SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Energiewende
Nationales Forschungsprogramm NFP 70

Swiss roadmap for electricity production from Deep Geothermal Energy

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Prof. Domenico Giardini
Head, SCCER-SoE

In cooperation with the CTI

Energy
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Deep Geothermal Energy: resources, efficiency, scaling up

- ✓ The Swiss ES2050 target for DGE is 7% of Swiss electricity supply
  → 4.4 TWh/yr, >500 MWe installed
- ✓ The EU-28 area consumes 3'200 TWh/yr of electricity; a 5% share of DGE would correspond to an installed capacity of the order of 20 GWe
- ✓ Cooling 1 cubic km of 200° C hot granite by 20° C could deliver heat sufficient to generate >10 MWe for 20 years → resource is unlimited
- ✓ The Carnot efficiency of the system is low compared to most other sources of electricity; the overall net efficiency of the conversion of heat to electricity in a DGE plant is expected to be (today) around 13-15%
- ✓ In Switzerland we find 170-190° C in crystalline rocks at 4-6 km depth
- ✓ A sustained water flow of 220 l/s at 180° C is required to generate 20 MWe

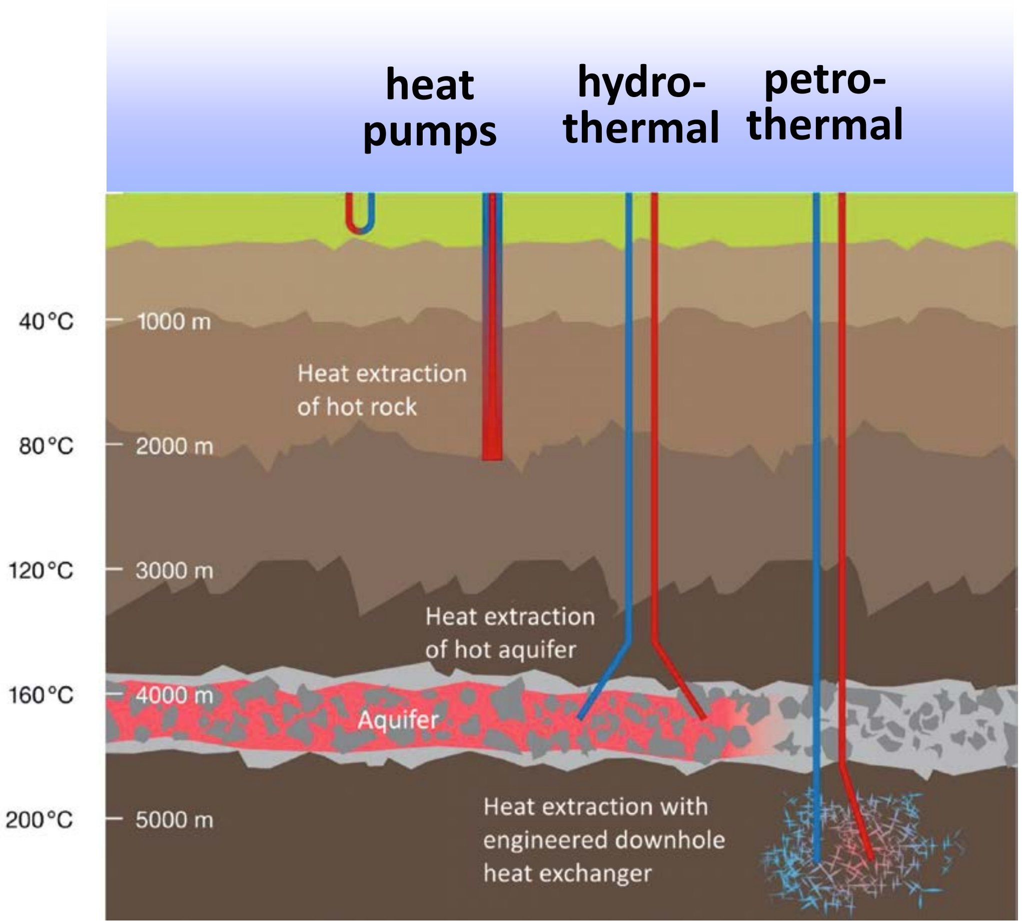
→ *Switzerland will need 25 20-MWe plants to meet the 7% quota*

