UPPSALA UNIVERSITET

SwedestoreCO2 and Mustang projects

Auli Niemi
Uppsala University
Department of Earth Sciences

CO2 Capture and Storage in the Baltic Sea Countries
Geological Survey of Finland (GTK), May 23rd, Espoo

Outline

- **MUSTANG**; a large-scale integrating EU FP7 project for developing methods for quantifying saline aquifers for CO2 geological storage (2009-2014) (including a pilot injection)

- **SwedSTORE^{CO2}**; pre-feasibility study to look at possilities to store CO2 in Sweden (including a possible test injection) (2012-2013)

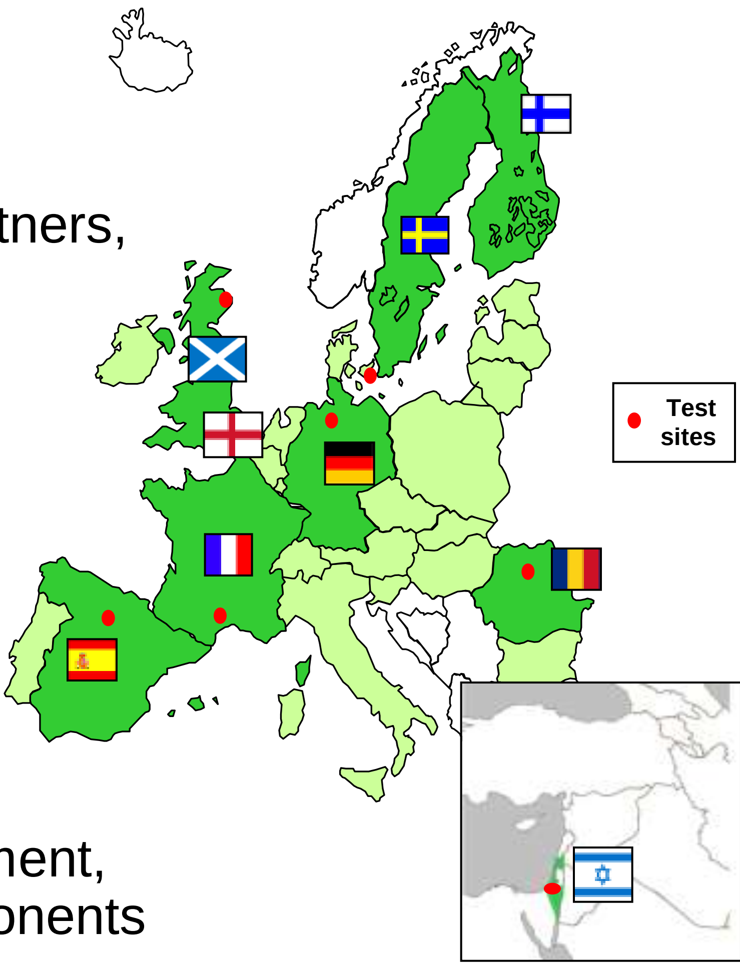
MUSTANG project

- Develop **methodology and understanding** for the quantification of saline aquifers for CO2
geological storage

- **Large scale integrating project**, 19 partners,
25 affiliated organizatons (coordinated by Uppsala/Niemi)

- 2009 - 2014

- **7 test sites** including
one deep injection experiment
and one shallow injection experiment
of CO2, as well as strong laboratory experiment, process understanding and modeling components



