RESEARCH PROGRAMME GEOENERGY

Geoenergy systems can play a key role in achieving the targets set by Switzerland's energy and climate strategy, as well as in shaping future energy systems, as they can provide a reliable and resilient foundation for both thermal and electrical power. Their ability to deliver consistent baseload heat and electricity, coupled with their potential as stable and scalable underground energy storage solutions makes them a key enabler for efficient energy conversion and enhanced grid stabilization in Switzerland's renewable energy future.

The SFOE's Geoenergy research programme promotes a holistic approach to the subsurface for energy purposes, to ensure the sustainable use of subsurface resources. The Research concept, in alignment with the Energy Research Masterplan of the Federal Government 2025–2028, is focused on accelerating breakthroughs in subsurface energy systems through cutting-edge science, innovative technology, and digitalization.

PERSISTENT CHALLENGES

The inherent uncertainty and often insufficient natural permeability of subsurface reservoirs have remained a significant impediment to widespread geoenergy development in Switzerland. This critical limitation directly translates to elevated project risk, particularly concerning well productivity and long-term sustainability. High upfront costs for exploration and drilling, coupled with the potential for encountering unproductive or poorly permeable formations, contribute to a financial risk profile that often discourages investors and delays progress.

PRINCIPLES/BASIS

The Geoenergy Research concept aims to address these challenges and unlock the potential of geoenergy across a variety of applications. It supports both upstream (e.g. resource characterization, exploration, drilling, production) and downstream research (e.g. heat distribution, electricity generation, storage, end-use).

The emphasis is on projects with a tangible impact and a clear pathway for practical implementation within Switzerland. The integration of relevant regulatory, societal, and economic considerations into the research design and execution is also desirable, with the explicit aim of generating outputs that can provide evidence as a basis for informed policy-making, public engagement, and economically viable solutions. The Geoenergy Research programme is closely linked to the Geothermal Market Support programme, and research projects should provide the innovation needed to resolve bottlenecks, while ongoing Market Support projects provide valuable real-world data to validate new ideas and technologies. Thus, mutual reinforcement between research and market deployment is encouraged.

Projects funded by the SFOE are expected to be made accessible under open-source principles, including data, codes (where applicable), and publications with minimal restrictions on use and redistribution.

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THEMATIC AREAS

Four **thematic areas** (A–D) are identified to guide research efforts towards critical challenges and opportunities. The **Appendix** lists **key topics** within these four areas, which are used to prioritize submitted applications.

A) Prospection and subsurface de-risking: Focus is on innovative methods to improve knowledge of the subsurface, with specific attention given to key aspects such as reservoir permeability and fluid flow. Such methods include advanced geophysical imaging, geochemical prospection, hydrogeological testing, reservoir modelling, as well as improved geological and hydrogeological models, and uncertainty quantification.

B) Unlocking subsurface energy potential: Priority is the development of alternative methods for enhancing reservoir permeability and its monitoring (e.g. microseismicity), as well as alternative energy harvesting (e.g. AGS). This includes novel stimulation, drilling methods and predictive models to improve permeability access and management, thermal energy extraction, and overall subsurface energy application efficiency.

C) Felxibility and integration into energy systems: Emphasis is placed on enhancing system flexibility of subsurface energy storage technologies and their integration into smart energy systems, grids, and heating and cooling networks. This thematic area includes Underground Thermal Energy Storage (UTES), in addition to exploratory methods to investigate storage possibilities for hydrogen (UHS) and other Power-to-X derivatives.

D) Sustainability, risk management and affordability: Attention is on ensuring the long-term sustainability, risk management and affordability of the resource supply by focusing on sustained permeability, minimal thermal decline and circulation fluid loss, environmental impact mitigation and wider system benefits of geoenergy systems. This area involves also developing strategies to improve public perception/acceptance and economic competitiveness.

For each of these themes, where appropriate, research projects should integrate smart digital technologies, such as automation, artificial intelligence (AI), and machine learning (ML). Digitalization and effective management of large and complex data sets are key to advancing research and enabling better modelling, analysis, and decision-making.

This research concept does not categorically exclude other research areas of interest (e.g., the use of CO_2 as working fluid, methods to investigate Natural Hydrogen, Compressed Air Energy Storage (CAES), etc.); therefore, applicants with novel geoenergy research ideas beyond those specifically detailed in the appendix are encouraged to contact the programme managers.

Specific geological CO_2 Storage topics - despite having many synergies with geoenergy aspects - are not addressed within the scope of this document: readers seeking information on geological CCS should refer to the dedicated research concept page. Similarly, while this document touches upon several subsurface energy storage aspects, a broader list of thermal storage research topics is also available within the dedicated SFOE Solar Heat and Heat Storage Programme .

Depending on availability, funds are allocated according to a bottom-up principle and quality control. Applications can be submitted at any time.

