

Annual Conference 2015



SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

Challenges for CO₂ Storage

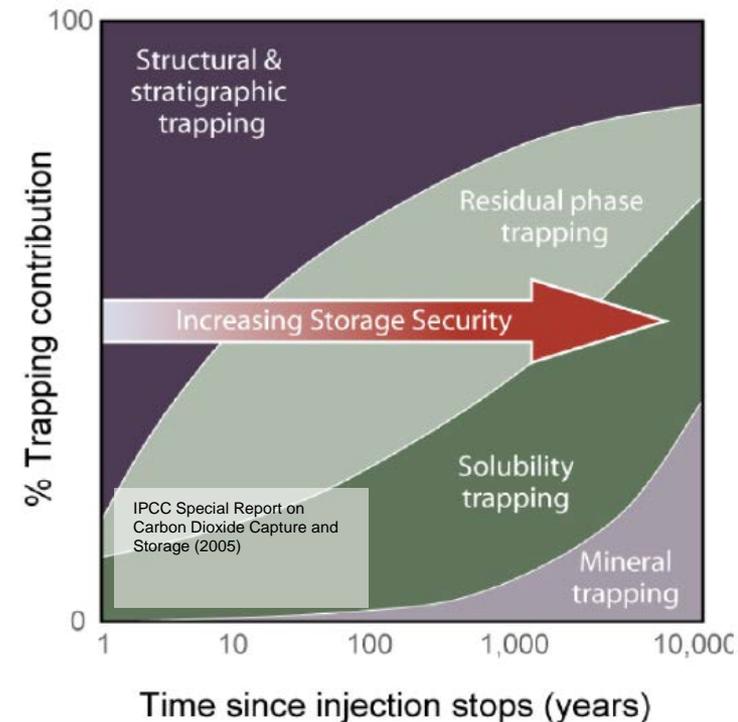
Martin Saar,
with help from Alba Zappone, Marco Mazzotti, Mischa Werner,
Xiang-Zhao Kong, Friedemann Samrock, Neeraj Shah, Markus Häring,
and several others

Challenges for CO₂ Storage

- Reservoir exploration and characterization (high-k reservoirs overlain by low-k caprocks)
 - injectivity
 - caprock integrity
 - poroelasticity
 - seismicity
- Understanding CO₂ trapping mechanisms (structural, residual, solubility, mineral)
- Fluid-mineral reactions and reservoir/caprock evolution (porosity/permeability evolution)
- Drilling, well completion, cementing
- Monitoring
- Costs
- Public acceptance

=> Significant research and progress has been made (see more later) but what is needed next is some sort of a field test (**pilot and demonstration project**).

Secure CO₂ Storage Increases Over Time



Focus today: Pilot and demonstration project for CO₂ storage (+ some examples from the GEG Group)

CARMA: Carbon Management in Power Generation (Jan. 2009-Jan.2013)
→ Roadmap 2013

Then:

- ECCSEL
- ERA-NET Cofund
- CO₂ GeoNet
- Mont Terri
- SCCER-SoE: CO₂ Injection Pilot