→ *Europe will need 1'000 20-MWe plants to meet the 5% quota*

Deep Geothermal Energy: costs

- ✓ Today's investement costs for a DGE plant in Switzerland are prohibitive, 40-50 Rp/kWh (without considering use of rest heat)
- ✓ In Germany, costs are approaching 10 Rp/kWh. The US/DOE is targeting pilot projects with costs of 6 cent/kWh
- ✓ 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 10 Rp/kWh (cfr BFE estimates)
- → 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)

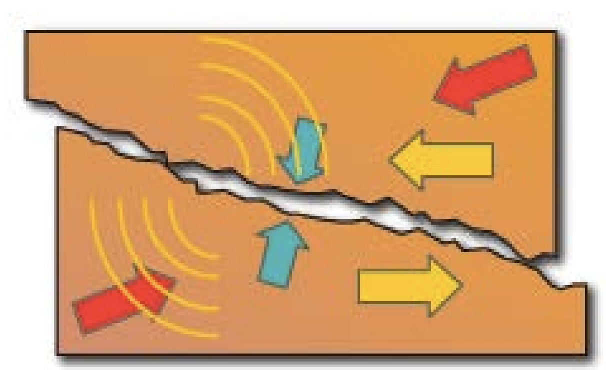
DGE challenge: where to find water ?

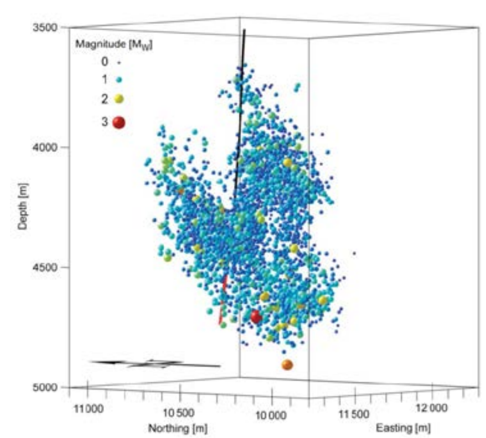


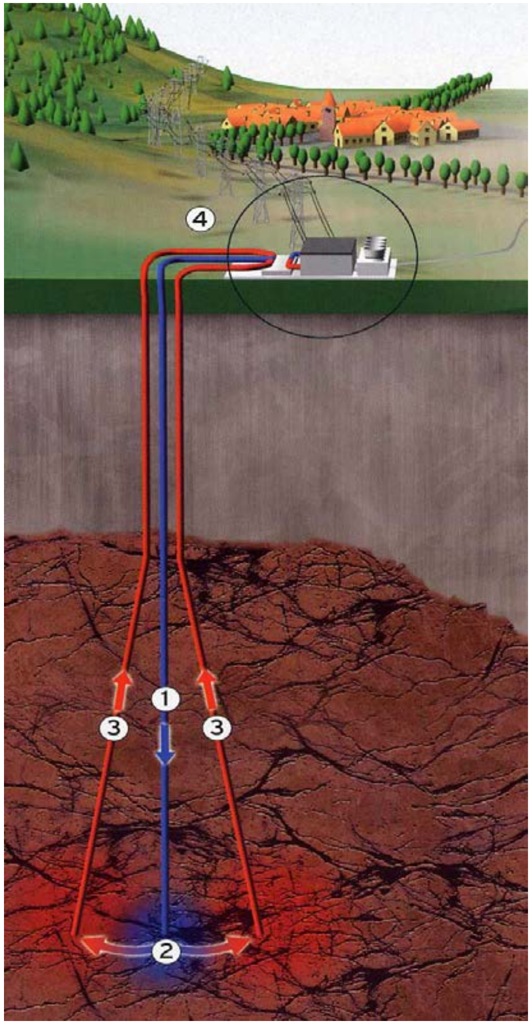
- High-enthalpy volcanic areas are few, limited and far between – Iceland, Italy – and cannot provide electricity to the whole Europe
- In normal temperature conditions, hydrothermal DGE has great potential for heating, less so for electricity → water is scarse and not easily found
- We need to create deep reservoirs in hot rock (EGS) and circulate water from the surface

