Swiss roadmap for electricity production from Deep Geothermal Energy

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Future of DGE electricity production

The future for DGE electricity production is bleak:

- DGE failed in Zurich, Basel, St.Gallen
- Too risky (induced/activated earthquakes, water table pollution, ...)
- Too costly (St.Gallen, 160MFr for 4MWel)
- All geoenergy sources are in trouble – shale gas, gas and oil extraction, EOR, DGE, CCS, gas storage – due to induced seismicity
- The Bund will not (sufficiently) finance DGE development
- Too cumbersome to obtain licenses from the Cantons
- NIMBY
- The electricity market is wild and industry has no money
- Impossible to predict 2050 conditions and prices

→ **DGE has no future, we should stop talking about it**

Future of DGE electricity production

… but the story is different:

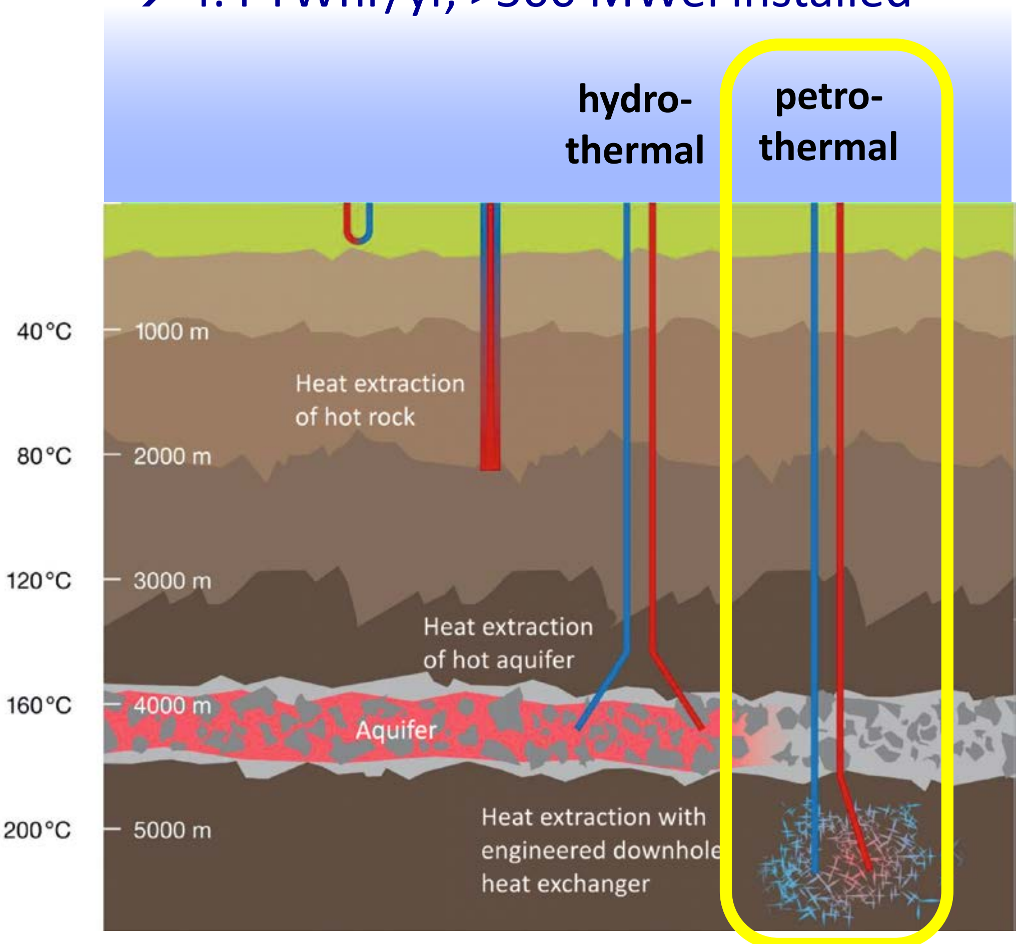
- Zurich, Basel, St.Gallen provide very valuable information, we need more detailed knowledge on our underground and validation of the DGE technologies
- We are learning what to do and what not to do
- Licensing underway in several cantons
- We are not alone, large international effort underway
- DGE is not an off-the-shelf mature technology, needs R&D
- Costs are high and efficiency low, but it will reverse
- Long-term horizon → Energy Strategy 2050
- We sit on an unlimited reserve of energy !

