alia through user feedback-based control, user interfaces, avoidance of rebound effects) and automated operating optimization;
- Innovative glazing, window systems and façade elements with improved, modifiable properties such as light transmission, heat input and storage;
- Thermal insulation: new materials and constructions that are energy-efficient, environmentally sound, cost-effective and space-saving;
- Minimization of material flows, LCA and increased recyclability towards a circular economy;
- Role of BIM in LCA and energy optimization (e.g. via BIM-assisted facility management);
- Role of machine learning and artificial intelligence for purposes of consulting, planning, construction and operation (e.g. fault diagnosis);
- Redesigning building culture, construction, operation and decommissioning processes so as to enable and accelerate the implementation of new technologies and concepts (take into consideration links between a circular economy, construction processes, flexibility of use and LCA).

Building technology

Decentralized technology

- Short-term heat storage: Integration of local heat and electricity storage facilities into the energy system;
- New heat storage technologies (thermo-chemical, latent);
- LCA, materials and cost reductions through decentralized storage systems;
- Efficient, legionella-proof domestic hot water systems for building renovation;
- Alternative concepts for residential ventilation in existing buildings with a lower degree of intervention, less grey energy expenditure and good, robust performance.

Thermal and electrical utilization of local renewable energy

— New types of solar façade elements (PV, solar thermal power, PVT) with flexible geometry and a good optical appearance for better building integration or suitability as a structuring element;
— Smart solar/solar-thermal systems (integration in energy management systems, function monitoring, automated fault message for fitters, self-consumption management for hybrid systems);
— Reduction of electricity demand during the winter through storage facilities and local energy provision (solar, combined heat and power, avoidance through substitution of waste heat, geothermics, etc.).

Heat pumps and combined heat and power (CHP)

— High-performance heat pumps for building renovation;
— Cost-effective, emission-neutral CHP systems (e.g. fuel cells) as a contribution to a climate-neutral building stock.

Cooling supply

— Potentials, concepts and technologies for energy-efficient, resource-saving space cooling in urban areas, integration of cooling and heating thermal storage facilities, resource- and cost-optimized solutions for active and passive cooling of buildings (incl. solar shading systems);
— Efficient retrofit systems (alternatives to split air-conditioning units);

Information and Communication Technologies (ICTs)

— Innovative ICT-based solutions for building automation, measurement, control and regulation technologies;
— Cost-effective sensors and controllers for networked operation.

Monitoring and operation optimization

— Analysis of the compliance of planned values with real consumption data for new buildings and renovations, identification and analysis of the causes of any discrepancies (diagnostic system) and derivation of recommendations;
— Development of cost-effective methods for energy consumption surveys and minimization of operating energy and energy for construction-related mobility;
— Analysis of technological possibilities for system self-regulation and analysis of its long-term effectiveness.

People, markets and policies

— Investigation of the possibilities (new approaches to incentives, standards and regulations) with a view to accelerating the transformation of the building stock and increasing the renovation rate;
— Analysis of who can most rationally use and operate critical energy infrastructure (network operators, homeowners, energy producers). Derivation of recommendations for action and policy and development of new business models;
— User needs in relation to and acceptance of building automation solutions with due consideration for privacy and security, flexible-use concepts and building-user interfaces;
— Investigation of influencing factors, drivers and obstacles as well as possible incentives that lead building owners to form networks and join energy supply systems (new participative processes and business models for all stakeholders, including tenants).