DGE challenge: how to engineer a reservoir ?

- ✓ The main challenge for EGS is to create a sustainable heat exchanger at depth, a system that will operate for 20-40 years with no or minimal loss in flow, temperature and efficiency, with a sustained flow of >200 l/s of water at 180° C.
- ✓ New approaches are required to enhance rock permeability, with optimal distribution of micro-cracks and porosity to maximize heat exchange, swept area and water circulation.





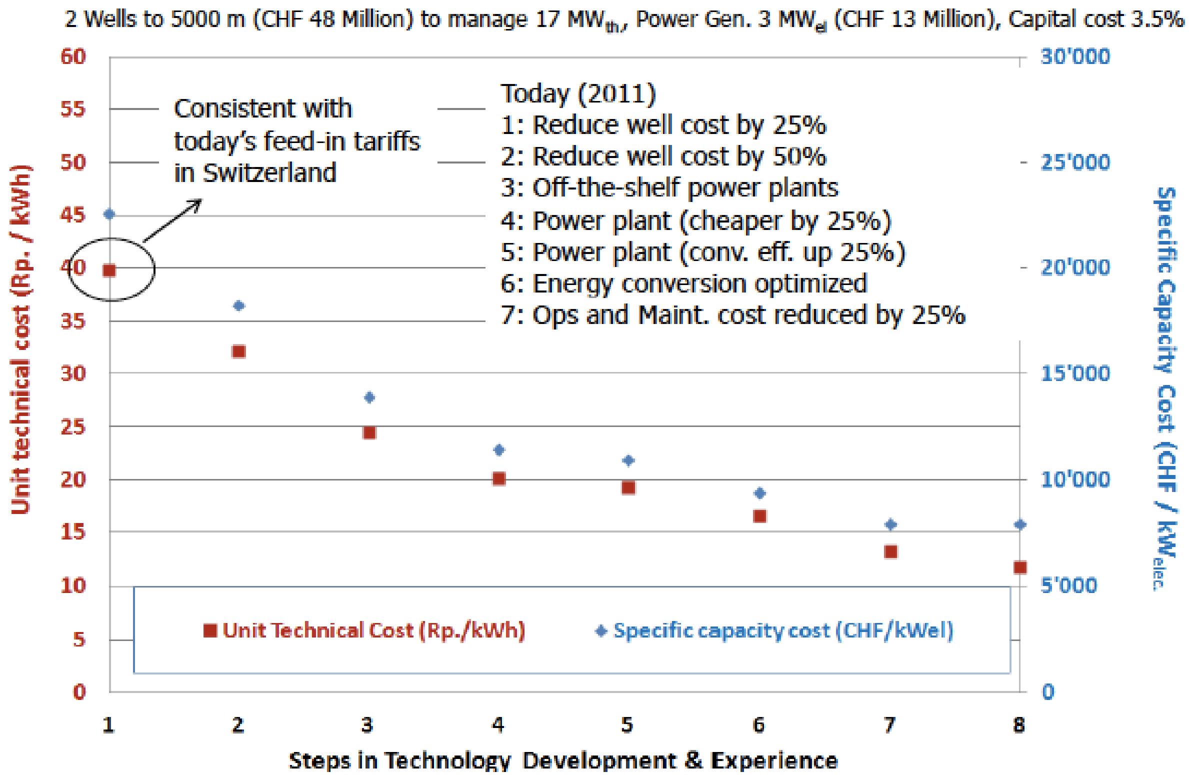


DGE challenge: induced seismicity

In the last decade, many geo-resources applications have experienced 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 **shale-gas** fracking in Blackpool
- ✓ Italy, 2012: 14 BEuros damage and 24 casualties from two M6 earthquakes, possibly associated to **oil 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: costs



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 (BFE).

