SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Roadmap for Deep Geothermal Energy

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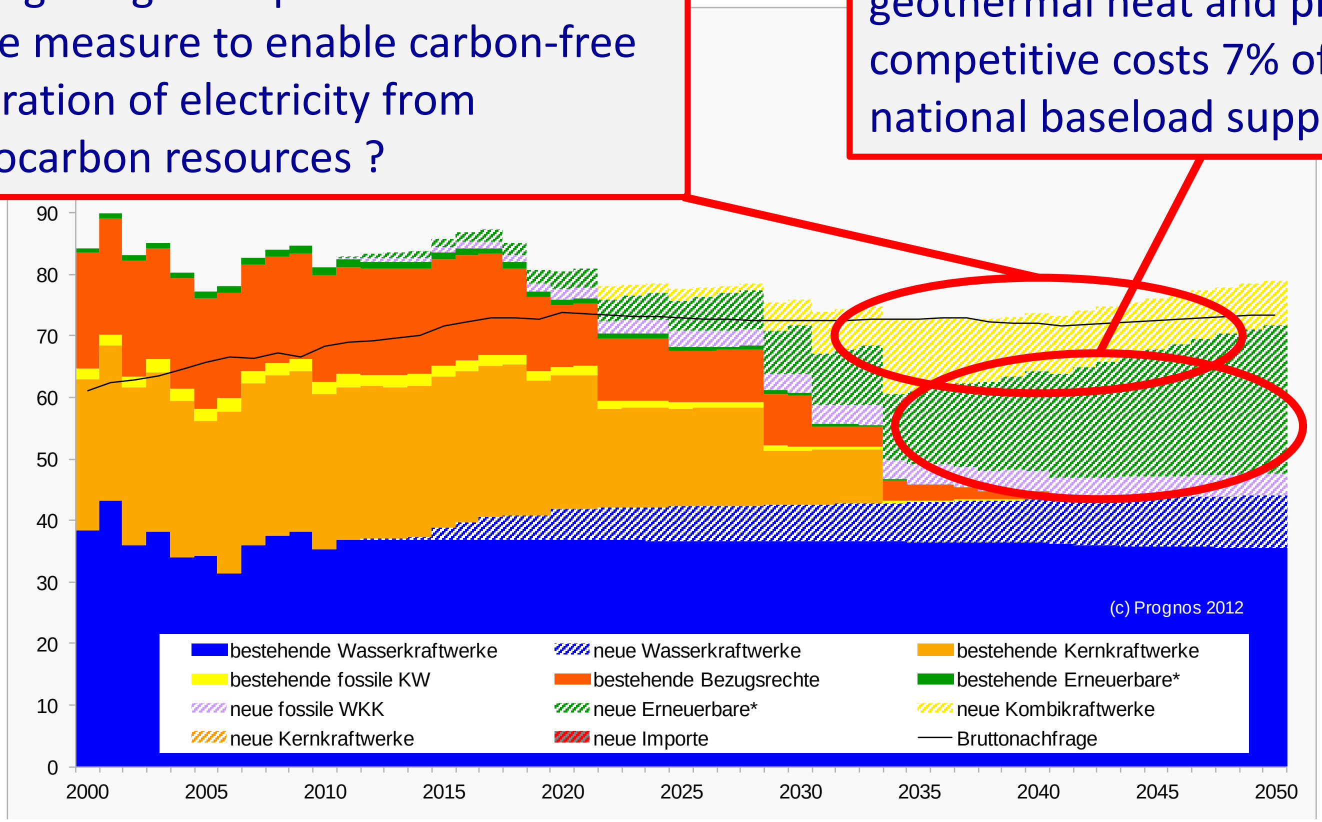
Sion, September 13, 2016

Energy funding programme
Swiss Competence Centers for Energy Research

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 ?