MOBILITY

Mobility as a comprehensive system

- Analysis on the potential of CO_2 emission reduction through improved multimodal transportation concepts;
- Analysis on the integration of renewable electricity production and the role of electromobility;
- Solutions for the full or partial electrification of heavy-duty road and maritime cargo transportation;
- Lowering CO_2 emissions in commercial air travel through the use of renewable fuels and partial electrification of the propulsion and auxiliary systems;
- Holistic monitoring of the environmental impact of selected aspects of the mobility system, such as user behaviour as well as fuel and propulsion system mix;
- Investigation of the impact of a large fleet of electric vehicles on the electrical grid;
- Analysis of the overall emissions of vehicles and their drivetrain technologies from a life cycle perspective, including potential impacts on the emissions from the electrical grid;
- Assessment of the impact of different penetration rates of various vehicle drivetrain technologies on the electrical grid infrastructure, for instance regarding the need for grid expansion or reinforcement;
- Investigation of questions regarding the acquisition, availability, security and property of mobility data.

New and intelligent mobility concepts through ICT technologies

- Investigation on how to achieve intelligent and efficient passenger and freight transportation systems in densely populated areas, both on the ground and in the air;
- Further development and implementation of concepts for smooth operational management in the public transport network;
- Reduction of inaccuracies in ecological balances and life cycle assessments by improving both the criteria and methodology of data collection, including addressing issues of data availability and estimating techniques for future scenarios;
- Investigating the implementation of modern ICT solutions for adequate business models for new mobility concepts, such as vehicle-to-X applications;
- Investigation of induced and rebound effects on the energy consumption of new mobility concepts;
- Investigation of the effects of new technologies on the logistical distribution of goods, such as possible modal choices and improved disruption resilience in freight logistic chains;
- Analysis of novel freight transportation solutions (e.g. platooning, alternative automated transport concepts) and their effect on the nature of vehicles (i.e. the conception of what an automobile is);
- Analysis of the role of electric vehicle-based demand side management with respect to the balancing of the electrical grid.

User behaviour, societal change, spatial planning, economic and regulatory aspects

- Development of measures and offers aimed to enhance the attractiveness of public transport and combined mobility;
- Analysis on how spatial planning, collaborative mobility and other measures can be used to reduce transport demand;
- Studies on the potential of improved marketing strategies by mobility providers;
- Investigation of approaches to promote pedestrian and bike traffic, for example in combination with health promotion measures;
- Socioeconomic and sociotechnical analysis of technologies, required infrastructure, business models, instruments, incentives and policies regarding work-related and recreational traffic, its effect on mobility demand and energy consumption, as well as possible rebound effects;
- Studies on the potential of improving the availability, connectivity, infrastructure, and energy efficiency of sustainable options in the choice of modalities;
- Visual analysis and simulation of vehicle traffic and user behaviour using artificial intelligence;
- Investigation of demand response measures, for instance through variable pricing, and its effect on the mobility system;
- Investigating public perception of novel drivetrain and vehicle concepts.

Energy storage and substitution of fossil fuels

- Development of hybrid energy storage solutions for vehicles, including e.g. hydrogen, batteries, and super caps;
- Optimization of battery properties regarding energy density, lifetime, materials, safety, and costs, fast charging capability, and second life applications.
- Derivation of scenarios regarding the establishment of synthesis and distribution infrastructure for synthetic fuels for road, air and sea traffic;
- Analysis on the influence of alternative energy carriers (e.g. hydrogen, synthetic and bio fuels) on CO_2 and other emissions when used in conventional combustion engines.

Vehicle efficiency

- Further development and optimization of vehicle components and systems for the efficient and economical use of electricity and alternative energy carriers (e.g. hydrogen, synthetic and bio fuels);
- Weight reduction of vehicles to reduce their energy requirements using novel materials, manufacturing technologies, and lightweight structural components;
- Improvement of the energy management of vehicles, optimization of the drivetrain, implementation of energy recuperation systems and reduction of non-traction-related energy requirements (ancillary components);
- Increase efficiency of conventional combustion engines for applications where electrification and/or fuel substitution is difficult, such as long-distance freight on land and water, as well as air travel.

ENERGY SYSTEMS

Energy networks, system integration, sector coupling and carbon capture

System integration
— Optimal control architectures of the different network infrastructures (heat, gas, electricity, water and potentially CO_2, hydrogen);
— optimized local energy production and self-consumption.