PROJECT PROPOSAL PROCEDURE AND EVALUATION

Interested applicants are encouraged to email an expression of interest with a project outline (max 2–3 pages) to the SFOE contacts below stating: thematic area, key topic(s) from the Appendix, project scope, project partners and **relevance to Switzerland**. Following an initial assessment, suitable applicants will be invited to prepare a more comprehensive application for their project (SFOE-specific full proposal and financial sheet). Please note that an invitation to submit a full proposal does not guarantee acceptance nor funding of a project.

The evaluation of the applications is conducted according to the following criteria:

1. priority of the key topics (i.e., please refer to the Appendix),
2. scientific/technical content and quality of the proposal,
3. demonstrated state-of-the-art reference and advancement, and
4. completeness of all the elements in the "SFOE-specific full proposal".

Projects are expected to be situated within TRL 3–8 and may start at any TRL within this range, provided that they demonstrate a clear and credible pathway for TRL progression during the project's timeframe. Wherever appropriate, participa-

tion from industry partners or cantonal/municipal authorities should be sought to ensure the research remains relevant to technological development and societal needs. An appropriate contribution of in kind and/or third-party funding is expected.

Applications of equal merit from organisations and institutions with no/little prior SFOE funding history will be prioritized.

Interested applicants are encouraged to consult information on ongoing projects in ARAMIS to identify potential synergies and, in particular, avoid duplication within the research programme.

COOPERATION

The Geoenergy Research Programme promotes collaboration across national and international R&D networks to strengthen knowledge exchange, and actively foster collaboration among a broad range of stakeholders in the research and innovation ecosystem to align efforts across institutions and borders. The SFOE is involved with the following national and international organisations and bodies. For more information or to get involved, please contact us.

- **Switzerland:**
  - other federal offices (e.g. swisstopo, FOEN), Geothermie-Schweiz, cantonal and municipal energy offices.
- **International:**
  - IEA Geothermal Technology Collaboration Programme: Switzerland actively participates in various working groups and tasks. Researchers and industry partners are welcome to contribute or share new ideas.
  - GEOTHERMICA Initiative: Supports collaborative research with other member countries and offers opportunities for transnational project development and co-funding.

CONTACTS

- **Florence Bégué**: florence.begue@bfe.admin.ch
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- Website Research Programme

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APPENDIX

THEMATIC AREA A
PROSPECTION AND SUBSURFACE DE-RISKING

1. **PERMEABILITY CHARACTERIZATION:** innovative geophysical methods for improved characterization of geothermal reservoir permeability, fracture properties, complex flow dynamics, and fluid detection capabilities to better resolve fluid pathways and fracture connectivity (advanced permeability imaging techniques, borehole geophysics and logging, conductive fracture imaging, hydrogeological, well and tracer testing, novel seismic imaging, electromagnetic and remote sensing methods, etc.), incl. automation methods to analyse wellbore image logs and seismic data for improved fracture identification and discrete fracture network (DFN) generation, characterization and integration with geomechanics, etc.

2. **GEOCHEMICAL ASSESSMENT:** advanced isotopic analyses, high-resolution and in-situ geochemical monitoring, novel sam pling and analytical techniques (downhole and fiber optic sensors, miniaturized field analysis devices, etc.), reactive tracers, geochemical models to derive site-specific parameters, incl. the expansion of thermophysical property databases (e.g. density, viscosity, heat capacity) of site-specific geothermal fluids as input parameters for corresponding models, automated data interpretation and pattern recognition within large geochemical datasets, geothermometry, etc.

3. **IN-SITU STRESS EVALUATION:** novel methods and tools for geothermal reservoir geomechanics and in-situ stress profiling, specifically to improve the understanding of the stress-dependent nature of permeability (incl. downhole stress sensors for continuous monitoring of stress changes during drilling, stimulation and production), solutions to address stress heterogeneity (incl. around boreholes), and development/training of automated stress interpolation/extrapolation methods, automated interpretation of wellbore breakouts and drilling-induced fractures, stress magnitudes from indirect data prediction, uncertainty quantification, non-linear relationships between stress, fracture aperture and permeability, real-time stress change monitoring and permeability evolution prediction, etc.

4. **UNCERTAINTY QUANTIFICATION**: advanced geostatistical techniques, probabilistic geomodelling, topology optimization and ensemble methods, algorithms for automated geothermal data integration and spatial modelling, and frameworks to assess and propagate uncertainties through the modelling workflow for more reliable predictions and decision-making in exploration.

5. **GEOTHERMAL MAPPING:** innovative digital mapping and conceptualization techniques, hierarchical and stochastic subsurface models, incl. AI/ML methods for large data integration, training on existing geothermal data for pattern recognition and predictive modelling, targeted exploration strategies and prospection favourability for geothermal resources.