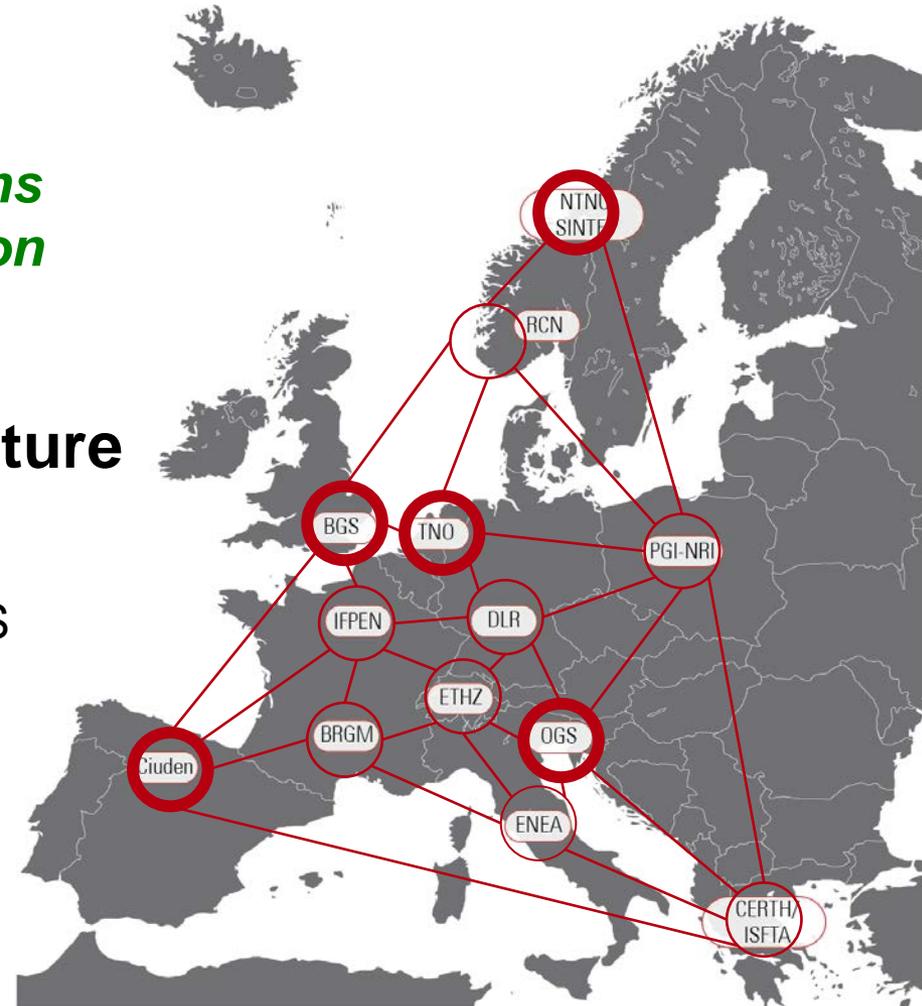


*Enabling low to zero CO₂ emissions
from industry and power generation*

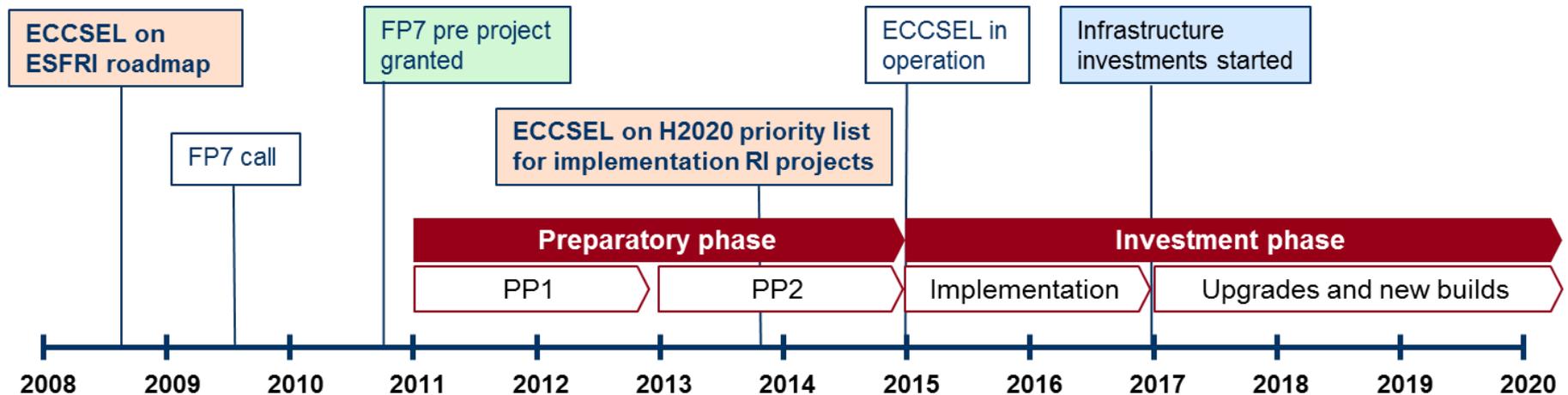
ECCSEL research infrastructure

European research infrastructure in CCS
(mostly capture but also some storage)

Thought to be a link of laboratories.



ECCSEL timeline



Implementation Phase started 1.09.2015

Kick Off meeting & General Assembly Meeting – Oslo, 10.09.2015 (yesterday)

- For storage side: in PP2: Mont Terri is part of a list of 4 shared key laboratories
- ETH/CH is not part of the steering committee (leaders of work packages) but observer
- Investment Phase: Each country provides funds –Y distributed back to researchers
- Gap analysis during Phase 1: What is available in CCS and what are key questions

April 8th 2014

ERA-NET Cofund - joint forces on CCS

Norway and Germany have taken the initiative to establish an ERA-NET Cofund proposal on CCS under Horizon 2020 by April 2015.

The following countries, in addition to Norway and Germany, have expressed interest for joining the ERA NET Cofund on CCS; Czech Republic, Finland, France, Greece, Italy, The Netherlands, Poland, Romania, Spain, Switzerland, UK

Norway, Germany, Switzerland and Romania have shown their likely cash contribution, which is highly appreciated.

We foresee a total budget of approximately € 50 million for a period of 3 - 4 years, including top-up financing from the European Commission. We plan to establish a consortium with as many nations as possible. By April 8th 2014 we have the following member contributions:

Norway: 6-10 M €
Germany: 6-8 M €
Switzerland: 4-5 M €
Romania: 2 M €

Other MS are invited to participate at similar levels.

We **suggest** the following topics to be included in the *Cofund CCS* :

- **CO₂ storage pilots including CO₂ transport solutions. CO₂ storage in aquifers and CO₂ for EOR will be included and possibly also offshore storage.**
- **Cost effective CO₂ capture technology:**

Further detailing of topics for the Cofund CCS will be established among participating nations.

CO₂ GeoNet

10th CO₂ GeoNet Open Forum: “CO₂ storage - the cornerstone of our low carbon future” Venice, Italy 11-12 May 2015



The European Network of Excellence on the Geological Storage of CO₂

A unique European Research Laboratory on CO₂ geological storage formed by a network of public scientific institutes durably engaged in mitigating climate change

our mission:
A FUTURE WITHOUT CO₂ EMISSION

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SWITZERLAND - ETH Zürich - Swiss Federal Institute of Technology Zürich

Department of Mechanical and Process Engineering, ETH Zurich
Department of Earth Sciences, ETH Zurich

ETH Zurich is one of the leading international universities for technology and the natural sciences. It is well-known for its excellent education, ground-breaking fundamental research and for implementing its results directly into practice. Founded in 1855, ETH Zurich today has more than 18,500 students from over 110 countries, including 4,000 doctoral students. To researchers, it offers an inspiring working environment, to students, a comprehensive education. Twenty-one Nobel Laureates have studied, taught or conducted research at ETH Zurich, underlining the excellent reputation of the university. According to the 2015 QS Rankings by Subject, ETH Zurich's earth scientists performed especially well, achieving the top rank for the subject Earth & Marine Sciences.

Among ETH Zurich's strategic focus areas are climate change and energy science. In particular, energy research at ETH Zurich is geared towards the aim of enabling the 1-tonne CO₂ society. Hence, ETH Zurich has taken the role of the leading house in various national projects dealing with the Carbon Capture and Storage value chain. The project CARMA explored the potential and feasibility of CCS systems deployment in Switzerland, and led to the development of a Swiss CCS roadmap to a CO₂ injection test. The storage pilot test got integrated in the ongoing Swiss Competence Centre for Energy Research - Supply of Electricity. Furthermore, ETH Zurich hosts the Swiss Seismological Service with its recognized specialists for injection-induced seismicity.

At European level, ETH Zurich is in the core group of ECCSEL, the European Carbon Dioxide Capture and Storage Laboratory Infrastructure project. The goal is to establish and operate a world class network of complementary distributed CCS laboratories and a limited set of pilots and test sites.

