The long-term fate of CO2 in the subsurface - Latest results from FP7 UltimateCO2 project

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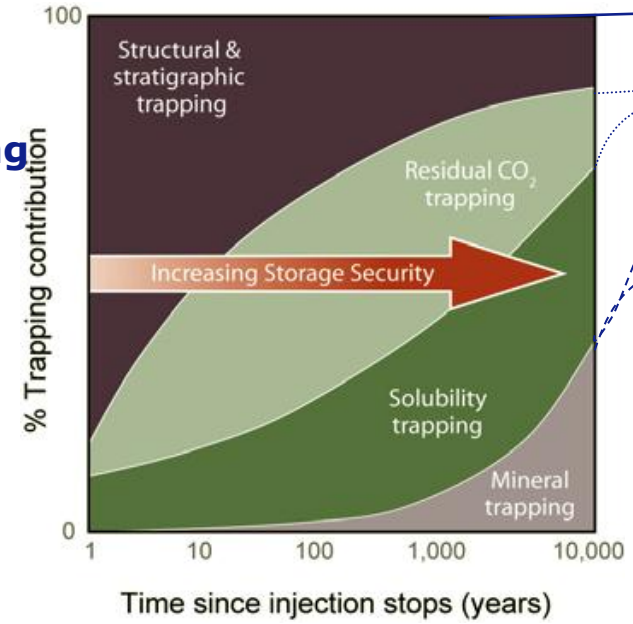
What is long term?

- Several milestones in the life of a CCS project can be defined as long term issues:
  - end of injection? end of monitoring? Site closure? (Regulation aspects)
  - disappearance of free CO2? stability of the systems? (Physical aspects)

SRDM Trapping
Structural
Residual
Dissolution
Mineral



When?

What if leakage (fault, wells)?

Stabilization?

What is the uncertainty in the predictions?

- ULTimateCO2 aimed at addressing some of these aspects in a non exhaustive manner

ULTimateCO2 consortium

Consortium

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Department of Energy & Climate Change

Private Consultant

T. Torp (retired STATOIL)

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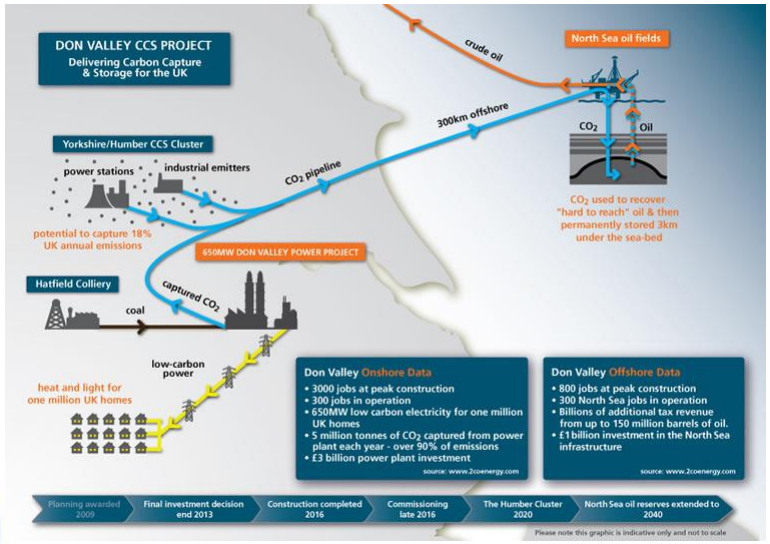
Long term coupled processes

- **Trapping mechanisms** of CO2 at the **reservoir scale**:
  - CO2 (+impurities) – brine flow and associated dissolution during and after injection?
  - Acidification and interaction with host rock?
  - Convective flux of brine? Mixing of the system?
- **Integrity** of the storage area:
  - Role of the acidification on mechanical integrity of caprock?
  - Resistance of wellbore compartment (casing, cement, rock interfaces) to mechanically and geochemically solicitation?
- **Regional impact** of CO2 storage (basin scale):
  - Fault reactivation? Brine displacement? Groundwaters chemical changes in case of CO2 leakage?