→ DGE electricity has a great future, but we need a strategy !

DGE potential

The ES2050 target for DGE is 5% of national electricity supply

→ 4.4 TWhr/yr, >500 MWel installed



- → Hydrothermal DGE has great potential for heating, less so for electricity → water is scarse and not easily found
- → We need to create deep reservoirs in hot rock (EGS)
- → Under normal conditions, we find 170-190° C in crystalline basemenet rocks at 4-6 km depth
- → Cooling 1 cubic km of 200° C hot granite by 20° C could deliver heat sufficient to generate >10 MWel for 20 years → resource is unlimited

Sources: Lund, Freeston, Boyd (2010), www.geothermie.stadt.sg.ch

DGE numbers: Europe

- ✓ The Carnot efficiency of a DGE system is low compared to most other sources of electricity and for temperature conditions of 50-170° C is around 25%. The overall net efficiency of the conversion of heat to electricity in a DGE plant is expected (today) to be around 13-15%.
- ✓ A sustained water flow of over 10 l/s at 180° C is required to generate 1 MWel, or >200 l/s to generate 20 MWel.
- ✓ The EU-28 area needs 3'200 TWhr of electricity per year; a 5% share of DGE would correspond to an installed capacity of the order of 20 Gwel.

→ Europe will need 1’000 20 MWel plants to meet the 5% quota

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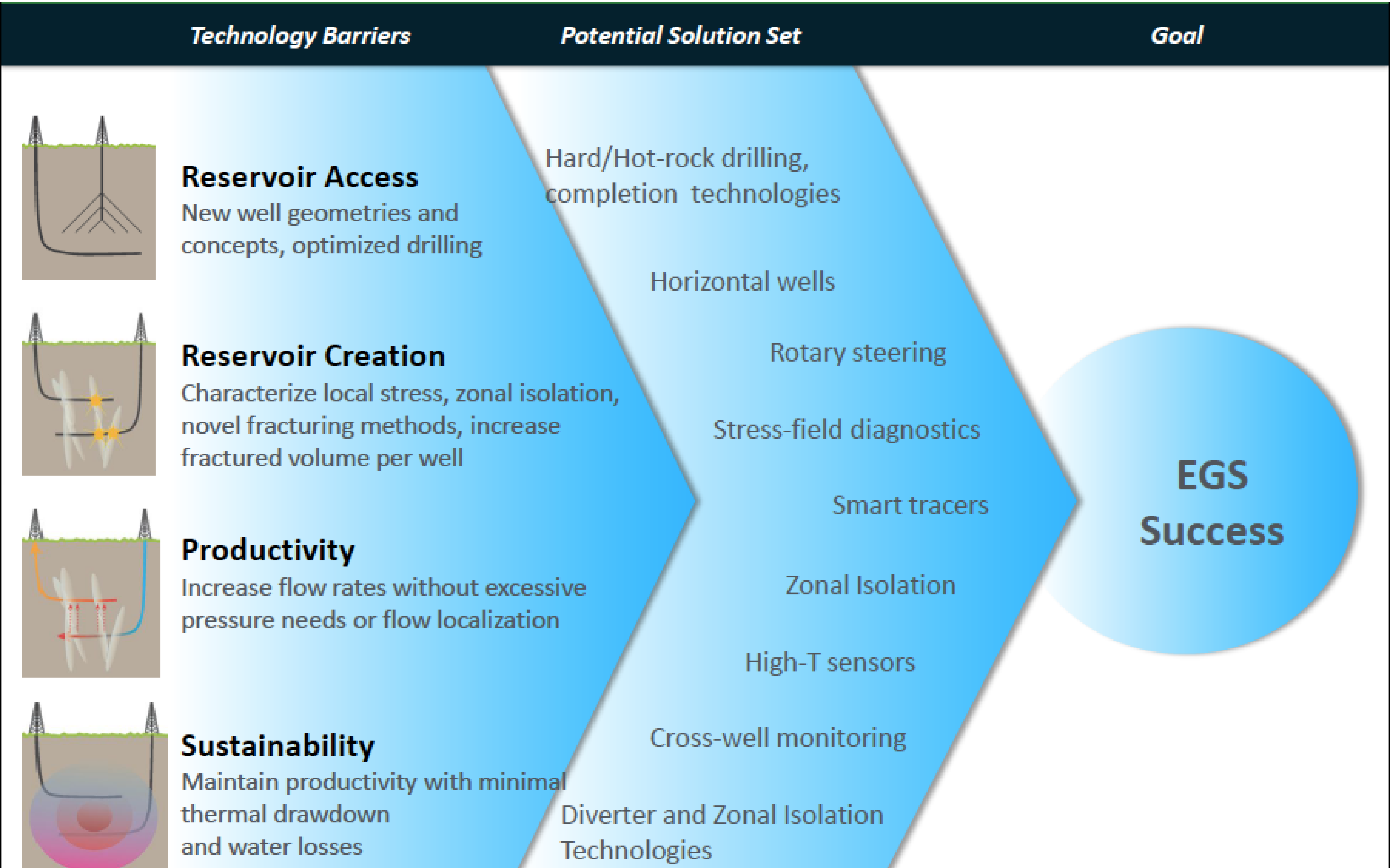
DGE numbers: Switzerland