Relevant memberships and project experience:

- ECCSEL (partner) - Pan-European CCS research laboratory infrastructure, FP7/H2020
- SCCER-SoE (leading house) - Geoenergy competence centre for energy research
- EERA (member): European Energy Research Alliance
- DECARBIT (partner): Novel pre-combustion capture systems, FP7
- CO₂NET and CO₂NET2 (member): FP5/FP6 sponsored thematic network
- CARMA (leading house): Feasibility of CCS in Switzerland

Swiss Federal Institute of Technology Zürich
Web Site www.ethz.ch/en.html
Contact Person Professor Marco Mazzotti
Institute of Process Engineering, Sämggstrasse 3, 8092 Zürich
Switzerland
Related Staff | Facilities

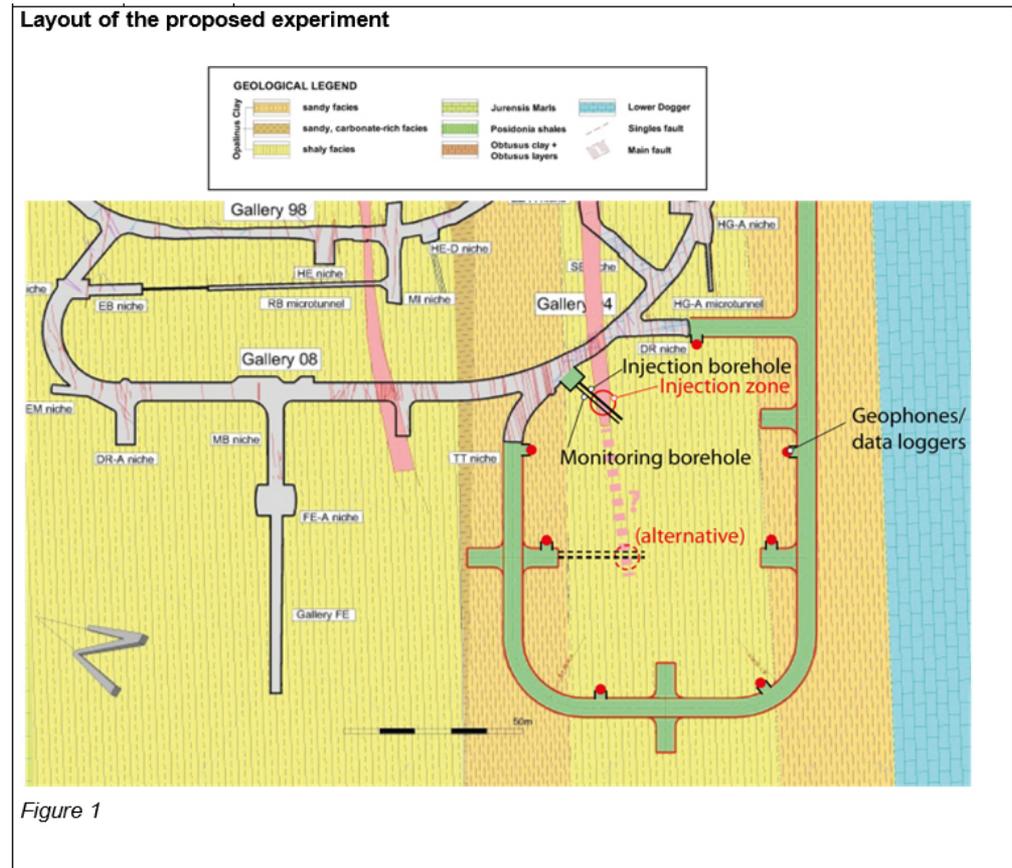
Partners

- AUSTRIA - GBA
- BELGIUM - RBINS-GSB
- CROATIA - UNIZG-RGNF
- CZECH Rep. - CGS
- DENMARK - GEUS
- ESTONIA - TTUGI
- FRANCE - BRGM
- GERMANY - BGR
- GERMANY - GFZ
- HUNGARY - MFGI
- ITALY - OGS
- ITALY - UniRoma1
- NETHERLANDS - TNO
- NORWAY - IRIS
- NORWAY - NIVA
- NORWAY - SPR
- POLAND - PGI-NRI
- ROMANIA - GeoEcoMar
- SLOVENIA - GEO-INZ
- SPAIN - Ciuden
- SPAIN - IGME
- SWITZERLAND - ETH Zürich
 - Staff
 - Facilities
 - Work Packages
- TURKEY - METU-PAL
- UK - BGS
- UK - HWU
- UK - IMPERIAL