Structure Phase 1

Deep Geothermal Energy & CO2 Sequestration

HydroPower: usage & infrastructure

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

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

SCCER-SoE P2: expanded scope, 1

- 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
  - I. an expanded scope of the risk assessment activities to encompass also risk of large dams (T4.1)
  - II. a wider scope of the evaluation of global electricity resources and technologies (T4.2)
  - III. 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

WP5 Pilot & Demonstration projects

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

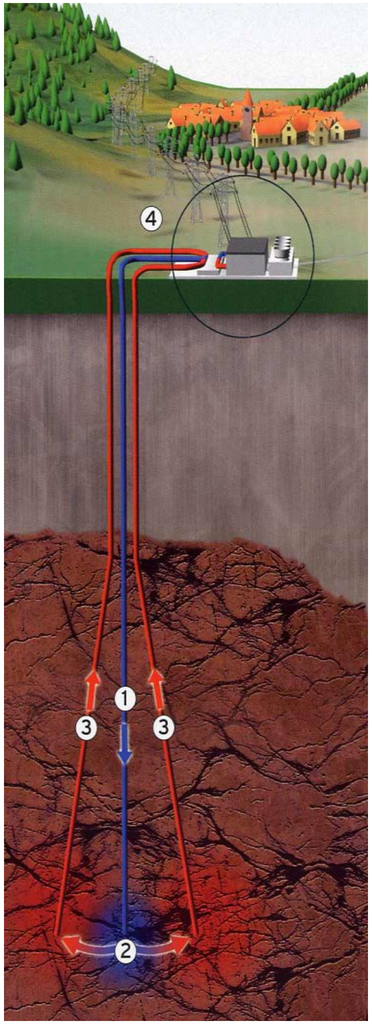
Capacity building, Technology Transfer, Outreach

Challenge 1: Resource availability

- ✓ In Switzerland we normally find 170-190C 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 20MWe per year from 2025 to 2050 to meet the ES2050 7% quota

- ✓ A sustained water flow of 220 l/s at 180C 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

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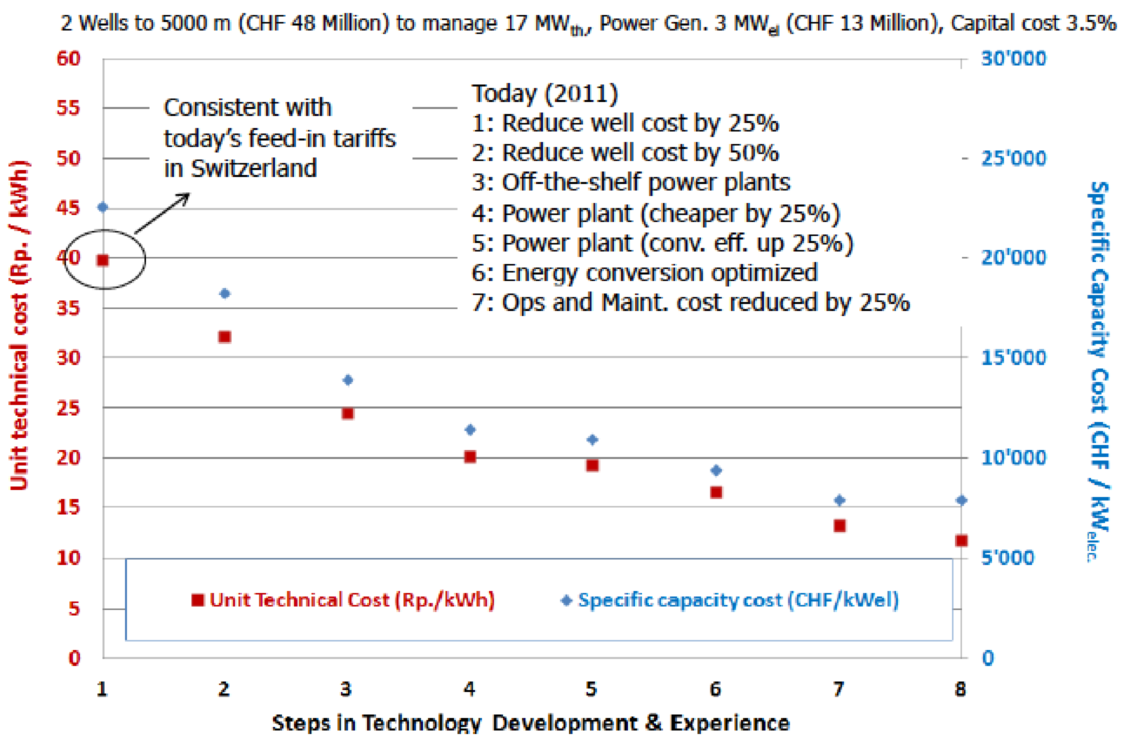
- ✓ Spain, 2011: the largest damaging quake in decades is associated with long-term ground-water extraction in Lorca
- ✓ Holland, 2012: Induced seismicity in Groningen, the largest on-shore gas field in Europe, is increasing and is forcing lower extraction rates, with significant impact on Dutch GDP 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
- ✓ …

