Roadmap for Deep Geothermal Energy

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ES 2050: Targets for geoenergies

Is the geological capture of CO2 a viable measure to enable carbon-free generation of electricity from hydrocarbon resources?

Can we extract safely the deep geothermal heat and produce at competitive costs 7% of the national baseload supply?
### Deep Geothermal Energy & CO2 Sequestration

**WP1 Geo-energies**
- T1.1 Resource exploration, assessment and characterization
- T1.2 Reservoir modeling and validation
- T1.3 P&D for reservoir creation
- T1.4 Geo-data infrastructure

### HydroPower: usage & infrastructure

**WP2 Hydropower**
- T2.1 Morphoclimatic controls of future HP production
- T2.2 Socio-economic drivers of future HP production
- T2.3 HP infrastructure adaptation
- T2.4 Environmental impacts of future HP operating conditions
- T2.5 Integrated simulation of HP systems operation

**WP3 Innovative technologies**
- T3.1 Geo-energy technologies
- T3.2 Hydraulic machines

**WP4 Integrative activities**
- T4.1 Risk, safety and societal acceptance
- T4.2 Global observatory of electricity resources
- T4.3 SCCER-SoE modeling facility

Capacity building, Technology Transfer, Outreach
A wider perimeter for Geo-Energies, maintaining the focus on exploration and Deep Geothermal Energy and adding new targets on usage of hydrothermal resources for direct heating and heat storage (new T1.3) and direct applications of CO2 for geothermal heat exchange and sequestration.

A new focus (WP5) on P&D projects, with 7 P&D projects under implementation or in an advanced stage of planning, for the implementation of innovative technologies (WP3) and of the integrative approaches and solutions developed in WP1-2, including 4 in geoenergies:

Demo-1: Flagship stimulation experiment in the Deep UnderGround Laboratory
ETHZ, NAGRA, UniNe

Demo-2: Reservoir engineering for heat exchange in Haute Sorne
GeoEnergie Suisse, ETHZ, UniNe

Demo-3: Geneva basin-scale hydrothermal play for heat extraction and storage
UniGe, UniBe, SIG

Demo-4: CO2 geological storage pilot, ETHZ, EPFL, UniGe, UniGE
SCCER-SoE P2: expanded scope, 2

- A clearer focus of the innovation agenda (WP3), now including innovative technologies (T3.1) and computational energy innovation (new T3.2, formerly T4.3), with the opening of a new AP in Computational Energy at USI.

- A clear track for technology developments, with SCCER funding for the selected technologies for up to four years, resulting in either (i) industry support after reaching TRL 5-6 and implementation in P&D projects, or (ii) abandonment if not promising (a possible outcome for high-risk low-TRL technologies).

- A more integrated approach to the future supply of electricity (WP4), with
  1. an expanded scope of the risk assessment activities to encompass also risk of large dams (T4.1)
  2. a wider scope of the evaluation of global electricity resources and technologies (T4.2)
  3. new resources and a closer integration with CREST on the socio-economic-political drivers of electricity supply (new T4.3, expanded from former T2.4)

- A new SCCER Joint Activity on Scenario and Modeling (new T4.4), encompassing all eight SCCERs (lead SCCER-SoE).

- A new SCCER Joint Activity on Socio-political conditions of the extension of hydropower and geothermal energy, with CREST (Lead) and SCCER-SoE.
SCCER-SoE P2: expanded architecture

**WP1 Geo-energies: DGE & CO2 Sequestration**
- T1.1 Resource exploration and characterization
- T1.2 Reservoir stimulation and engineering
- T1.3 Hydrothermal resources and geofluids: exploitation and storage
- T1.4 Geo-data infrastructure and analysis

**WP2 Hydropower: usage & infrastructure**
- T2.1 Morpho-climatic controls
- T2.2 HP infrastructure adaptation
- T2.3 Environmental impacts of future HP operating conditions
- T2.4 Integrated simulation of HP systems operation

**WP3 Innovation agenda**
- T3.1 Innovative technologies
- T3.2 Computational energy innovation

**WP4 Future supply of electricity**
- T4.1 Risk, safety and societal acceptance
- T4.2 Global observatory of electricity resources
- T4.3 Socio-economic-political drivers
- T4.4 Joint SCCER Scenario & Modeling Initiative

**WP5 Pilot & Demonstration projects**

**Capacity building, Technology Transfer, Outreach**
Challenge 1: Resource availability

- In Switzerland we normally find 170-190°C temperatures at 4-6 km depth
- Water at these depths is scarce and not easily found → hydrothermal energy has good potential for heating, less so for electricity
- We need to create deep reservoirs in hot rock (EGS) and circulate water from the surface (petrothermal energy)

- The Swiss ES2050 target for DGE is 7% of Swiss electricity supply → 4.4 TWh/yr, at least 500 MWe installed
  → Switzerland will need to install 20 MWe per year from 2025 to 2050 to meet the ES2050 7% quota