ETHZ/CH joined in 2015

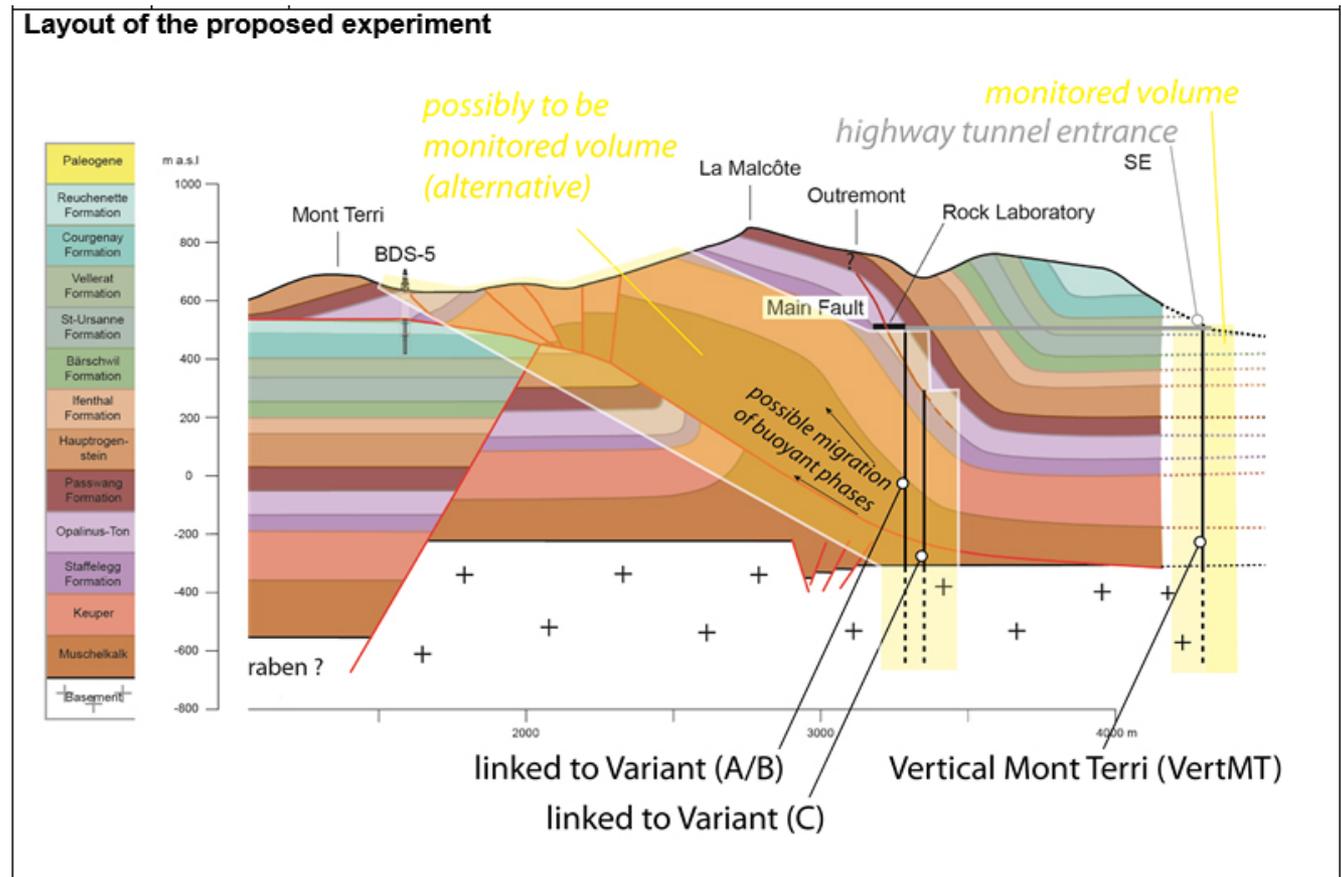
Mont Terri, new research program for deep geological disposal and geo-energy experiments → current review of proposals

Example 1:
(Zappone, Mazzotti):
 Testing of a fault subjected to CO₂ injection



Mont Terri, new research program for deep geological disposal and geo-energy experiments → current review of proposals

Example 2: (Zappone, Mazzotti): Vertical Mont Terri



CO₂ Injection Pilot (Information Meeting, July 3, 2015, Swiss National Bank, Bern) (organized by Markus Häring)

Generic well site



Example: Well site 5'000 m well Basel 1

CO₂- Injection well:

technically less complex:

- smaller rig size
- smaller foot print
- less immissions

technically possibly more complex:

- less developed infrastructure
- access to water
- access to power
- access heavy loads

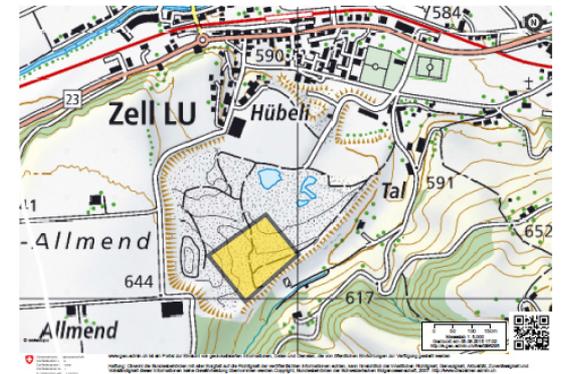
courtesy M. Häring

CO₂ Injection Pilot (Information Meeting, July 3, 2015, Swiss National Bank, Bern) (organized by Markus Häring)

Outcomes:

- Master plan
 - Follow Roadmap 2013
 - Test all potential aquifers
- Organization
 - Access to all Unis
 - Geochemical, geomechanical, hydraulic aspects
 - Need of an operator (continuity for management and operations)
- Owner/liability:
 - Consortium involving the owner of the mineral rights, i.e. Canton
 - Swiss confederation as partner (public acceptance.)
- Funding
 - Separate funding for construction, operation drilling and individual experiments

Generic test site

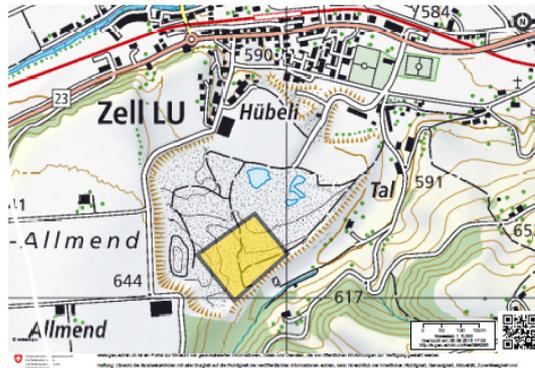


Generous lay out for

- drilling injection well 2'500 m + 1-2 monitoring wells
- injection operations without rig
- on site operation management
- on site monitoring labs
- additional on site lab facilities
- storage space solids
- storage space liquids
- storage space gas
- pipe stack
- warehouse
- car parking
- security / site control
- service staff accomodations