Activity Overview of GeoEnergy

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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

Roll-out
Prototyping
Validation
Concept
System

Petro-thermal plants
20MWe per year

Hydro-thermal plants
Heat and Storage

CCS-CCUS
Industry & air capture

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

CCS field-scale demonstrator 1
CCS Demo 2

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

Energy funding programme
Swiss Competence Centers for Energy Research

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

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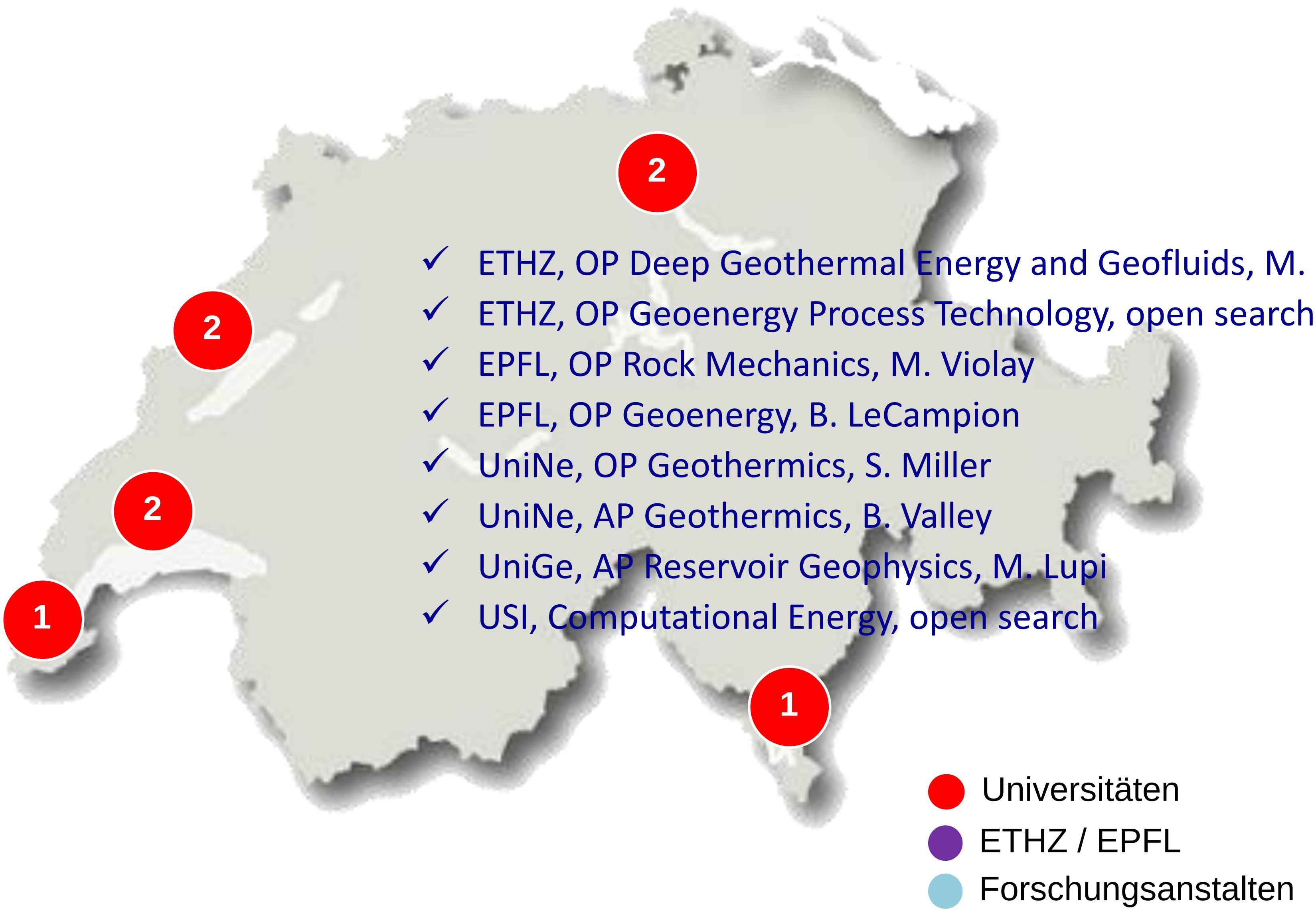
- ✓ ETHZ, OP Deep Geothermal Energy and Geofluids, M. Saar
- ✓ ETHZ, OP Geoenergy Process Technology, open search
- ✓ EPFL, OP Rock Mechanics, M. Violay
- ✓ EPFL, OP Geoenergy, B. LeCampion
- ✓ UniNe, OP Geothermics, S. Miller
- ✓ UniNe, AP Geothermics, B. Valley
- ✓ UniGe, AP Reservoir Geophysics, M.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