- A sustained water flow of 220 l/s at 180°C is required to generate 20 MWe
  - The main challenge is to create sustainable heat exchangers at depth, systems that will operate for 20-40 years with minimal temperature loss
Challenge 2: Induced seismicity

- Spain, 2011: the largest damaging quake in decades is associated with long-term ground-water extraction in Lorca

- Holland, 2012: Induced seismicity in Groningen, the largest on-shore gas field in Europe, is increasing and is forcing lower extraction rates, with significant impact on Dutch GDP and European supply

- Switzerland, 2006 and 2013: Induced seismicity released during a EGS stimulation (Basel) and hydrothermal injection (St.Gallen)

- UK, 2011: Felt seismicity stopped DGE hydro-fracking in Blackpool

- Italy, 2012: 14 BEuro damage and 24 casualties from a sequence of M5-6 earthquakes, possibly associated to hydrocarbon extraction

- Spain, 2013: the EU-sponsored Castor offshore gas storage field near Valencia is halted after producing earthquakes during the first fill

- Italy, 2014: seismicity is induced by waste-water injection in Val d’Agri
Challenge 3: Cost

Today’s costs are in the order of 40-50 cents/kWh (SFOE), we need to bring them down to 10 Rp./kWh or less, if we want DGE to be a competitive source of band-electricity.

R&D is needed to reduce costs for successful DGE exploitation: innovative drilling technologies, energy techniques, improved heat exchange and efficiency, corrosion, cooling, M&O, reservoir engineering, exploration and imaging, life-cycle sustainability, risk mitigation, monitoring and abatement of induced seismicity.
Challenge 4: acceptance

- DGE failed in Basel and St. Gallen
- Too risky
- Too costly
- To be relevant, we need LOTS of it in Europe ➔ so far, no EU strategy
- Negative domino effect for all geoenergy sources (shale oil and gas, conventional oil and gas, EOR, DGE, CCS, gas storage)
- Still weak governmental support for DGE
- Licensing too lengthy and cumbersome
- NIMBY
- The electricity market is wild and industry has little money
- Impossible to predict 2050 conditions and prices
- ...

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Activity Overview of GeoEnergy

Target electricity production for 2050: 4400 GWh

Key goals:
- extract safely the deep geothermal heat and produce electricity at competitive cost
- geological capture of CO2 to enable carbon free electricity from hydrocarbon resources

- **EGS Pilot 1: Project Haute Sorne**
- **EGS Pilot 2**
- **EGS Pilot 3**

**Hydrothermal P&D 1: Geneva basin**

**Hydrothermal P&D 2**

**Hydrothermal P&D 3**

**Laboratory and Deep-Underground Laboratory testing**

**Phase 1-2**

**Innovation technologies**
- Advanced cementious grouts
- Corrosion resistant heat exchanger
- Sensors for harsh environment
- Optimisation of geothermal energy conversion
- Next generation numerical methods and simulation tools for DGE reservoir eng.
- Real time, data driven reservoir characterization and risk assessment

**Integrated solutions**
- Resource exploration and characterization
- Reservoir enhancement and engineering
- Limit induced seismicity while creating an efficient reservoir
- Hydrothermal and aquifer resource exploitation and storage
- Chemical processes in the reservoir

**Phase 3**

New innovation technologies and integrated approach

**Risk, safety and societal acceptance**
- Technology assessment
- Energy economic modeling

**GeoData infrastructure and resource exploration on national scale**

- **2014 – 2016**
- **2017 – 2020**
- **2021 – 2025**
- **2026 – 2035**

**Petro-thermal plants**
- 20MWe per year

**Hydro-thermal plants**
- Heat and Storage

**CCS-CCUS**
- Industry & air capture

**2021 – 2025**

- Laboratory and Deep-Underground Laboratory testing

**Phase 1**

**Hydrothermal P&D 1: Geneva basin**

**Phase 2**

**Laboratory and Deep-Underground Laboratory testing**

**Phase 3**

New innovation technologies and integrated approach
10-year Technology Roadmap for DGE

1. Capacity building

2. A national Geodata Infrastructure, with 3D mapping to 5km depth

3. R&D agenda: resource and reservoir exploration, assessment and characterization; fractures and reservoir creation; reservoir modeling and validation; induced seismicity; monitoring; well completion; chemical interactions and transformations.

4. Three main classes of experimental facilities:
   i. National, distributed rock deformation laboratory to handle 20-60cm size samples at conditions found in 4-6 km depth
   ii. National Deep UnderGround Laboratory infrastructure, to conduct 10-100m scale injection experiments at depth of 500-2‘000 m
   iii. Up to 3 deep EGS reservoirs, conducted as P&D projects, with a target of 5-10 MWe installed capacity each

5. Identification, testing and validation of innovative technologies
SCCER-SoE: 8 new AP and OP in Geo-Energies

- ETHZ, OP Deep Geothermal Energy and Geofluids, M. Saar
- ETHZ, OP Geoenergy Process Technology, open search
- EPFL, OP Rock Mechanics, M. Violay
- EPFL, OP Geoenergy, B. LeCampion
- UniNe, OP Geothermics, S. Miller
- UniNe, AP Geothermics, B. Valley
- UniGe, AP Reservoir Geophysics, M. Lupi
- USI, Computational Energy, open search
WP3 Innovation Agenda

Optimizing the performance of future geothermal operations will be a key to meet energy strategy 2050 expectations. Supplying tools for developing efficient reservoir engineering methods with near real-time characterization and risk assessment during hydraulic stimulation are a priority for EGS-type operations. For all types of future geothermal operations, smart energy conversion process optimization that integrates and tailor the whole energy conversion chain from reservoir responses to the actual power plant will be a major element for success.