Geo-energy challenge: bad reputation !

- ✓ Too dirty
- ✓ Too risky
- ✓ Too costly
- ✓ No EU strategy
- ✓ Negative domino effect for all geoenergy sources (shale oil and gas, conventional oil and gas, EOR, DGE, CCS, gas storage)
- ✓ No/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
- ✓ ...

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:

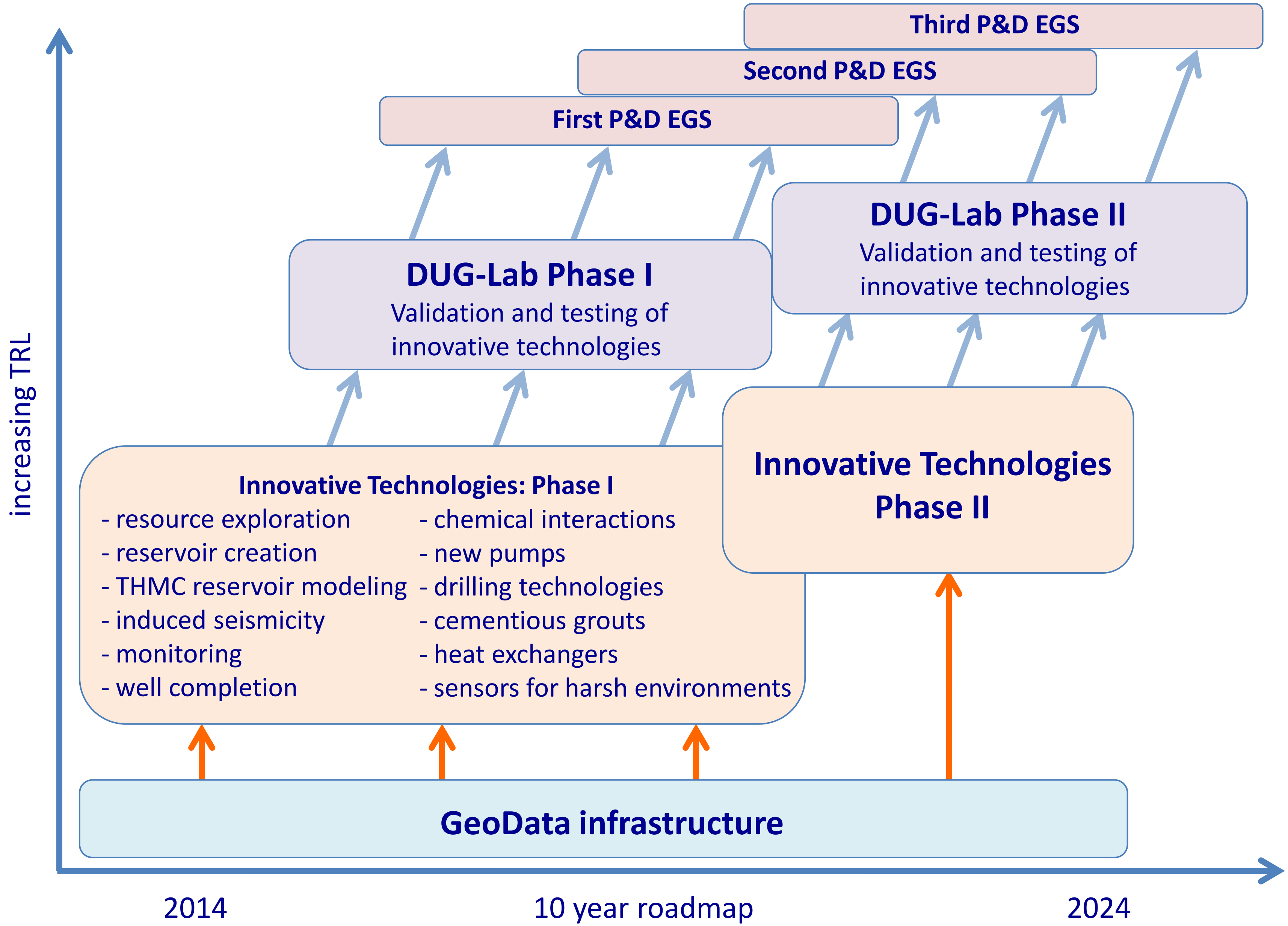
a. DGE roadmap, identifying the required technologies and a plan for their developments (release October 1, 2014)