6. **NUMERICAL MODELLING:** novel geothermal reservoir, reactive transport and Thermo-Hydro-Mechanical-Chemical (THMC) models, incl. advanced digital twins, physics-informed neural networks (PINNs) and training/development of AI/ML algorithms to improve and speed up simulations, history matching, uncertainty quantification and sensitivity analyses, parameter inversion to predict permeability, optimization of reservoir management, thermal breakthrough forecasting, evaluation of fluid-rock interaction processes, acceleration of geochemical calculations, surrogate modelling for complex reactions, etc.

THEMATIC AREA B
UNLOCKING SUBSURFACE ENERGY POTENTIAL

1. **PERMEABILITY DEVELOPMENT:** developing alternative approaches for permeability enhancement and monitoring in different Swiss geologic and geomechanics settings (for any type of reservoir), incl. novel stimulation techniques, multilaterals, zonal control/isolation techniques, temperature-delayed flow diverters and thermal breakthrough mitigation, advanced data-driven methods should be considered to improve stimulation operations, optimal parameter selection (e.g., fracture number, spacing, etc.), adaptive control and real-time data processing from downhole sensors, optimal injection schedule and perforation parameter prediction/optimization to ensure favourable fracture initiation, and microseismic cloud monitoring.

2. **ADVANCED GEOTHERMAL SYSTEMS (AGS):** innovative working fluids for enhanced heat transfer, novel well completion and integrity solutions, coaxial vacuum insulated tubing (VITs), multi-laterals and complex well architectures, system optimization, predictive models of thermal drawdown, real-time monitoring and control, etc.

3. **DRILLING METHODS:** non-conventional and enhanced rock disintegration technologies, advanced wellbore construction and integrity solutions, intelligent drilling automation, with algorithms for drilling parameter optimization, historical drilling data and real-time sensor information training, autonomous trajectory control, predictive maintenance of downhole tools, targeted laboratory studies to validate performance under controlled conditions, techno-economic analyses to assess cost-effectiveness, and scalability in real-world geothermal drilling operations.

THEMATIC AREA C
FLEXIBILITY AND INTEGRATION INTO ENERGY SYSTEMS

1. **UNDERGROUND THERMAL ENERGY STORAGE (UTES):** integration of UTES with smart energy systems and grids (incl. intelligent control strategies and optimization algorithms that can manage the charging and discharging of UTES), high-temperature UTES for industrial applications (incl. thermal, hydraulic, and mechanical behaviour of geological formations), seasonal storage injection/extraction strategies coupled with Advanced Geothermal Systems (AGS), and integration in district heating & cooling networks and anergy grids, innovative smart grid concepts in relation to thermal grids, varying supply and demand and opportunities for contributions of geoenergy to sector coupling. Novel methods for operational risk management, and studies of possible environmental risks and long-term behaviour of thermal storage as a function of cyclic heat loading, performance prediction, heat exchanger and geometry placement optimization, etc.

2. **UNDERGROUND HYDROGEN STORAGE (UHS) AND OTHER DERIVATIVES FROM POWER-TO-X**: investigations and tools for underground hydrogen flow dynamics system modelling, advanced monitoring methods, well design and operational optimization solutions, incl. analysis of mechanisms of hydrogen loss (e.g., diffusion, microbial consumption), storage integrity, etc.

THEMATIC AREA D
SUSTAINABILITY, RISK MANAGEMENT AND AFFORDABILITY

1. **INDUCED SEISMICITY:** novel induced seismicity risk mitigation, monitoring, and management strategies, incl. AI/ML-driven induced seismicity monitoring and analysis, novel algorithms for seismic event detection, real-time event location and characterization, automated phase picking, pattern recognition and anomaly detection, and training on data from diverse Swiss geological settings.

2. **LONG TERM PRODUCTIVITY**: innovative management methods to ensure long-term and sustained geothermal reservoir permeability and productivity, intelligent flow management and novel methods for enhanced circulating fluid recovery in EGS (reduced fluid loss), reduced thermal short-circuiting and thermal breakthrough, reactive transport models for mitigating permeability reduction due to rock-fluid interaction processes and for preventing corrosion and scaling, studies on novel proppants for different Swiss geologic settings, advanced data-driven methods for thermal decline forecast in EGS and AGS, optimal proppant placement, settling, transport and degradation prediction.

3. **ENVIRONMENTAL AND WIDER SYSTEM BENEFITS AND IMPACTS:** innovative methods to minimize and monitor environmental impacts including water consumption, land use etc., advanced methods to quantify the wider system benefits and impacts of geoenergy, such as contributions to decarbonization, energy system resilience, grid stability, local economic development, etc.

4. **PUBLIC PERCEPTION:** novel communication frameworks and proactive community engagement strategies to address public perception/societal acceptance and concerns regarding seismic risk and water usage associated with geoenergy development.

5. **ECONOMIC COMPETITIVENESS:** innovative methods to enhance the economic viability and competitiveness of geoenergy technologies and projects, incl. sustainably extracting value from geothermal fluids (co-production of critical raw materials, etc.), technologies and workflows to reduce drilling costs, and drilling downtime and maintenance costs reduction.