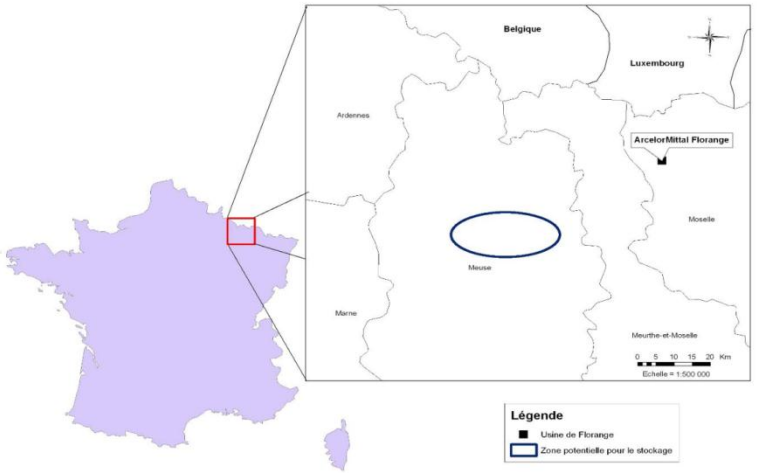
Long Term Reservoir trapping evolution

- Elaboration of static geological models based on two demonstration sites:

Off shore North Sea UK, Don Valley project, 2Co Operator combined with EOR



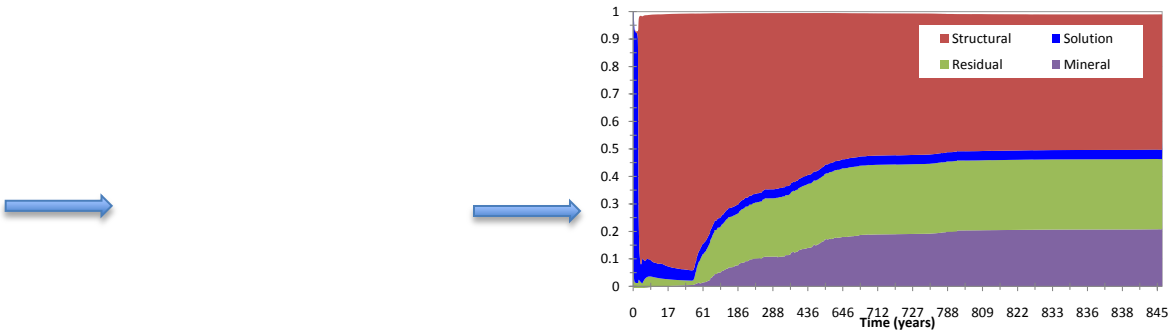
On Shore outcropping former ULCOS, NER300 candidate in Lorraine in France



- BUT: difficulties encountered with Don Valler operators to collaborate (very buzzy), ULCOS project eventually closed

Long term reservoir trapping evolution

- Classical reservoir multiphase flow simulation with a focus on dissolution, residual trapping + coupling with chemical change of the reservoir fluid composition
- **Gas phase evolution**
- **Impact of heterogeneity on convection flow**
- **Balance versus time of the SDRM trapping magnitude**
- **Long term residual trapping in slopping aquifer**

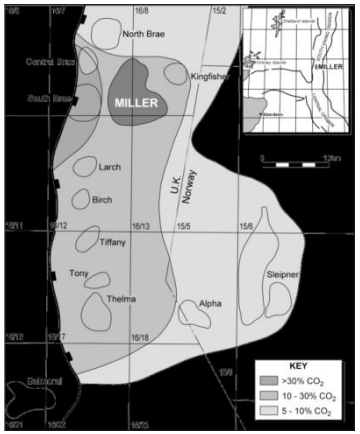


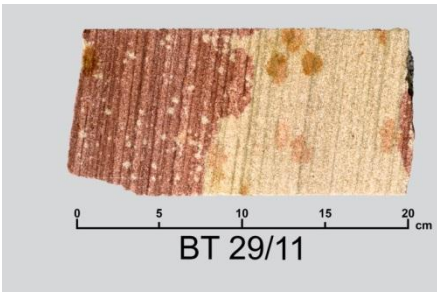
See Peter Fryckman poster!