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).

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


Third P&D EGS
Second P&D EGS
First P&D EGS
DUG-Lab Phase II
Validation and testing of innovative technologies
DUG-Lab Phase I
Validation and testing of innovative technologies
Innovative Technologies Phase II
Innovative Technologies: Phase I
- resource exploration
- reservoir creation
- THMC reservoir modeling
- induced seismicity
- monitoring
- well completion
- chemical interactions
- new pumps
- drilling technologies
- cementious grouts
- heat exchangers
- sensors for harsh environments
GeoData infrastructure
increasing TRL
2014
10 year roadmap
2024

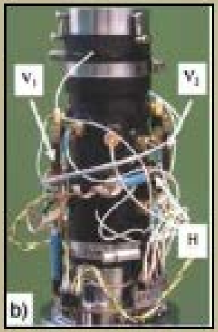
Innovation roadmap

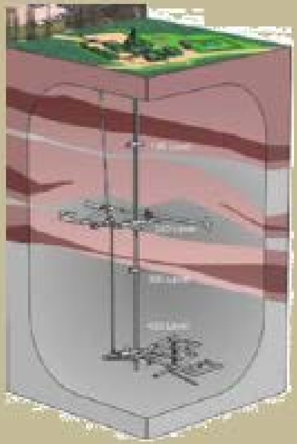
The innovation roadmap covers a number of technologies, including

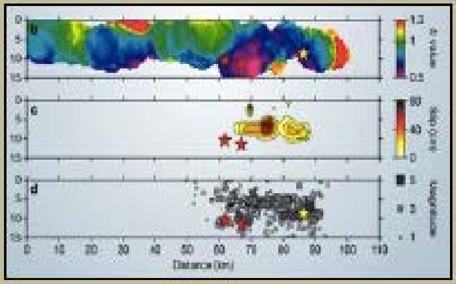
- ✓ New pumps for geothermal applications
- ✓ Innovative drilling technologies
- ✓ Cementious grouts for bore hole cement in geothermal wells
- ✓ Heat exchangers for geothermal applications
- ✓ Sensors for harsh environment
- ✓ Diverter and zonal isolation technologies for well completion
- ✓ Stress-field 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