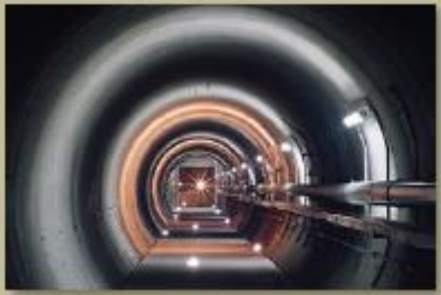
- ✓ Optimization of geothermal energy conversion
- ✓ Deep well: long-term durability and monitoring induced seismicity
- ✓ Borehole stability

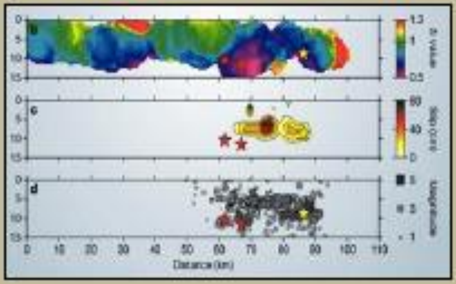
Task 3.2: Computational energy innovation

- ✓ 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

10 cm | 10 m | 100 m | 1 km | 10 km

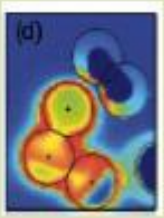




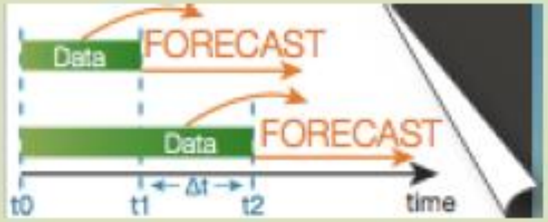
Laboratory Scale

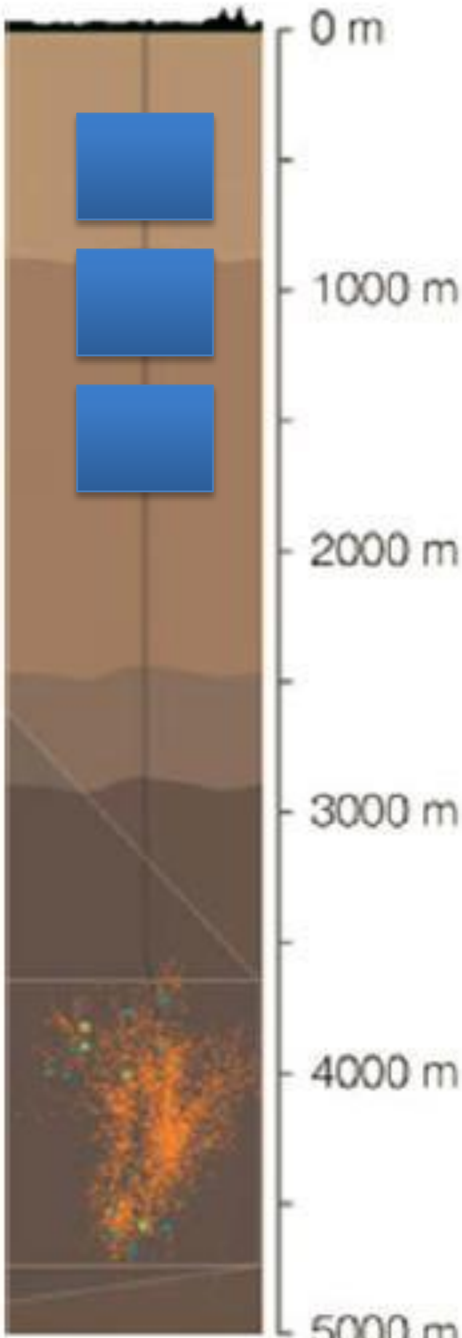
Underground Lab Scale

Natural Systems



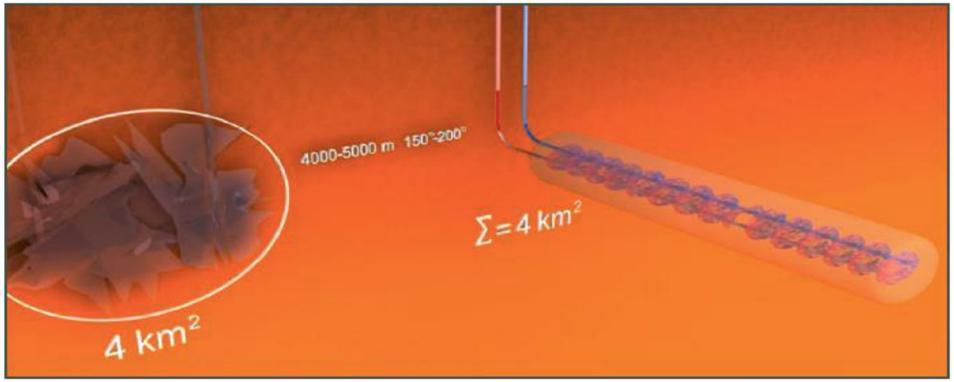
High Performance Computing, Modeling & Validation





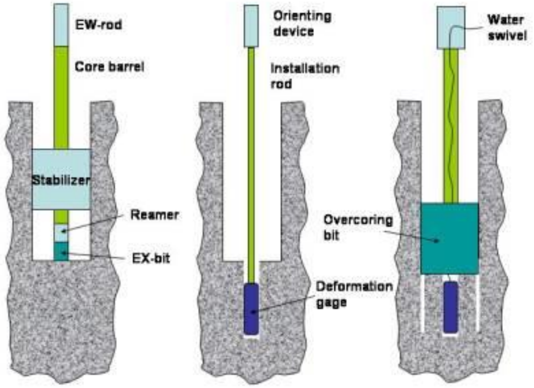
Why a DUG-Lab ?

- ✓ 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 !



ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

nagra

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

GEO ENERGIE SUISSE

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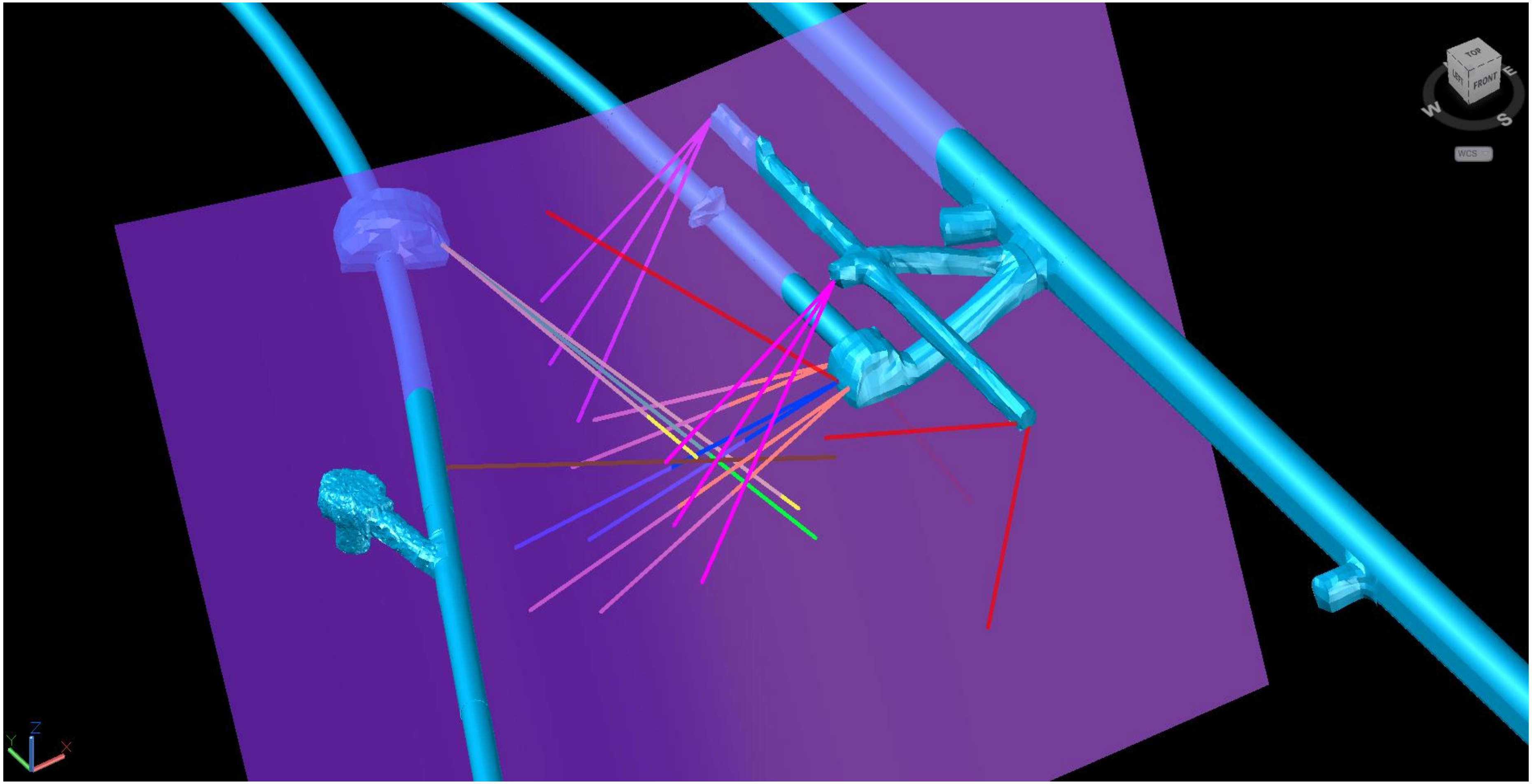
SUPPLY of ELECTRICITY