Long term reservoir trapping evolution

- Evaluation of long term chemical processes occurrences in storage formation
  - Empirical assessment of impurity (H2S, SO2, NO2) impacts & Fe mobility

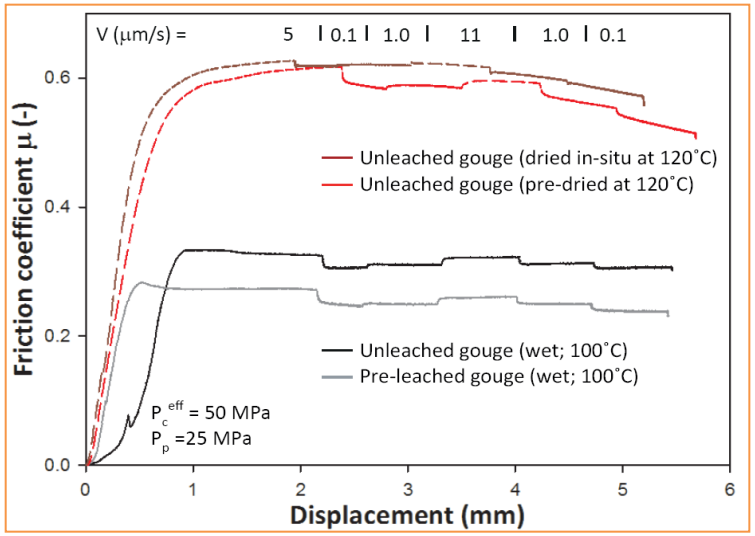
- Evidence for long term trapping evolution in storage formation reservoir
  - Kingfisher field (UK)
    - CO2 gradient
  - Bad Teiner (Germ.)
    - Outcrop Fr demo
  - Werkendam (Holland)
    - CH4/CO2 nat analog.

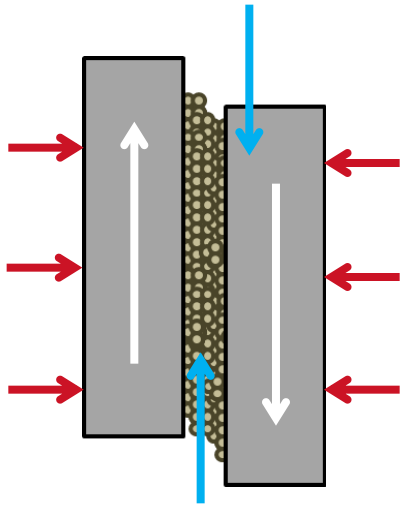




Long term fault sealing integrity

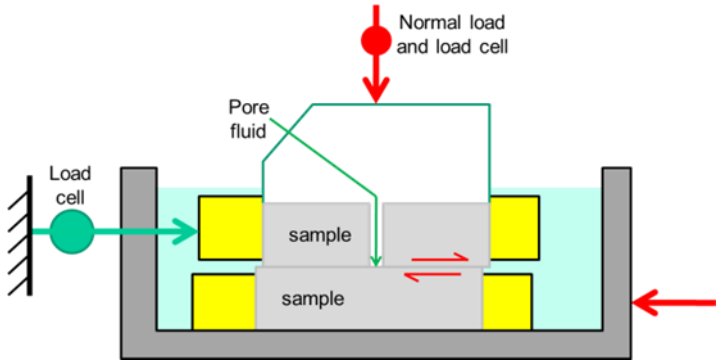
- Faulted caprock: effects of fluid-rock interaction
  - Great interest in the Netherlands: offshore storage in depleted gas field
  - Quantify effects of carbonate content and temperature on frictional & transport properties of simulated caprock fault-gouge
  - Experimental method: Direct shear friction experiments on gouge at 20˚C - 120˚C , Velocity stepping plus permeability tests





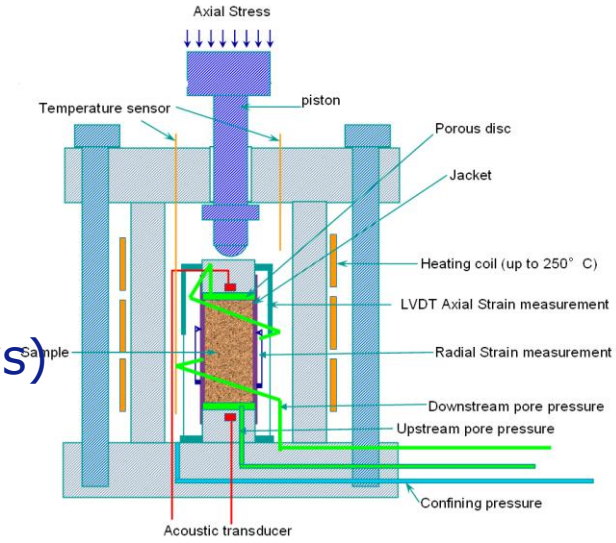
Long term fault sealing integrity

- Fracture caprock: examination of flow
- Monitored parameters (at steady-state):
  - Pore pressure, Pp, on the fracture plane
  - Applied stresses (σN and σS)
  - Fracture dilation
  - Fracture transmissivity: for different permeants
  - Fracture roughness: pre- and post-testing (3D laser scanner)
  - Post-test petrological/mineralogical analysis
  - examine potential for geochemical changes