Multiscale modeling approach

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





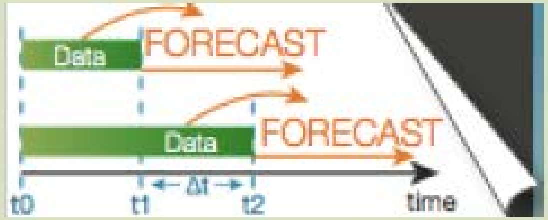


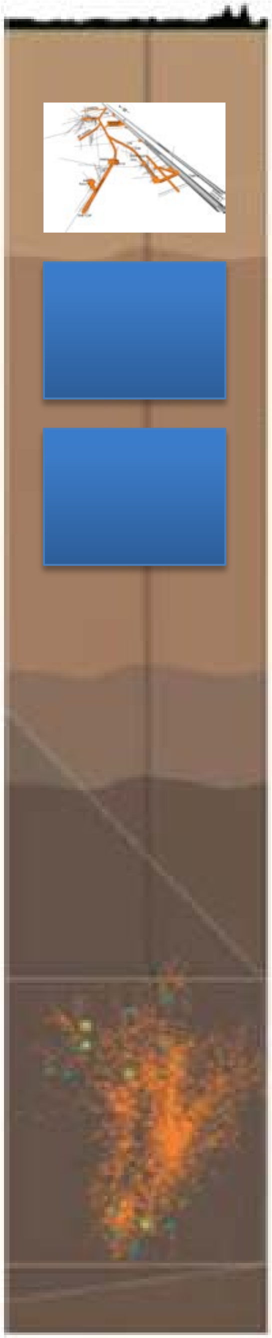
Laboratory Scale

Underground Lab Scale

Natural Systems

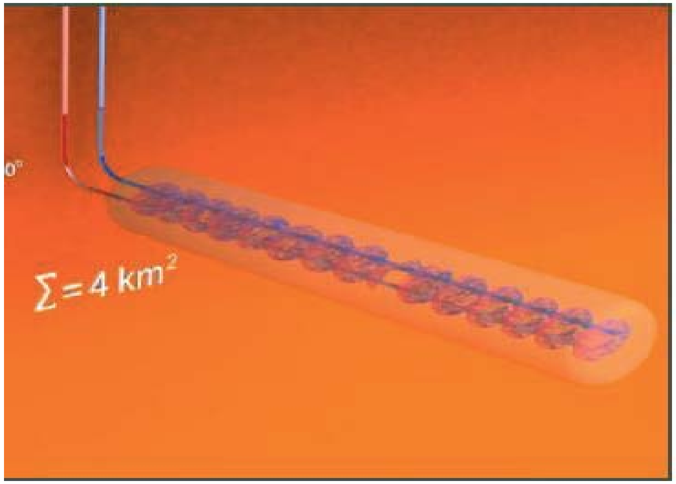
High Performance Computing, Modeling & Validation