KWO GRIMSELSTROM

Università della Svizzera italiana

unine UNIVERSITÉ DE NEUCHÂTEL

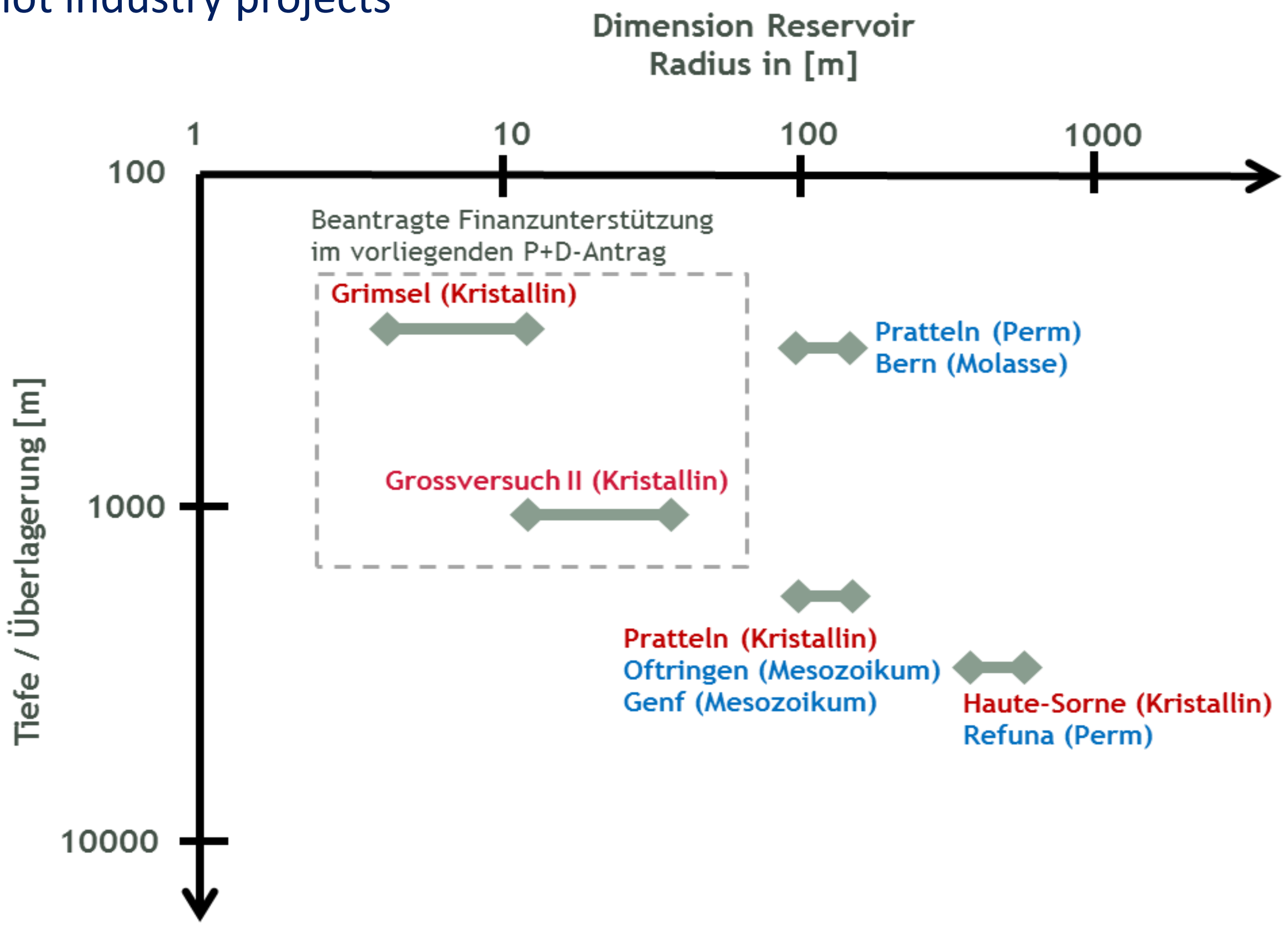
Instrumenting the DUG-Lab



Injection Borehole (BHINJ)
Stress Measurement, Tilt-meter Borehole (SBH)
GPR, Active Seismic Boreholes (BHAM)
Passive Seismic Borehole (BHSM)
Stress, Strain, Temperature (FBG) Borehole (BHST)
Pressure, Temperature Borehole (BHPT)
Strain, Temperature (DTS) Borehole (BHDS)