Long term fault sealing integrity

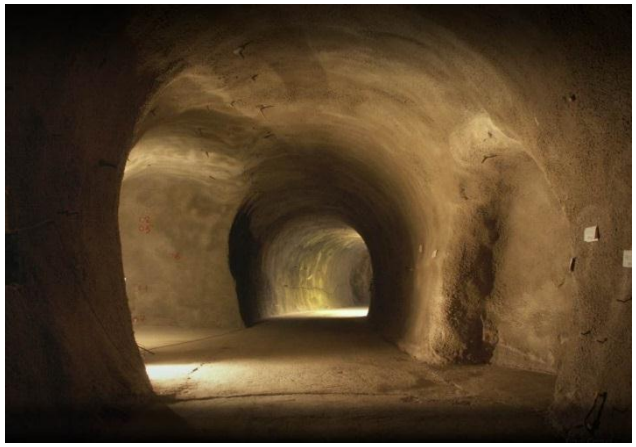
- Fractured caprock: chemical effect on mechanics
  - Derivation of elastic parameters of intact material
  - Cyclic loading & strain gauges
  - Ultra-sonic velocity measurements
- Pre-damaging techniques used:
  - Tri-axial loading to failure
  - Drying in oven (105 C° during 5 days)
  - Freezing water content (~1.4%)