- www.co2mustang.eu

Mustang Partners and SIRAB

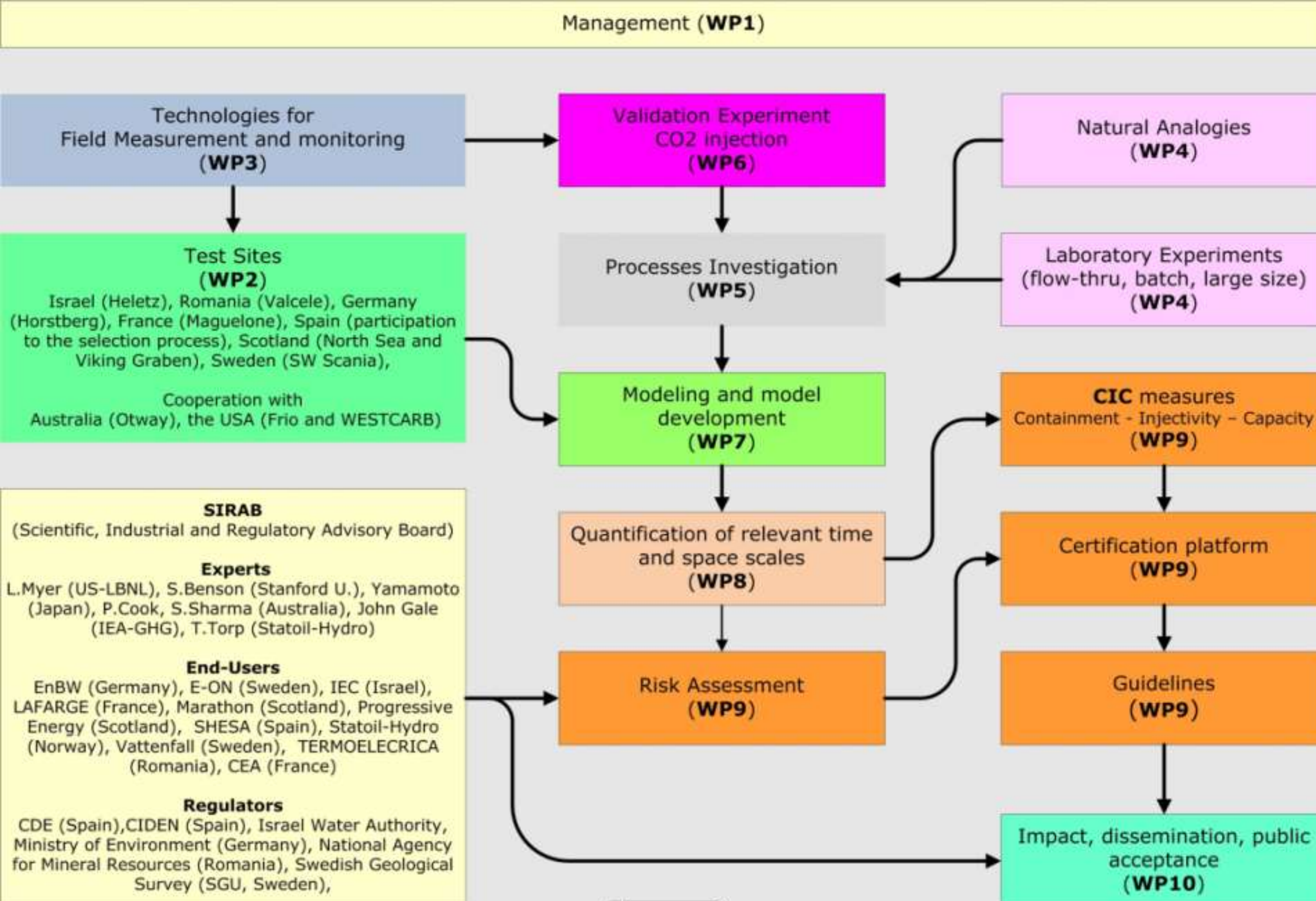
MUSTANG PARTNERS

MUSTANG SIRAB

International advisors

Industries/ end-users

Regulators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Modeling and model development (**WP7**)
CIC measures
Containment - Injectivity – Capacity (**WP9**)