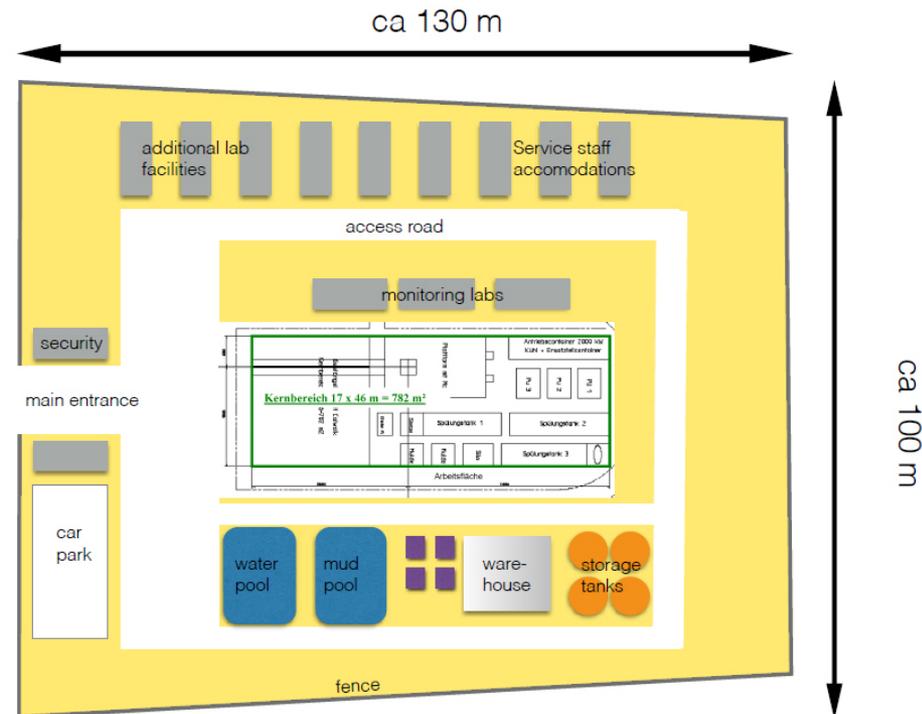
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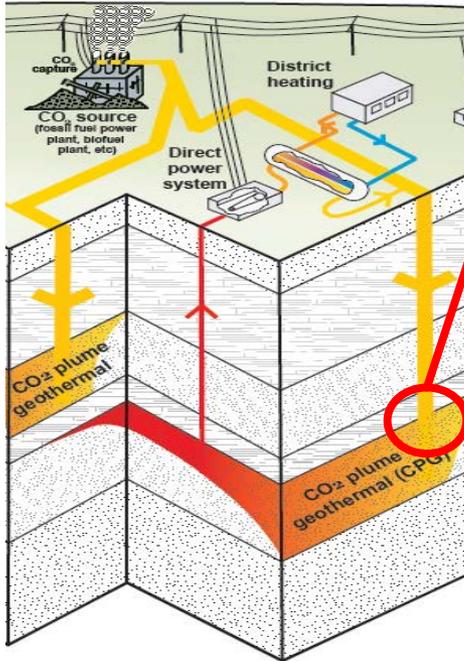


Next meeting: November 24, 2015:
Topic: discuss realistic field experiments that can be carried out at a CO₂ injection pilot

CO₂ Storage Research in the Geothermal Energy and Geofluids Group

- Reactive flow-through experiments (bench-top scale)
- Reactive flow-through numerical simulations (bench-top to reservoir scale)
- Coupling CCS with geothermal energy utilization
- Reservoir exploration (for geothermal, CCS, and CCS-geothermal)

Reactive flow-through experiments (bench-top scale) → see also Poster by Xiang-Zhao Kong



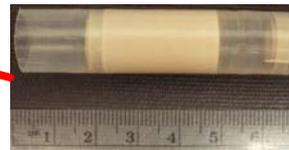
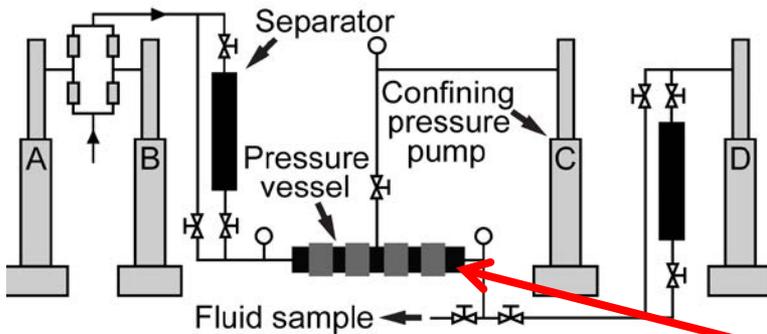
Pore-size distribution affects:

- Injectivity
- capacity
- security

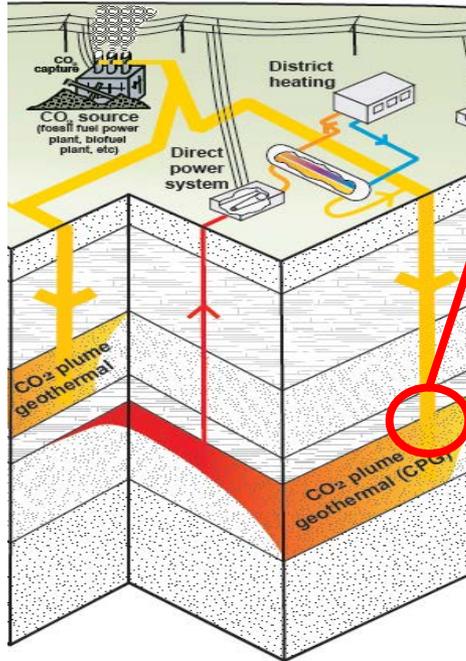
Quantify (mechanical, reactive) changes to porosity + permeability



Pore size distribution and permeability need to be determined



Reactive flow-through experiments (bench-top scale) → see also Poster by Xiang-Zhao Kong