Sector coupling
— Development of technologies for sector coupling (e.g. power-to-X) and analysis of the environmental and economic impacts.

Heating and cooling
— Demand forecasting for heating, cooling and electricity of different sectors including changes in cooling loads due to climate change;
— potential cooling technologies and solutions for existing neighbourhoods;
— evaluation of optimal district heating design configurations.

Carbon capture
— Improve cost and energy efficiency for clean energy potential carbon dioxide removal technologies (e.g. bioenergy and CCS – BECCS;
— direct air capture of CO_2 and storage or conversion);
— potentials, co-benefits and trade-offs from a global perspective.

Digitalization

Data analysis
— Big data analysis for planning and control;
— data-driven interoperability platforms and asset management.

Data sharing and privacy
— Development of data sharing platforms for energy market actors and anonymization mechanisms

Data-driven models
— Data-driven models for the analysis and control of large-scale networks;
— exchange between transmission and distribution systems operators.

Data security aspects
— collection, aggregation, broadcast control signals, cyberattacks, protections

Crosscutting issues
— Application of artificial intelligence;
— inclusive, digital marketplaces to enable increased customer participation;
— power consumption of digitalization and strategies for consumption reduction.

Power grids

Technologies and data management
— Quantification of flexibilities on the customer side;
— planning and operation of distributed storage systems (including electric vehicles);
— data sharing and interoperability, asset management, data security aspects.

Flexibilities
— Ancillary services from distribution to transmission grids;
— integration of small- and large-scale hydro assets;
— multi-time horizon and multi-spatial scale forecasting, aggregation of resources.

Transmission grids and markets
— Resilient operation and planning of transmission grids;
— pricing schemes vs network use;
— integration of policy objectives and market structures and within the EU context.

Control methods and protections
— Distributed sensing;
— resilient protection and fault-location systems;
— function-based central vs decentralized controls;
— stability of transmission grids experiencing reduced inertia

Grid components
— Performance assessment of power electronic architectures;
— advanced technologies for medium frequency conversion;
— materials for high-performance insulation of HV grid components.

Storage

Storage Concepts
— Future energy supply/demand situation;
— environmental and economic impact of storage technologies;
— best storage options (centralized/decentralized, short-/mid-/long-term, heat/electricity/ chemical, location-time).

Pumped hydro storage
— Cost-effective retrofitting options, dynamics of reversible storage and generation systems

Compressed air energy storage
— Efficiency increase by novel plant designs, cavern options in Switzerland;
— turbomachinery and thermal energy storage for dynamic operating conditions.

Long-term storage
— Advanced concepts of catalytic chemical and electrochemical CO_2 reduction;
— transformation of biomass to storable biofuels;
— novel concepts for H2 generation.

Batteries
— Material availability and manufacturing concepts for large-scale battery production;
— cost effective and reliable technologies for stationary and mobility applications;
— recycling and second-life applications including economic and environmental aspects.

Heat storage
— Thermo-mechanical stability of solid-phase sensible heat storage options for heating and cooling;
— heat transfer and degradation in phase change material systems for latent heat storage;
— stable coatings and heat exchangers for thermochemical heat storage;
— large scale underground heat storage.

Scenario modelling and systems analysis

Pathways towards net-zero GHG emissions
— Energy system modelling for cost-optimal technical solutions;
— spatial and time scales and their implications for infrastructure and storage;
— uncertainty aspects in modelling;
— interdependencies of energy technologies in a sector-coupled energy system;
— monitor and benchmark the development of new technologies and impact on the energy system.

Risks
— Include risk aspects into energy system modelling optimization and scenario analysis;
— hazard and risk assessment of single energy system technologies and infrastructures;
— comparative and integral risk assessment across a highly coupled energy system.

Prepare for the unforeseen
— Impact of natural, technical and political disruptions to enhance system resilience and reliability;
— energy system modelling testing the robustness of scenario variants for the impact of e.g. strong reduction of biomass and hydropower availability due to accelerated climate change or sudden nuclear exit following an incident in Europe.