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(Scientific, Industrial and Regulatory Advisory Board)
Experts
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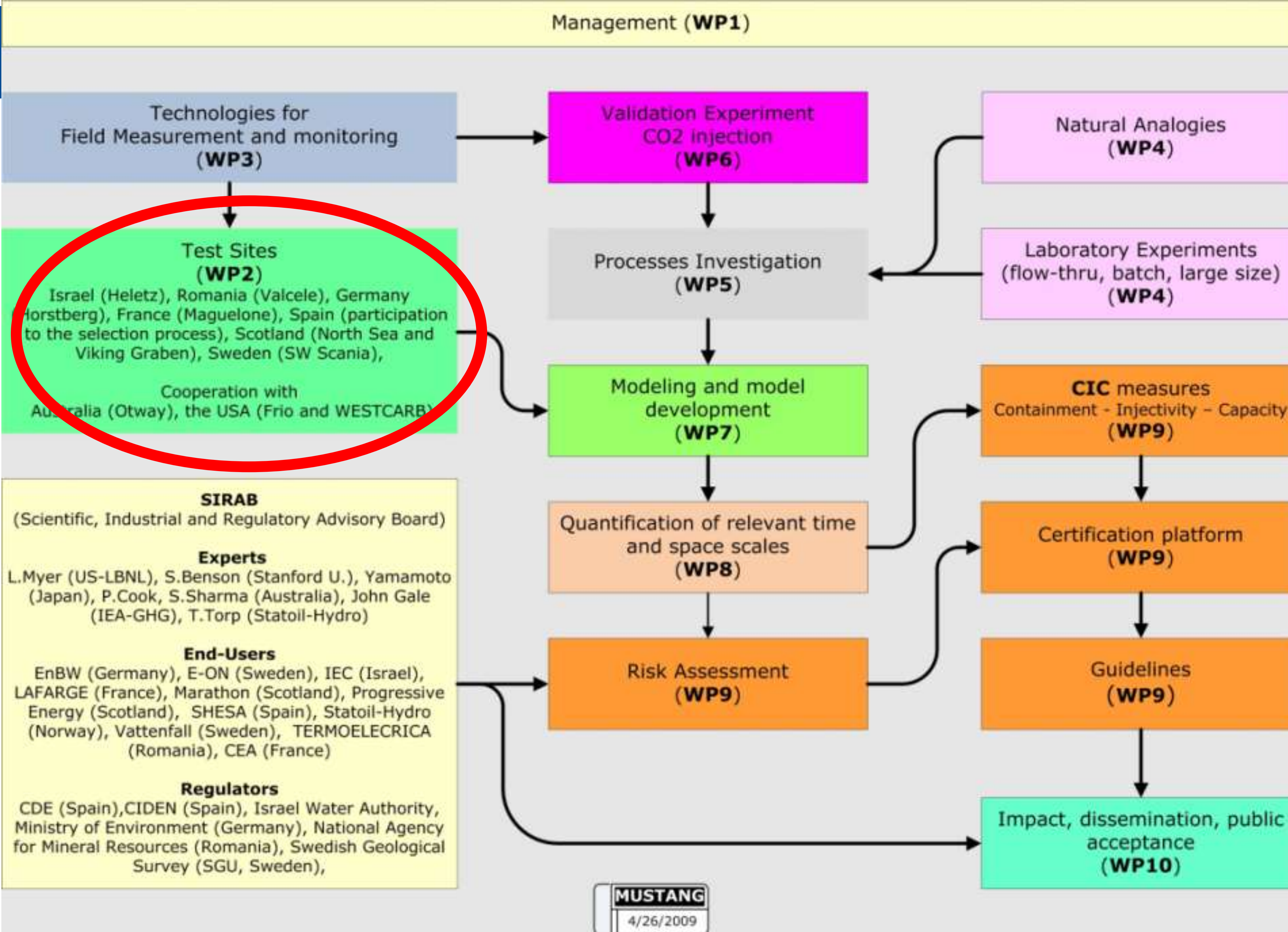
Certification platform (**WP9**)
Risk Assessment (**WP9**)
Guidelines (**WP9**)
Impact, dissemination, public acceptance (**WP10**)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MUSTANG
4/26/2009