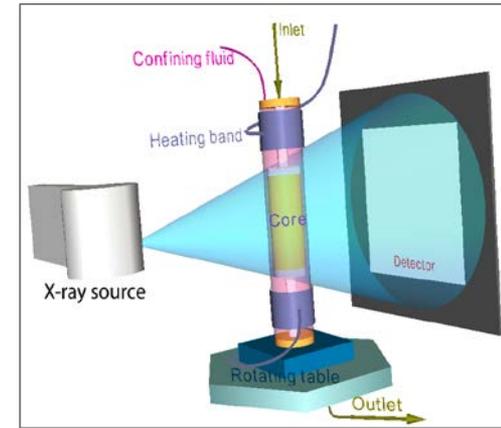
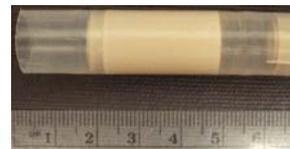
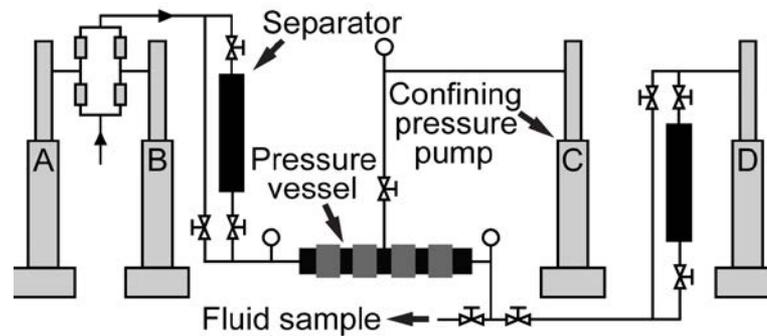
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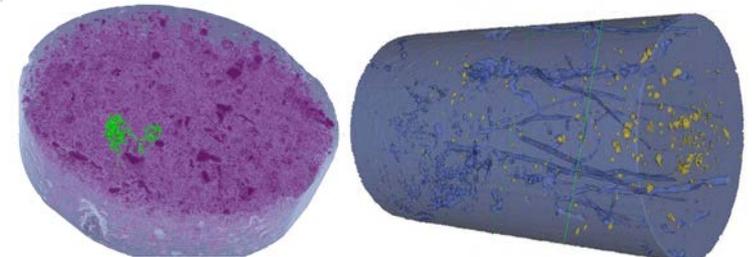
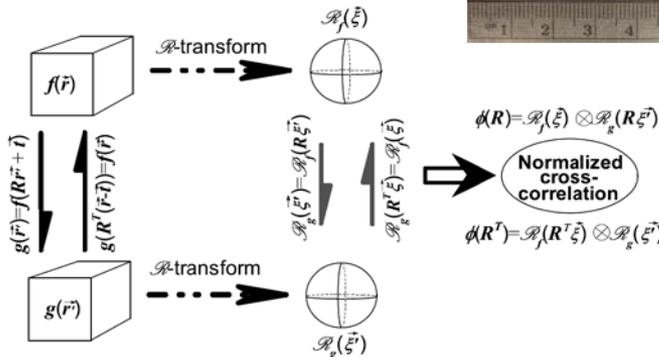


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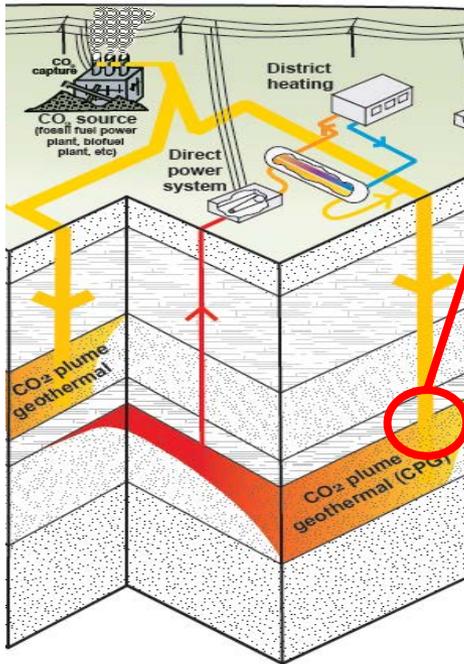
Quantify (mechanical, reactive) changes to porosity + permeability



Before and after reaction XRCT imaging + Radon Transform for volume registration



Reactive flow-through experiments (bench-top scale) → see also Poster by Xiang-Zhao Kong



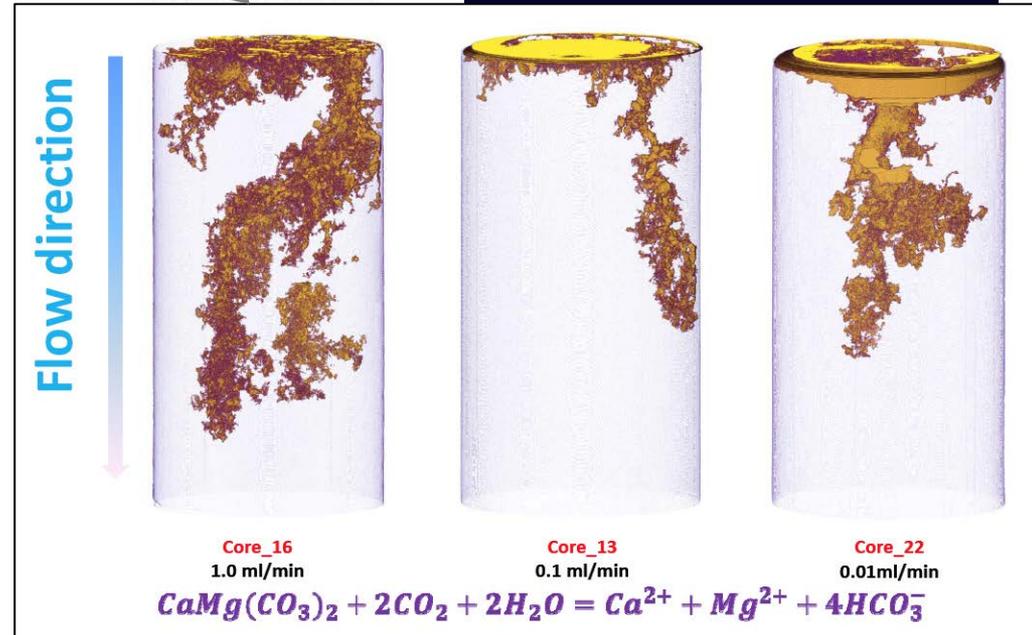
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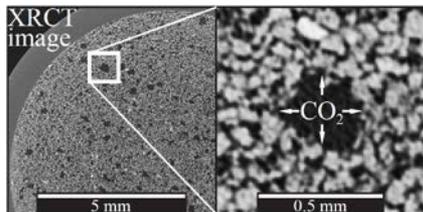
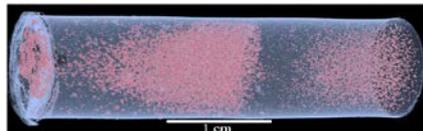