Renewable energy, Natural resources

Hydropower

Hydropower production

— Innovative approaches to regulatory compliance (Water Protection Act);
— hydropower potential in sensitive locations.

Short-term flexibility

— Innovative flexibility solutions;
— plant digitalization and real-time monitoring to optimize production
— O&M;
— hybridization of hydropower plants by using stationary batteries.

Shift generation to winter months

— Identification of potential of deglaciation for new periglacial dams;
— dam-heightening, interconnection of reservoirs, intra-seasonal runoff forecasts;
— minimized volume loss from sedimentation in infrastructure-critical storage reservoirs

Operational safety research

— Techniques for extending useful lifetimes as well as detection of safety-critical failure modes;
— design and testing criteria for novel hydraulic structure materials for extended operating ranges;
— impact and mitigation of climate change on safe and continued hydropower system operation.

Photovoltaics (PV)

Photovoltaic cells

— Cost reduction by improving the conversion efficiency and/or manufacturing technology;
— novel high-efficiency devices for broader range of applications (incl. light-to-X/fuel conversion).

PV modules

— Processes and materials for improved operational reliability of modules, systems and plants;
— novel industrial manufacturing methods and test protocols;
— improved PV lifecycle characteristics.

PV systems, solar building and unconventional systems

— Development of industry standards;
— digital tools to accelerate conception and installation of PV systems in buildings;
— potentials, performance and costs of PV installations in unconventional infrastructures.

Integration of PV in the energy system

— Reliable, temporally and spatially accurate PV generation forecasting;
— PV integration into low-voltage networks and massive penetration of PV in the grid;
— methods to assess the system value of PV.

Bioenergy

Biomass as feedstock

— Biomass mobilization, logistics, pre-treatment and storage;
— concepts and processes to maximize biomass use from waste;
— utilization of new bioenergy substrates for high-value energetic use.

Biomass for gaseous and liquid fuels and the chemicals industry

— Fermentable biomass resource base through novel microbiological processes;
— biofuels with minimized impact on refining and distribution infrastructure;
— approaches for the flexibilization of biogas production along the process chain.

Biomass combustion

— Clean biomass combustion technologies;
— innovative concepts and processes for providing process heat with low emissions.

Utilization of biomass in energy storage and for climate control technologies

— Novel ways to utilize biogenically sourced CO_2 for power-to-gas and power-to-liquid schemes;
— biomass coupled with carbon capture and storage as a net negative emission technology.

Utilization of biomass within the energy system
— Optimized integration of bioenergy plants including sector coupling;
— end and side-products of biomass conversion for closed material cycles;
— biorefinery concepts.

Geoenergies
Searching and finding renewable subsurface energy resources
— Geology, architecture and dynamics of Switzerland's subsurface;
— integrated prospecting methods to improve probability of success of a first exploration well;
— reduced uncertainty via advanced static and dynamic resource and reservoir modelling.

Renewable geothermal subsurface resources
— Heating, cooling and storage concepts for urban and district heating areas;
— novel concepts to reduce drilling/well completion costs and to enhance reservoir performance;
— drilling, completion and stimulation technologies for hydrothermal and geothermal systems.

CO_2 in the subsurface for large-scale CO_2 storage and utilization
— CO_2-injectivities in deep saline aquifers to constrain Switzerland's CO_2 storage potential;
— CO_2 as a heat exchange medium in geothermal applications for direct use and power generation

Safety and systems research
— Novel methods to observe, control and mitigate risks associated with induced seismicity;
— safety research of co-located geothermal and hydrocarbon resource exploration and production;
— value of geoenergy utilization to Switzerland's energy system

Subsurface Storage of Heat and Gas
— H2/CH4-injectivities in deep saline aquifers to constrain Switzerland's gas storage potential;
— explore sub-surface heat storage for heat grids for seasonal heat storage.