- ✓ The CH 2050 target is of at least 500 MWel installed
- ✓ Today's investement costs for a DGE plant are prohibitive, 40-50 Rp per kW/hr (without considering usage of rest heat)
- ✓ The largest driver for DGE cost reduction and increased public acceptance will be the installation of over 1'000 plants in Europe; a realistic cost target is of 10 mln Fr per installed Mwel (cfr BFE estimates)
- → Switzerland will need 25 plants with 20 MWel capacity each to meet the 5% quota
- → With expected increase in efficiency and decrease in costs, a global investment in the order of 5-7 BFr will be required in Switzerland by 2050 (comparable with the price of a new NPP)

Technology barriers



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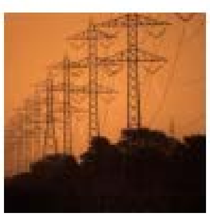
Key market barriers

Market Barriers	Potential Solution Set	Goal

Permitting Challenges
A non-competitive process can doom projects

Data Access
Creates more prospects, lower risk and cost, more efficient geothermal research and resource development

Financing
Relatively small size of the Industry + perceived risk = project financing challenges



Grid Integration
Solutions to supply geothermal electricity to the grid

Potential Solution Set:

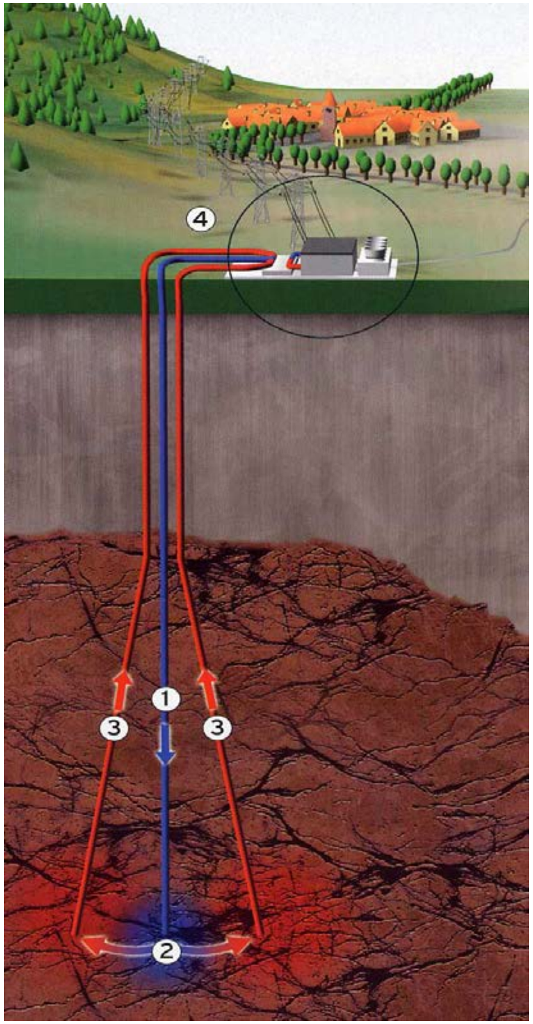
- Regulatory road-mapping Initiative, Programmatic EIS
- National Geothermal Data Repository
- Demonstrations
- Techno-economic analysis
- Modeling
- Market reports
- Working groups