Mustang Test Sites

USA

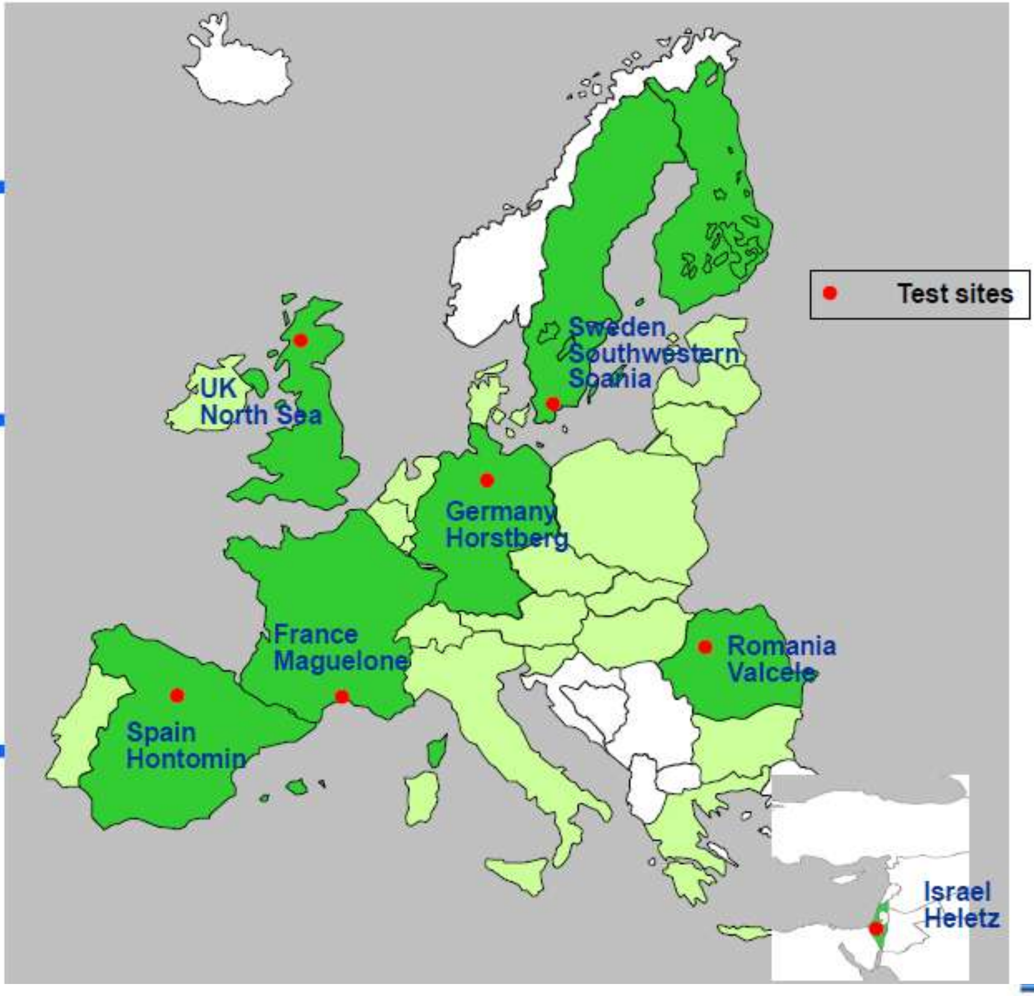
exchange with LBNL (Westcarb, Frio), natural analogue sites

Australia

CO_2CRC, Otway site

Japan

Oil, Gas and Metals Corp, natural analogue studies



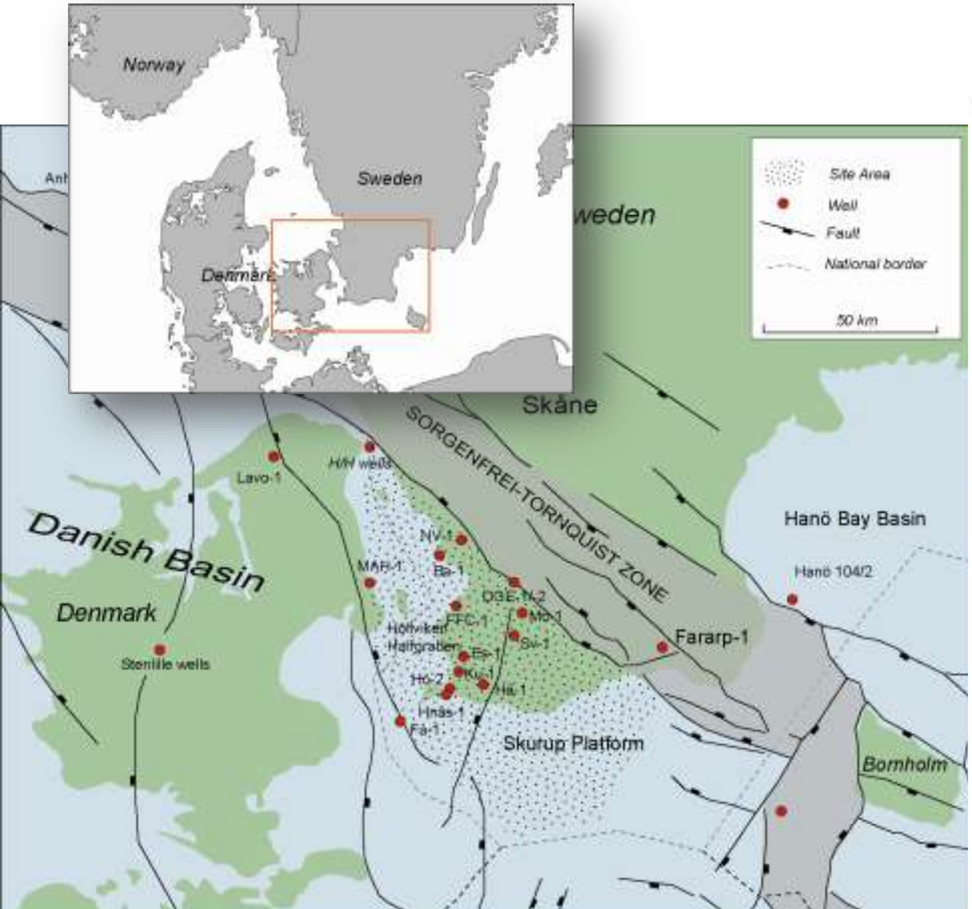
Contributing: UU, SGU, UNOTT, CSIC, LIAG, UGÖTT,GII, IIT, EWRE, UB, CNRS, UEDIN