Task 3.1: Innovative technologies
✓ Optimization of geothermal energy conversion
✓ Deep well: long-term durability and monitoring induced seismicity
✓ Borehole stability

Task 3.2: Computational energy innovation
✓ Next generation numerical methods and simulation tools for deep geothermal reservoir engineering
✓ Real-time, data-driven reservoir characterization and risk assessment
Multiscale experimental and modeling approach
Why a DUG-Lab?

- To perform stimulation experiments under a fully controlled environment at increasing depths and realistic conditions
- To validate protocols and procedures before deployment in deep EGS
- To provide a testing ground integrating experimental, modeling and monitoring technologies
- To develop and test innovative methodologies for reservoir engineering
- To increase public confidence in geo-energy technologies
ISC-GTS experiment started

- Pre-stimulation campaign on-going, stimulation expected for November 2016
- Several boreholes drilled, in situ stress measurements & rock characterization
- Evaluation of shear zone stress state for preparation of stimulation experiments
- Funding and personnel secured
- Risk study and project plan approved by NAGRA and KWO, July 2016
- Today the largest, best-monitored fault stimulation experiment in world!
Instrumenting the DUG-Lab
Going forward

✓ Second flagship experiment in preparation (1km depth, 100m scale, target Bedretto tunnel)
✓ 5-year budget for DUG-Lab experiments: 12.4 mCHF, of which 10.2 mCHF already secured by initial grants (Shell, EKZ), in-kind ETHZ, SCCER-SoE, SNF and EU H2020 projects; pending P&D BFE request
✓ Pilot industry projects
CCS 2016

- CCS is again high on the H2020 and IEA priority list; advances expected after UNFCC COP21 in Paris
- Little incentives available in Switzerland, as the price of CO2 emissions is very low and CCS is not allowed as compensation measure
- Roadmap 2013 prepared by BFE, ETHZ/ESC, ALSTOM and other SCCER-SoE partners
- Strong Swiss role in the ERANet-Cofund ACT, call issued in summer 2016
- P2 roadmap revision and planning for a national demonstrator
National integration

Cooperative national programs:
- SFOE GEOSIM, GEOFEST
- CCES GEOTHERM-2
- SNF COTHERM

National research infrastructures:
- Deep Underground Laboratory
- Rock deformation laboratories
- NAGRA GTS, MontTerri
- Valais EPFL campus

Integration with other SCCERs:
- Joint SCCER Scenario & Modeling Initiative
- Energy system analysis
- Risk and socio-economic drivers (CREST)
- Storage

WP1 Geo-energies: DGE & CO2 Sequestration
WP2 Hydropower: usage & infrastructures
WP3 Innovation agenda
WP5 Pilot & Demonstration projects
WP4 Future supply of electricity

Capacity building, Technology Transfer, Outreach

International programs:
- IPGT (AU, IS, NZ, US, CH)
- EERA, ERA-NET, IEA
- DOE FORGE, IDDP, DRG
- ICOLD
- ICDP

- EU FP7 projects: STREST, IMAGE, HYPERBOLE, GEISER, NERA, EPOS-PP
- EU H2020 projects: CONSENT, EPOS-IP, DESTRESS, SERA, CHALM
- ESFRI RI: EPOS, ECCSEL

Input from additional energy resources: biomass, WP, SP, nuclear, oil&gas

NRP 70-71-75

- Swiss Geological Survey@Swisstopo
- FOEN
- SFOE
DGE outlook

✔ If we want to reach the ES2050 target of 7% electricity supply from DGE (500 MWe installed), we need to

➢ until 2025, demonstrate the DGE feasibility by completing three EGS reservoirs, reaching 5-10 MWe each, and

➢ between 2025 and 2050, add 20 MWe installed capacity per year

✔ With a target cost of 10 MFr per installed MWe, a total investment of 5-7 BFr will be required in the 2025-2050 period to reach the 7% target

✔ The cost target of 10 cents/kWh for DGE electricity will only be achieved by coordinated developments in the US and Europe and with the installation of a large number of DGE plants in Europe

✔ In Switzerland, we need to concentrate all efforts on the development of the first successful EGS reservoirs and plants, with the joint participation of industry, academy and government partners → SCCER-SoE and ETHZ are considering joining the next GeoEnergie Suisse EGS

✔ We now have a nationally coordinated roadmap!