Pore size distribution and permeability need to be determined

Quantify (mechanical, reactive) changes to porosity + permeability



Mechanical changes in unconsolidated sediment due to CO2 exsolution and grain movement → a new CO2 trapping mechanism

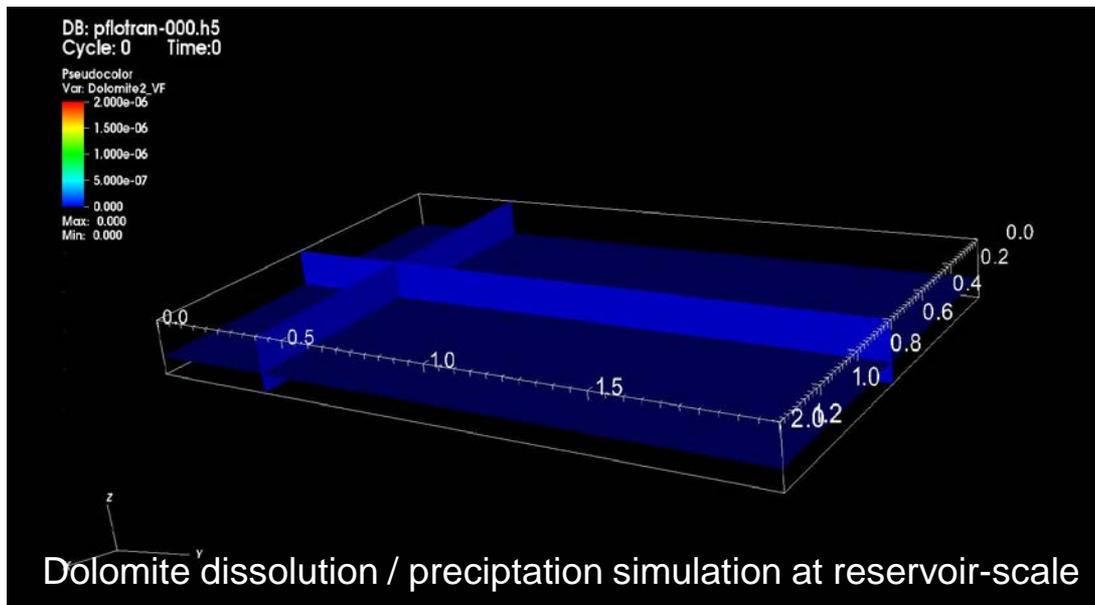


Reactive flow-through numerical simulations (bench-top to reservoir scale): Example: Injection of CO₂ in carbonate aquifer

Massively parallel simulations using PFLOTRAN

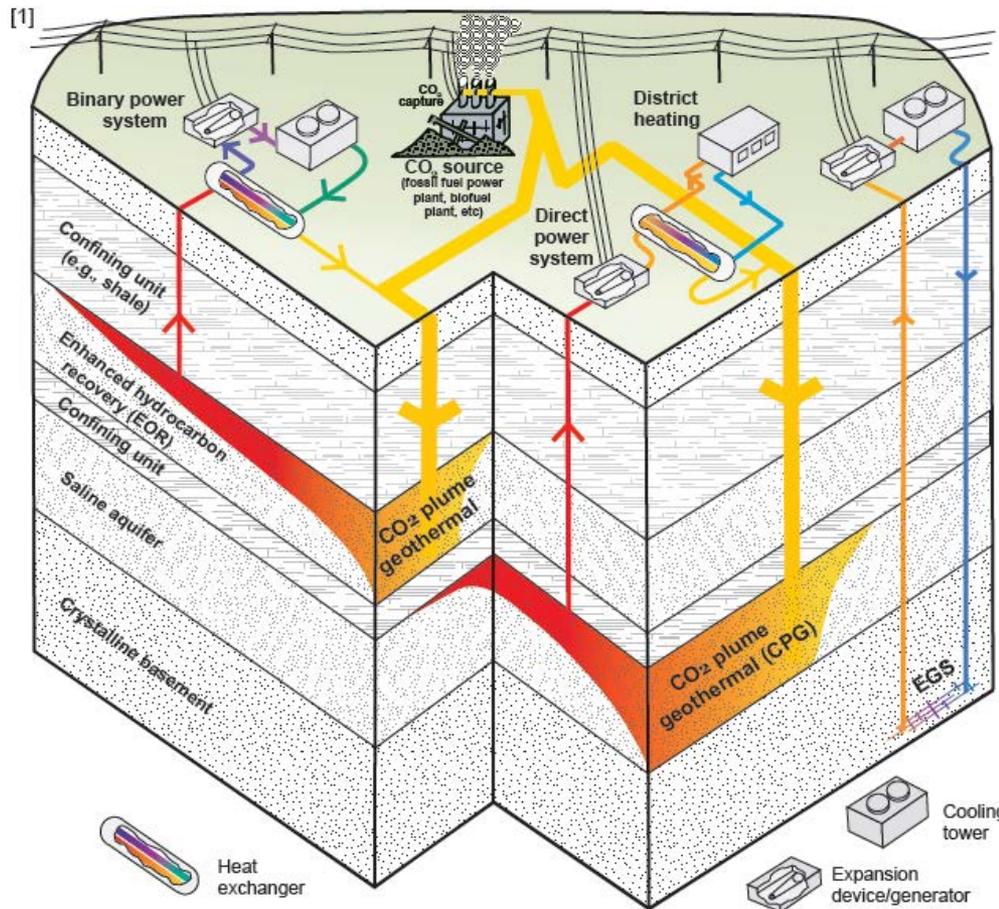
PFLOTRAN

by Dr. Ben Tutolo (formerly in GEG Group, now at Oxford)