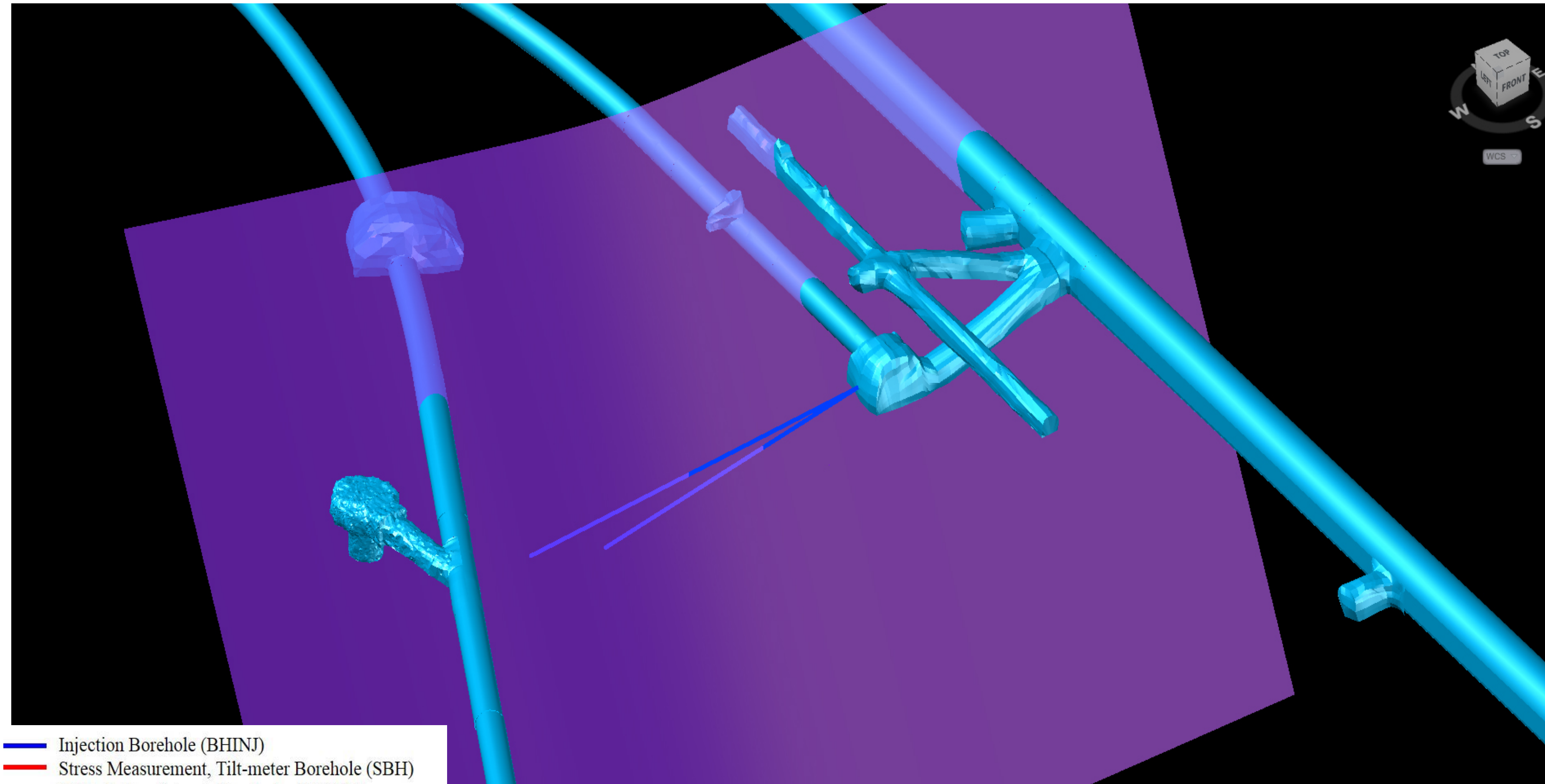


Underground R&D

- ✓ To perform stimulation experiments under a fully controlled environment at increasing depths
- ✓ 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



Boreholes Trajectory w.r.t. S3 Fault



- 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)

US/DOE priorities

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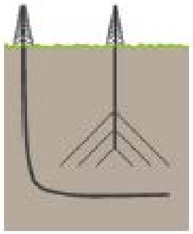
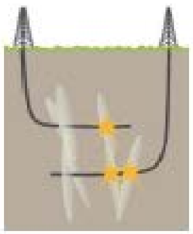
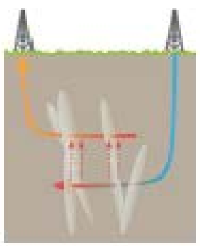
Technology Barriers	Potential Solution Set	Goal



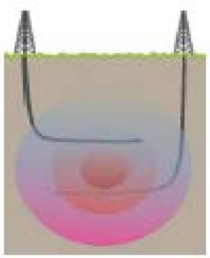
Reservoir Access
New well geometries and concepts, optimized drilling



Reservoir Creation
Characterize local stress, zonal isolation, novel fracturing methods, increase fractured volume per well



Productivity
Increase flow rates without excessive pressure needs or flow localization



Sustainability
Maintain productivity with minimal thermal drawdown and water losses

Hard/Hot-rock drilling, completion technologies

Horizontal wells

Rotary steering

Stress-field diagnostics

Smart tracers

Zonal Isolation

High-T sensors

Cross-well monitoring

Diverter and Zonal Isolation Technologies

EGS Success

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 discussing joining the Haute Sorne EGS project of GeoEnergie Suisse
- ✓ We need a single, nationally coordinated roadmap for the next 10-20 years → the on-going discussions in the Bund go in the right direction
- ✓ Petro-thermal and hydrothermal R&D and projects provide complementary challenges and results, and will be both pursued by SCCER-SoE in the future