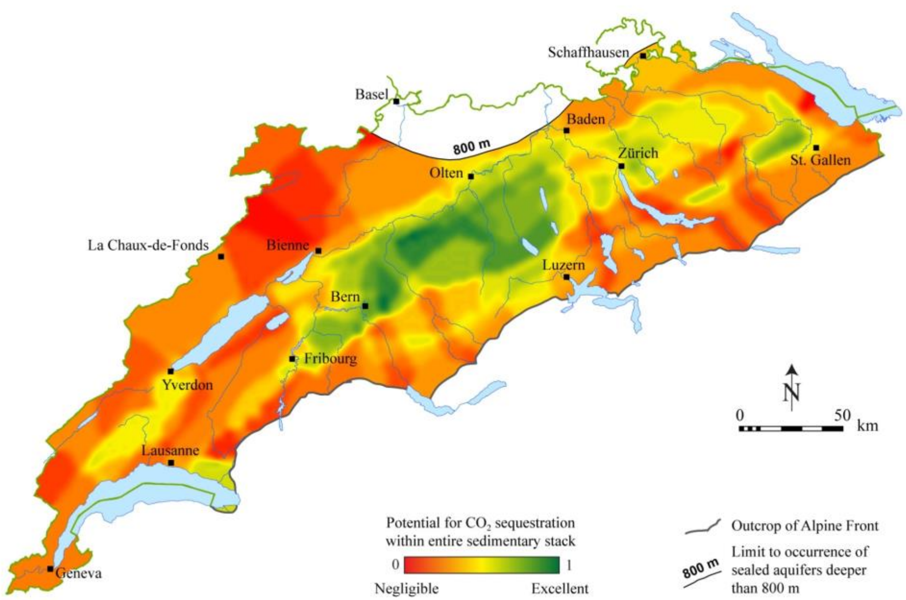
Going forward

- ✓ 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

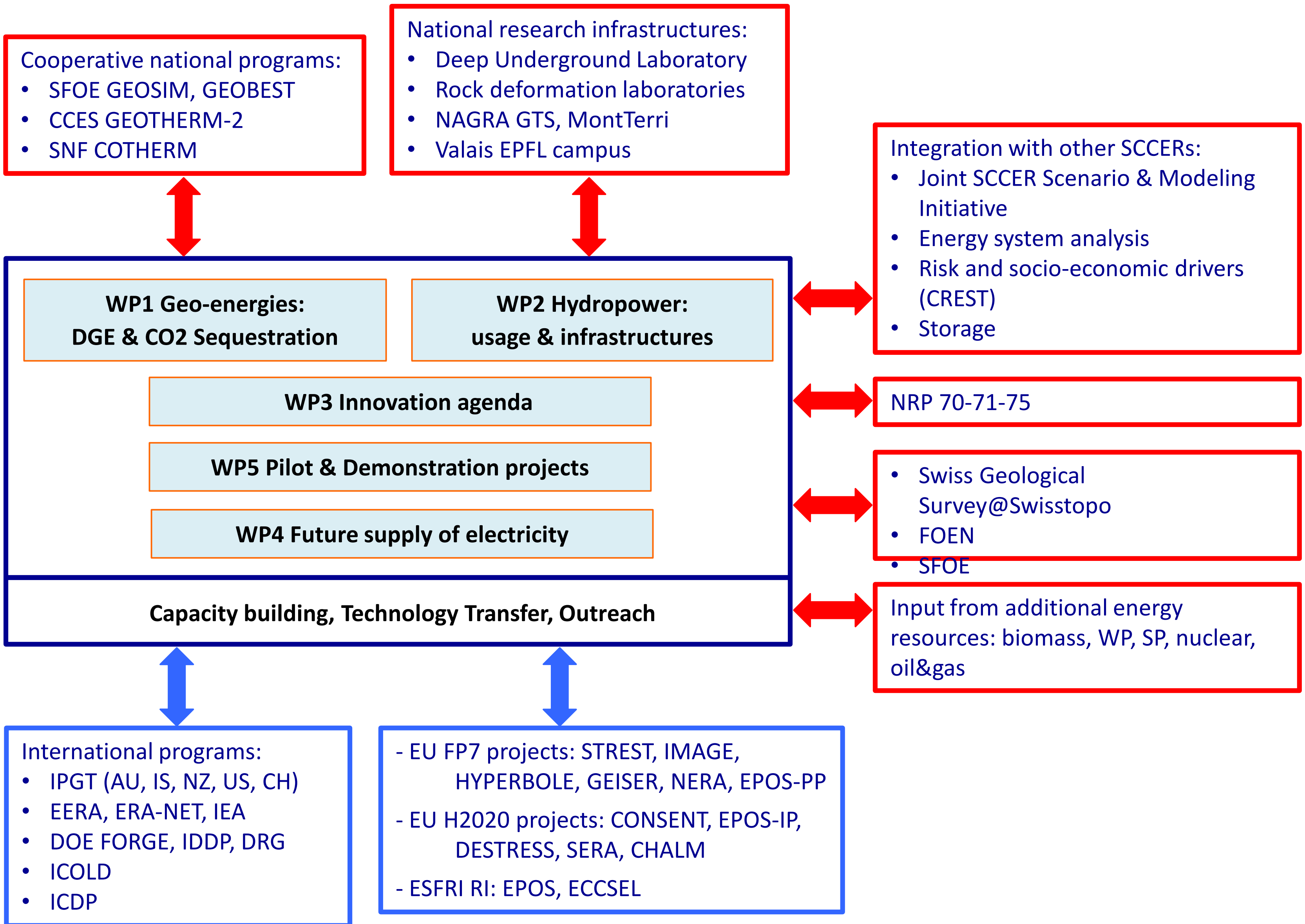


CCS 2016

- ✓ 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



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 !