Goal: **A Clearer Pathway for Geothermal Development**

DOE, 2014

EGS challenge: developing the reservoir

- ✓ Important cost reductions for EGS can be achieved by maximizing efficiency and by technology advancements in heat exchangers, cooling, drilling and geophysical exploration.
- ✓ Technical challenges related to residual heat, grid configuration, combined energy systems and environmental footprint also need to be tackled.
- ✓ The immediate challenge is to prove that we are able to consistently create productive deep reservoirs in hot basement rocks, sustainable for 20-40 years, and minimizing the risk of induced seismicity.



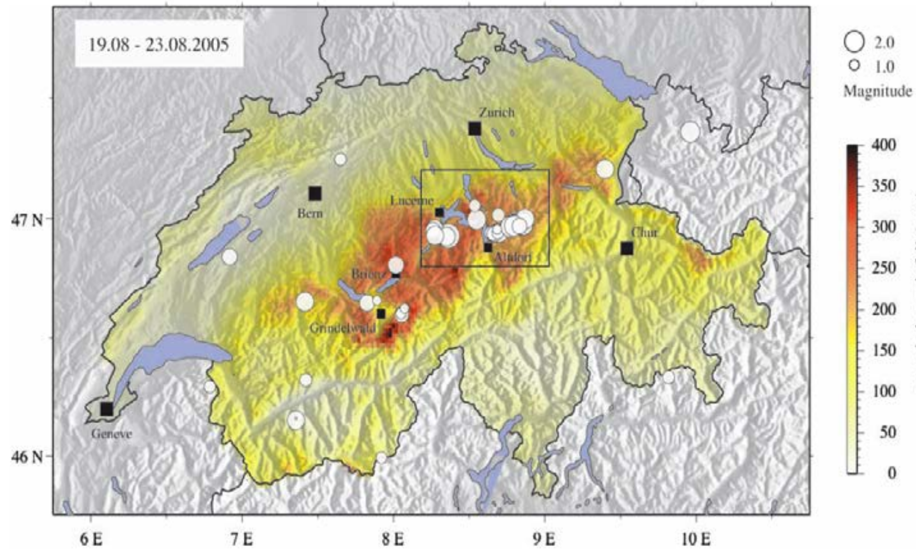
EGS challenge: induced seismicity

- ✓ US, 2000: after 30 years, industry succeeds in drilling horizontally and fracking deep, thin rock layers to extract shale-gas; 180’000 wells were drilled in 10 years, restarting the US economy; seismicity associated to the re-injection of wastewater exceeds natural seismicity 100 times
- ✓ Spain, 2011: the largest damaging quake in decades in Lorca, associated with long-term ground-water extraction
- ✓ 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, 2006) and hydrothermal injection (St.Gallen, 2013) halts the two projects
- ✓ UK, 2011: Felt seismicity in the UK stops hydro-fracking in Blackpool
- ✓ Italy, 2012: 14 BEuros 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

Induced seismicity in Switzerland

Induced seismicity is well known in Switzerland. In recent years, it has been associated to the NEAT tunnel excavation, the DHM Basel and St.Gallen projects, heavy rain and the loading/unloading of large dams.