Wind
— Swiss specific wind power application aspects, e.g. plant layout, forecasting, noise or icing.

Other solar technologies – beyond photovoltaics
Solar-thermal (low temperatures)
— Collector stagnation temperature;
— unpressurized drain back;
— simplified and standardized systems;
— PVT collectors.

Solar-thermal (high temperatures)
— Cost reduction of concentrating solar technologies;
— temperature-stable heat transfer fluids;
— integration of solar high-temperature heat in industrial processes.

Solar fuels and materials
Thermochemical approaches
— Efficient, stable and earth-abundant redox materials;
— optimized coupled heat and mass transport in solar reactors;
— efficient solar fuel processing and scalable processes for solar materials;

photo-electrochemical (PEC) approaches
— Efficient, stable and sustainable materials for PEC water splitting;
— scalable PEC devices by optimizing coupled heat, mass and charge transport;
— PEC materials and routes for reactions beyond water splitting.

Nuclear energy and radioactive waste

Long-term operation and ageing management
— Performance of deterministic and probabilistic safety assessments of Swiss nuclear power plants;
— long-term operation, structural integrity, material ageing;
— material and thermal hydraulics behaviour of new complex fuel assembly designs;
— safety-technology upgrades, e.g. retrofitting passive safety systems, accident-tolerant fuel types;
— investigation on severe accident management measures and implementation of new guidelines;
— risk studies on the impact of external hazards and cyberattacks on nuclear power plants;
— safety assessments of load-follow operation scenarios for the Swiss nuclear power plants;
— maintenance of large, critical nuclear infrastructures in Switzerland

Decommissioning and dismantling of nuclear power plants
— Safety and radiation protection of the decommissioning process of nuclear power plants;
— optimal procedures for dismantling, decontamination and conditioning of radioactive waste;
— advanced measurement techniques for the clearance of radioactive waste;
— spent fuel assembly behaviour during long-term dry intermediate storage

Radioactive waste and deep geological disposal
— Challenges related to the implementation of the new radiation protection ordinance;
— research support on geochemistry and nuclide transport process modelling for the Sectoral Plan (Sachplan geologische Tiefenlager);
— impact of low-dose radiation on environment and public health;
— impact of long-term dry storage of spent fuel (ageing processes)

Dimensioning and materials of transport and storage casks;
— properties of Opalinus clay (host rock) and their variability affecting tunneling and processes in and around a deep geological repository;
— long-term landscape evolution providing keys to the understanding of future erosion processes (glacial, fluvial)

Advanced and innovative reactor concepts
— Participation in international research activities on advanced reactor technology options and novel developments through Euratom, OECD/NEA, IAEA, Generation-IV International Forum;
— research on improved safety and sustainability features of the main Generation-IV reactor concepts;
— assessment of advanced and novel (closed) fuel cycles in terms of life cycle requirements;
— potential of advanced systems like Accelerator Driven Systems or Sodium Fast Reactors;
— monitoring of spent fuel and nuclear waste partitioning technologies.

INDUSTRIAL PROCESSES

This section lists a selection of proposed research topics for the period from 2020 to 2024, collected and prioritized in a broad stakeholder consultation process. Every topic cluster describes an innovation pathway towards the vision of resource efficient industrial processes in a circular economy. Priority was given to technology innovations that promise to significantly reduce the overall footprint of industrial processes or enable efficiency and resilience in other sectors. Non-technological research topics aiming at understanding and overcoming implementation barriers are also included.

Products and processes for energy efficient value chains;

Materials for reduced product footprints

— Substitution of fossil raw materials with locally available bio-based or waste materials;
— Sustainable carbon capture, utilization and storage (CCUS) processes to close the carbon cycle;
— Alternatives to composite materials;
— Coatings and surface treatments enabling new product functionalities;
— Materials that enable longer maintenance and replacement cycles of durable goods;
— Materials and product design for improved recyclability and integrated end-of-life management.