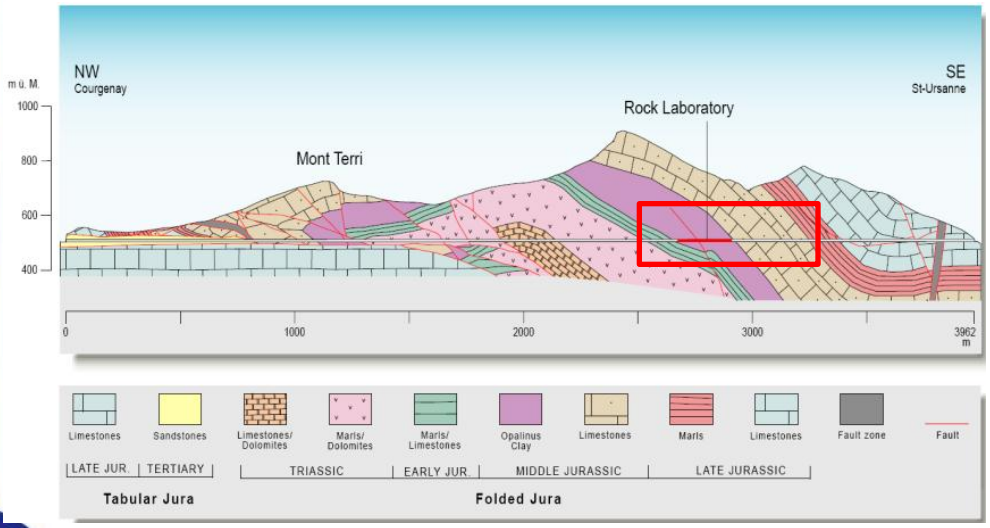


ALL MECHANICAL EXPERIMENTS CONDUCTED ON OPALINUS CLAY FROM MONT TERRI UNDERGROUND ROCK LABORATORY

Long term wellbore sealing integrity

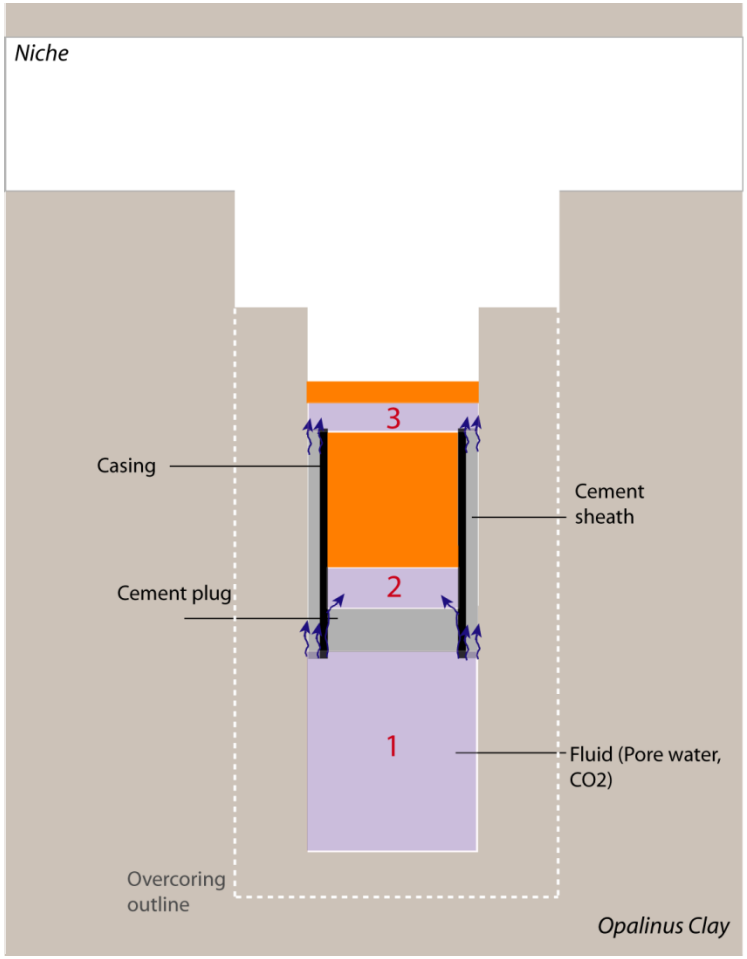
Use of Underground Rock laboratory, Mont Terri in Switzerland





after Mont Terri project website, 2013

Mont-Terri URL field experiment Concept



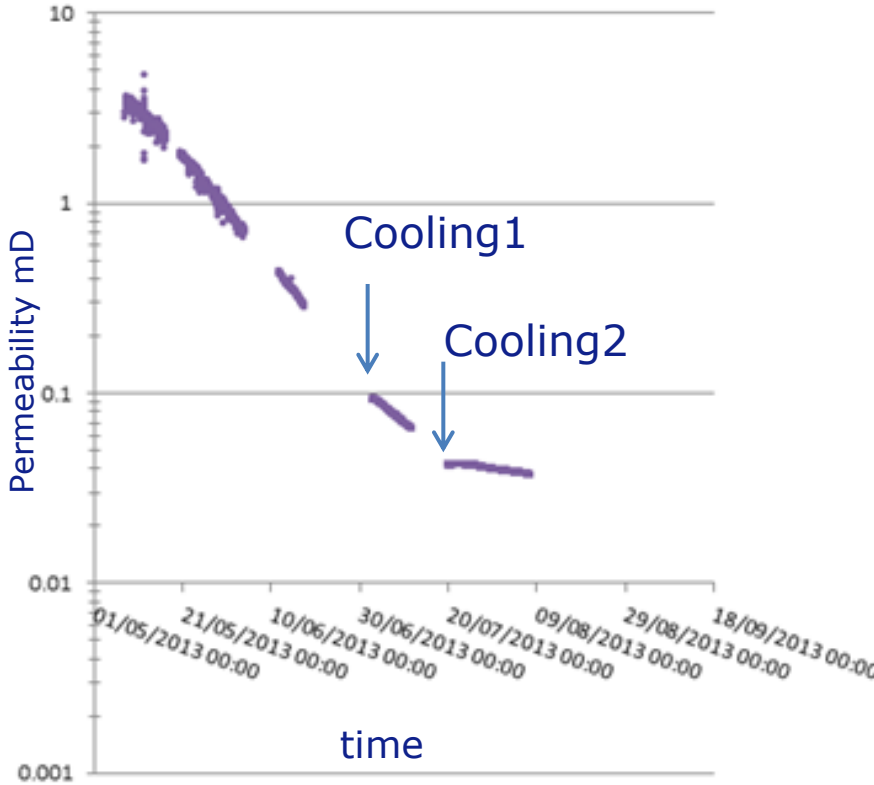
Not to scale

- Main Objectives
  - Build well components
  - Measure the permeability between chambers 1, 2 and 3
  - Inject CO2 at the bottom (Chamber 1)
  - Evaluate the chemical changes
  - Overcore the whole system (casing, cement, clay)
  - Measure permeability change and observe evidences of leakage