DHMB, 2006



NEAT, 2007

Roadmap DGE 2014

The DGE Masterplan 2013 was part of the original SCCER-SoE proposal: a strategic plan with industry to develop up to three deep reservoirs and surface plants for electricity production.

A key deliverable of the first year is the DGE R&D roadmap 2014, developed during 7 workshops with participation of industry and federal offices.

The DGE roadmap consists of two coordinated documents:

a. DGE roadmap, identifying the required technologies and a plan for their developments (release October 1, 2014)
b. DGE summary roadmap 2014

The SCCER-SoE roadmap exercise was coordinated with the TA-Swiss report on prospects for DGE in Switzerland (release fall 2014).

Roadmap DGE 2014

The result of the roadmap exercise is a concerted strategy of RD&D, covering

- Resource and reservoir exploration, assessment and characterization
- Reservoir modeling and validation, including numerical modeling of reservoir processing, and the installation of three main classes of experimental facilities: (i) rock deformation labs, (ii) deep underground labs, (iii) deep reservoirs (EGS)
- Large coordinated projects: SFOE P&D, KTI clusters, SNF NFP70, H2020
- International framework
- Innovative technologies

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Geo-Energy Technologies

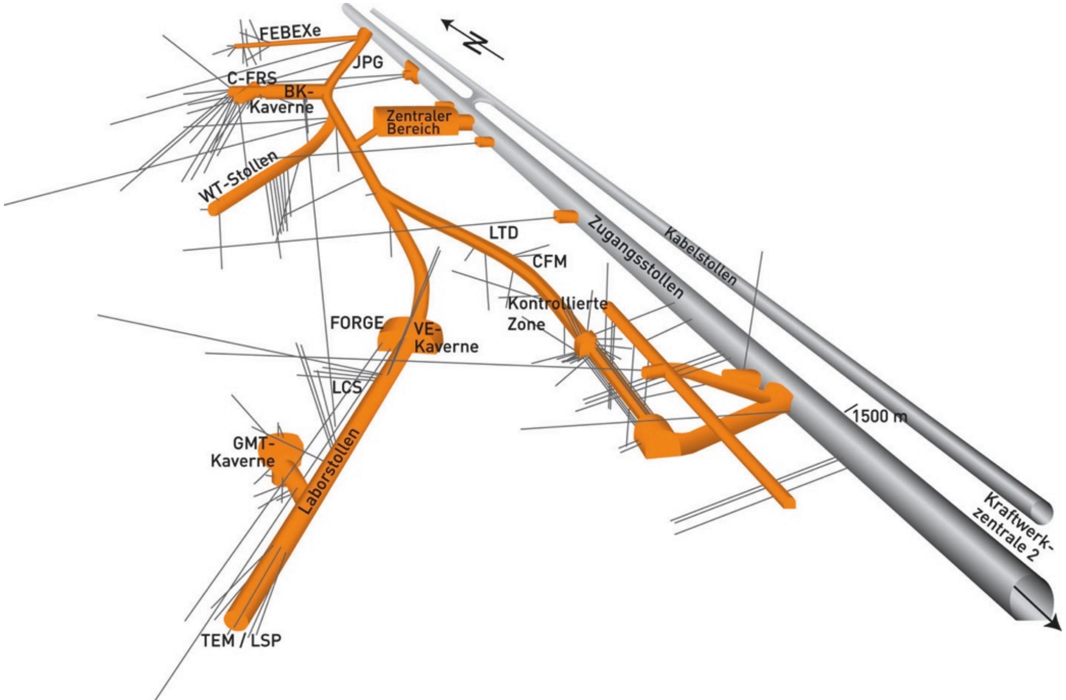
The innovation roadmap covers a number of technologies, including