Innovative and optimized production processes

— Catalysis and metabolic engineering for faster, more efficient and selective material transformations at benign operating conditions;
— Biotechnical syntheses and downstream processes with low energy demand;
— Targeted energy inputs enabled by power electronics, e.g. in drying processes;
— Advanced separation processes (e.g. sorption, membranes, reactive separation) with high yield and selectivity at minimal energy consumption;
— Hybrid processes with combined unit operations (e.g. reaction and separation) to eliminate intermediate steps and minimize losses;
— Equipment materials and design for minimal heat and product losses during processing and simplified cleaning and changeover routines;
— Continuous processes with stable operations and minimized losses, esp. in solids processing (e.g. agglomeration, filtration of pharmaceuticals and specialty chemicals/novel materials, fluid-dynamically optimized design and advanced manufacturing techniques for compact components with improved heat and mass transfer characteristics,
— Compact and affordable zero-energy consumption sensors for remote process monitoring
— Dynamic control and scheduling schemes in highly integrated processes;
— Digitalization concepts for the monitoring, control and optimization of the energy consumption in production facilities;
— Development of software and ICT hardware according to energy efficiency principles (energy-aware computing).

Closing resource loops with minimal energy consumption

— Efficient processes to refurbish products, recycle materials and treat residual waste at the appropriate scale with minimal energy input;
— Flexible process designs that can accommodate the variability and heterogeneity of flows in a circular economy;
— Material reuse and heat integration to improve the energy and emission footprint of waste handling
— Integrated approaches to improve the resource efficiency and flexibility of waste water treatment at various scales;
— Systematic approaches to retrofitting of production plants, apparatuses and components for improved energy efficiency and longer life times.

Systems perspectives in planning and development

- Integration of future-oriented LCA based methods into product design and process development to promote energy and resource efficiency throughout the entire product life cycle;
- 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;
- Generic process models and virtual production plants for holistic scenario analyses in early development and planning stages;
- Sector blueprints with assessments of actual vs. minimum energy consumption for the prioritization and planning of efficiency and integration measures.

Industrial processes in a sustainable and resilient energy system

Products and processes for future energy technologies

- Efficient and environmentally benign processes for the pre-processing of complex biomass to be used for materials and fuels;
- Integrated production processes for climate-friendly biobased or synthetic fuels, incl. power-to-gas and or other power-to-X approaches;
- 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.

Integration of production plants and industrial sites into future ready energy systems

- Sophisticated methods and practical tools for the design of efficient, reliable and flexible process integration solutions, from the level of production plants up to large-scale systems including retrofitting of existing plants;
- Efficient systems for the recuperation, exchange and storage of chemical, thermal and electrical energy in industrial production processes as well as in background ICT systems;
- Integration of fluctuating renewable energy sources (solar thermal, ambient heat, photovoltaics, etc.) into production processes with storage and optimal scheduling;
- Innovative process control schemes to harness the flexibility and resilience advantages of integrated systems. Valorization concepts to enable the use, transformation and exchange of residual heat, esp. at low temperatures and in disperse energy streams (e.g. heat pumps, ORC);
- Electrification of production processes (e.g. heat pumps) to enable decentralized power generation
- Multi-energy systems for the provision of heat and power to industrial plants in networks with fluctuating energy sources and dynamic use patterns;
- Industrial symbiosis to reduce and flexibilize energy demand and create business opportunities from the local exchange of heat, power, material resources and equipment;
- Optimization methods for the design and operation of multi-energy infrastructures.

Sector-specific research in the social sciences and humanities

- — Barriers to energy optimized production planning and operations;
- — possible solutions, incl. management models;
- — Business models that facilitate energy efficiency and system integration, with associated monitoring and management tools;
- — Success factors in the market launch of new energy efficient products, incl. training and education;
- — Definition of context sensitive multiple benefits that reach beyond energy aspects;
- — Purposeful stakeholder engagement in multi-criteria assessments for decision support.