Coupling CCS with geothermal energy utilization

CO₂-Plume Geothermal (CPG)



Randolph and Saar, 2011

Reservoir exploration (for geothermal, CCS, and CCS-geothermal)

→ see also Poster by Friedemann Samrock and Neeraj Shah

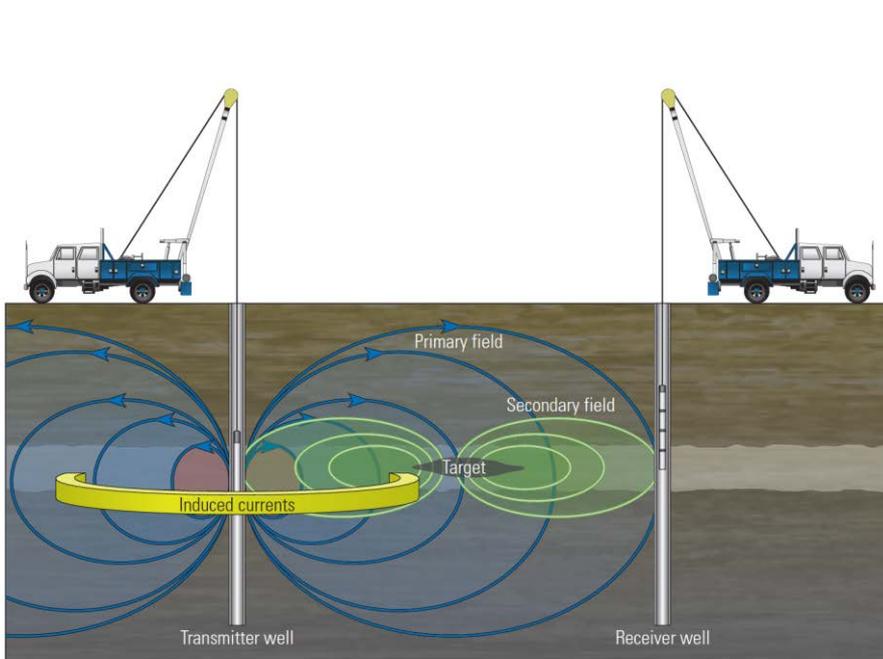
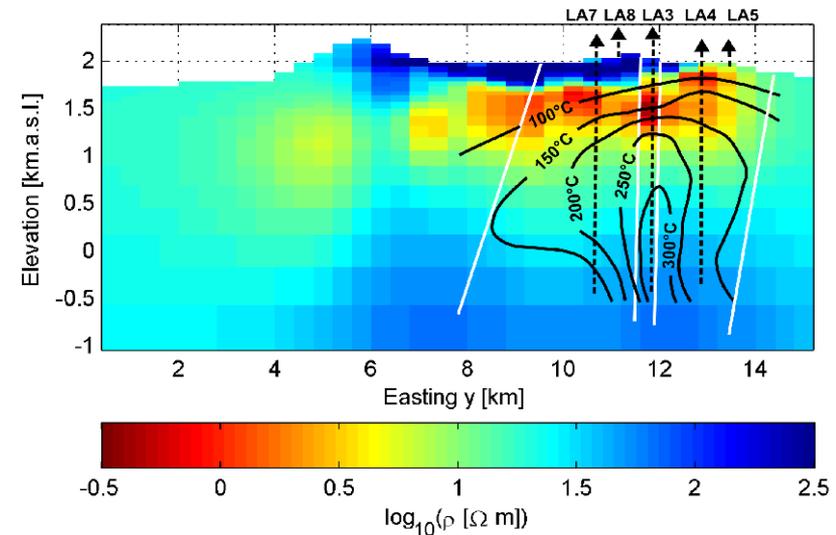
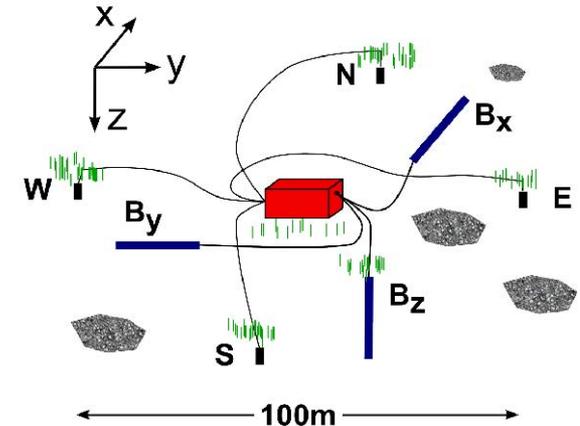


Fig. 4: Basic setup and principle of crosswell EM (Oilfield review summer 2009, 21, no. 2. Schlumberger).

$$\begin{pmatrix} E_x(\omega) \\ E_y(\omega) \end{pmatrix} = \begin{pmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{pmatrix} \cdot \begin{pmatrix} H_x(\omega) \\ H_y(\omega) \end{pmatrix}$$



Summary

- CCS research is being conducted worldwide.
- A few field-scale (test) sites exist but more test sites are needed to investigate different conditions, including in CH.
- Thus, a pilot and demonstration plant in CH is needed to make significant further progress in CO₂ storage research and eventual widespread implementation.
- Planning for specific pilot CO₂ storage field tests has started (e.g., for Mont Terri and the SCCER-SoE efforts) but is very much in the beginning stages and funding is not secured.
- Need to secure funding, determine and plan sites, and integrate these efforts in a European framework.
- Information of the public and public engagement is critical. One way CO₂ storage (research and implementation) may be more acceptable to the CH public is to combine it with geothermal energy extraction. → this was also suggested by several people at the meeting in Bern on July 3, 2015, with Markus Häring.