- ✓ New pumps for geothermal applications
- ✓ Innovative drilling technologies
- ✓ Cementious grouts for bore hole cement in geothermal wells
- ✓ Heat exchangers for geothermal applications
- ✓ Sensors for harsh environment
- ✓ Diverter and zonal isolation technologies for well completion
- ✓ Stress-field diagnostics
- ✓ Smart tracers
- ✓ Advanced seismic and imaging techniques for seismic and aseismic deformation and fluid flow
- ✓ Injection protocols to minimize size of induced events
- ✓ Data-driven, risk-based probabilistic traffic-light systems

DUGLab Roadmap

The DUGLab is a pillar of the experimental facilities for the Geoenergy Roadmap

- ✓ ETHZ-lead RI, with national (SCCER-SoE) and international partnership (IPGT, Australia, Germany, US/DOE)
- ✓ Three otions under investigation: NAGRA Grimsel laboratory and a deeper tunnel for DGE, Mont Terri for carbon sequestration
- ✓ Funding: grant from ETH Foundation (SHELL), H2020, SNF R'Equip, BFE P&D, industry, KTI, start-up credits (Wiemer, Saar)



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DUG-Lab roadmap

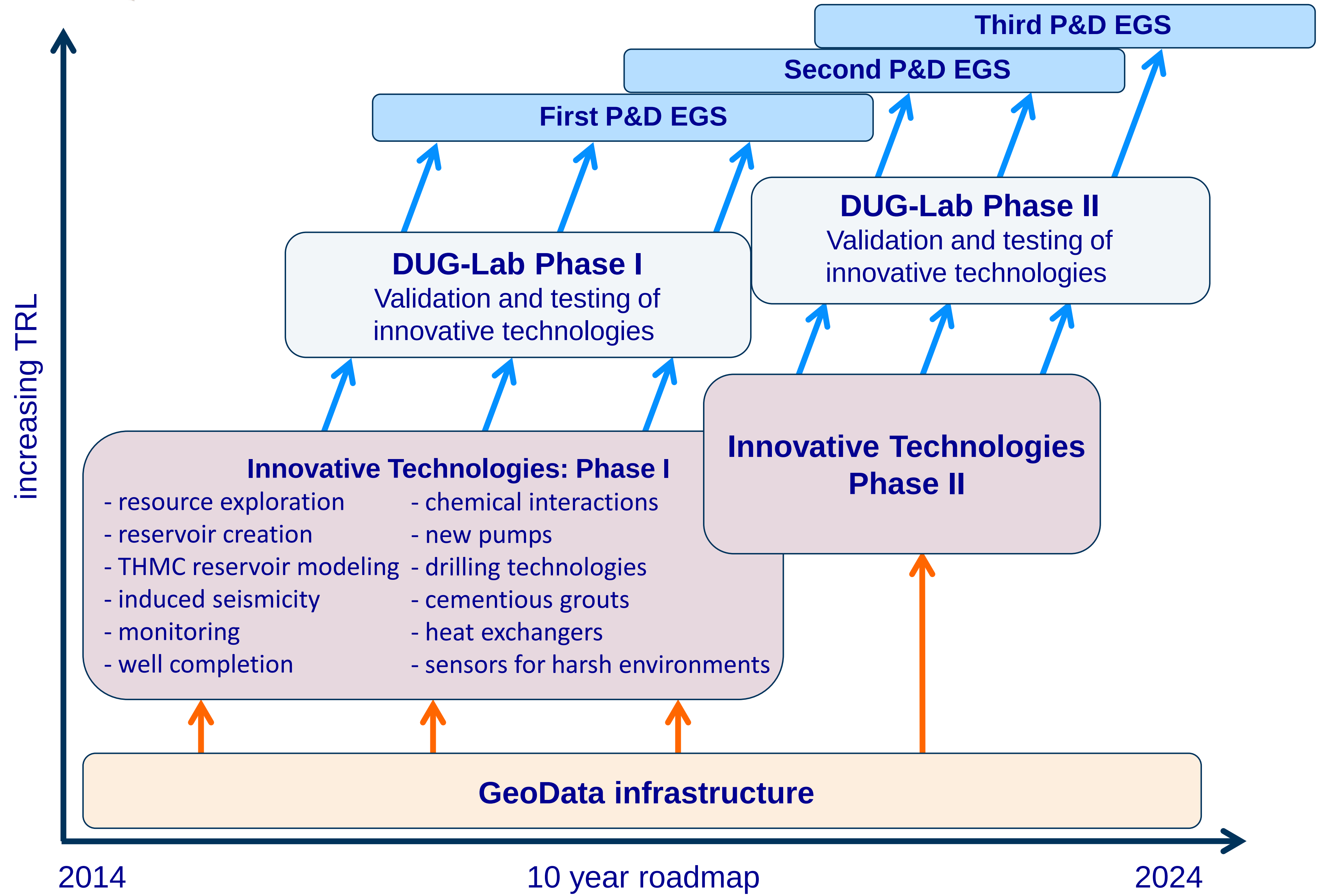
A preliminary list of experiments planned includes:

- ✓ injection in a mapped fracture zone to control its activation, the connectivity between fracture elements and the evolution of the size of micro-events; this experiment will be paired with a similar fault activation experiment conducted in opalinus clay at the Mont Terri underground laboratory (Switzerland)
- ✓ stimulation of a volume containing a known fracture zone to maximize the connected permeability away from dominant permeable structures, either through the creation of new fractures, or the shear-activated stimulation of minor fractures
- ✓ stimulation of volumes with different orientations of the fracture system with respect to the local stress axes, to control the mechanisms of permeability/porosity enhancement activated by shear (e.g. shear-dilation, wing-cracks, pull-apart aperture at fault jogs or block rotation) and the factors favoring the activation of each mechanism (i.e. impact of fracture connectivity, size scaling, density, presence of filling or alteration)
- ✓ selective stimulation of multiple zones within the deep geothermal reservoir, and subsequent control of production/injection flow at stimulated feed zones, to verify interconnectivity and the capability of maintaining zonal isolation (also termed "multi-frac”)
- ✓ injections conducted just below and just above the minimum principal horizontal stress to evaluate the rock mass response
- ✓ tests of well completion strategies permitting zonal isolation, including testing the efficiency of perforation through grouted casing, the influence of grouting on near-well permeability and the ability to reconnect the well to existing permeable structures

DUG-Lab progress

- ✓ Grant from ETH Foundation (SHELL) approved
- ✓ 3 H2020 proposals submitted in early September:
  - ✓ VALI-DGE (1st stage LCE-2) brings together major underground infrastructures, monitoring facilities and modeling centers
  - ✓ GIGANTIS (INFRAIA Crustal Fluids and Georesources) coordinates all laboratories, including deep labs
  - ✓ PRISE-LAB (INFRADEV-1) is a design study for a future European infrastructure on DGE, to be included in EPOS
- ✓ DUG-Lab Scientific Manager appointed
- ✓ Detailed roadmap for underground R&D in preparation
- ✓ Submission of CTI clusers and BFE P&D projects in preparation
- ✓ On-going discussions with BFE and ENSI on new NFP on underground R&D
- ✓ On-going discussions on the inclusion of deep research infrastructures in the national roadmap of Research Infrastructures

Roadmap DGE 2014



Final (bold) statements

- ✓ If we want to reach the ES2050 target of 5% electricity supply from DGE, we need to create the conditions to install one 20 MWel petrothermal plant per year between 2025 and 2050
- ✓ Until 2025, we need to successfully complete three EGS reservoirs, to demonstrate the DGE feasibility
- ✓ The Bund – together with participating cantons – should fully support the first three EGS installations, as a national P&D program, leaving to industry the commercial exploitation; after 2025, increased efficiency, improved security and reduced costs will enable the industry to take over also the development phase with a reduced risk guarantee
- ✓ Until successful EGS stimulation is demonstrated, avoid urban areas
- ✓ We need to work actively in the European and global arena
- ✓ SCCER-SoE is ready to help and participate