Mont-Terri URL field experiment

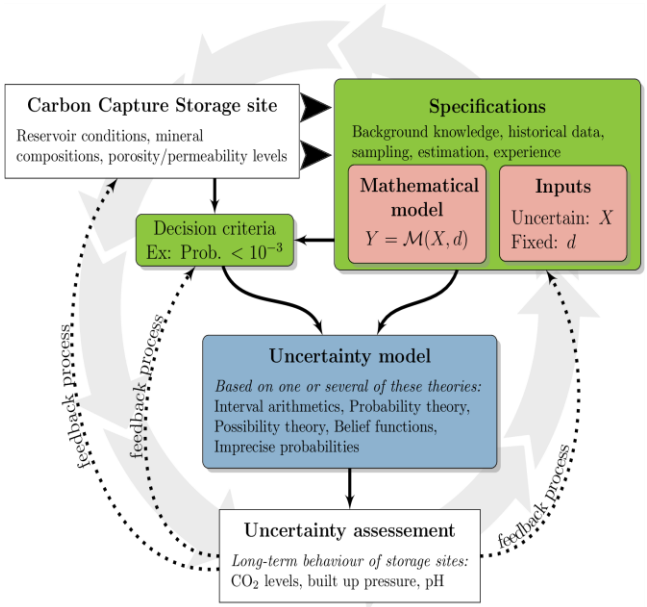
Mont-Terri experiment: Role of temperature

- Initially T = 15° C, (without CO2)
- Increase to 50° C
  - Permeability drops from 10 mD to less than 0.1 mD
- Cooling 1 of 5° C
- Cooling 2 of 20° C
- Global reduction of Permeability decrease but no increase
- **Explanations**
  - Thermo-mechanical
  - Chemical (etringite precipitation)



Uncertainty analysis

- How confident can we be with our predictions, evaluations, measurements, observations?
- Long term issue increases the level of uncertainty
- Is there any methodology coming from other application that could be used for CCS?



Uncertainty analysis

- Our method: **3 Discussion groups to build scenarios**

Groups →	Geochemical (GCH)	Geo-mechanical (MK)	Reservoir (RES)
Geometry	0D	1D to 2D	3D
Uncertainty parameters	Porosity, Kinetic rate, Surface area, list of minerals	Chemical (GCH group), initial calcite content, friction coefficient, initial state stress, elastic properties (young modulus, poisson ratio)	Heterogeneity, porosity, permeability, Krel, capillary pressure.
Targets	Caprock and Reservoir	Caprock	Reservoir (Caprock?)
Performance indicator: Safety	Porosity change. release of unwanted elements	Flux across the boundary of faults. cumulative density function of the quantity of CO2 that comes across the boundary limit (before escape)	Brine displacement
Performance indicator: Capacity and Effectiveness	Mineral trapping (how much CO2 in secondary phases.	??	Structural, Residual, Dissolution trapping.

- 3 studies to evaluate the long term uncertainty of the identified performance indicators using a dedicated plateform to calculate the surface response for each scenarios

Conclusion & Perspectives

- ULTimateCO2 suffers from the difficulties encountered in Europe for CCS site deployment:
  - NER300 European funds did not finance new sites; ULCOS French project is abandoned (industrial plants closure)
- Does not prevent ULTimateCO2 team to progress and provide new insights on coupled processes of long term CO2 storage, with specific focus on
  - the role of chemistry on trapping, and
  - efficiency processes associated with CCS and at several scales
- More to come in 2014 & 2015:
  - Injection of CO2 in Mont Terri
  - Regional scale study
  - Experimental program
  - Uncertainty methodology

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Research needs for CO_2 storage

- We need data!
  - Demo sites data compilation
  - Demo sites data to improve modeling concept and so prediction
- To be more economically persuasive
  - Develop adequate business model (too late?)
- To improve the confidence with CCS
  - Develop Communication with public

- More specifically
  - Identify better the role of heterogeneity on CO2 capacity-> capacity prediction is the crucial parameter for the life of a project (Sleipner heaven)
  - Improve our knowledge on chemical impacts (from near well to groundwaters aquifers): does it realy matter?
  - To develop proven technologies for mitigation- remediation in case of failure: confidence improvment
  - To improve our confidence with the pressurization and the risk of induce seismicity (Zoback comment): improve confidence

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ULTimateCO2 Work Program