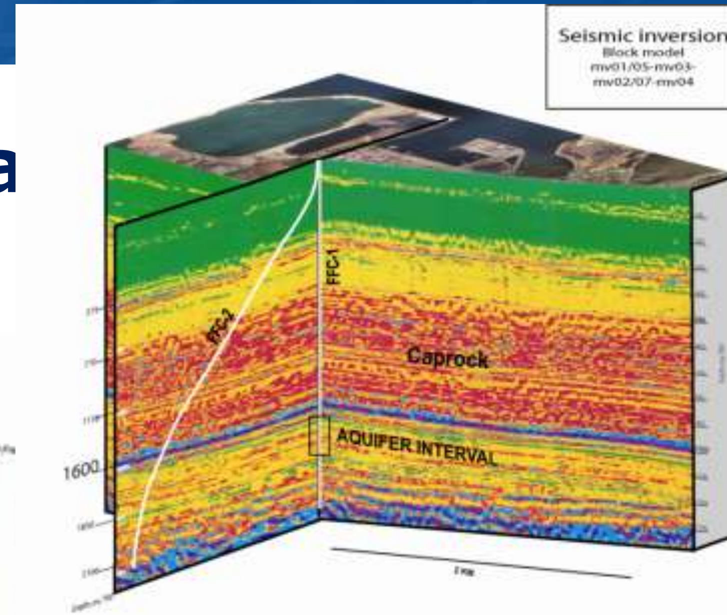
Test Sites – Overview of properties

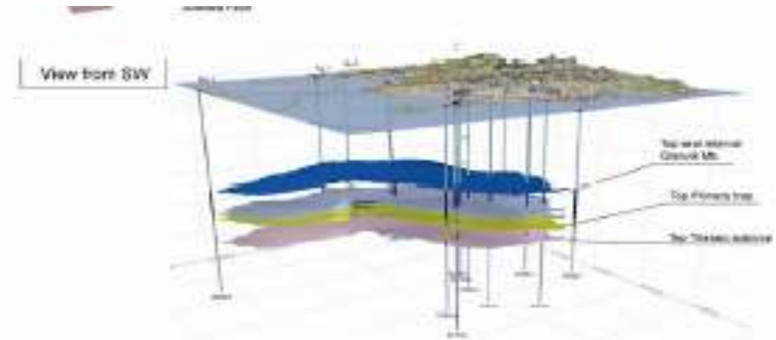
	South Scania	Horstberg	Valcele	Hontomín	Heletz
Character	Multilayered sequence of heterogeneous as well as uniform aquifers	Deep, low permeable aquifers High temperature	Oil and gas field Complex structural setting Large data set	Exploration site Pre-investigation phase	Abandoned oil field Well known geology Field test site
Structure	Subhorisontal	Inversion structure	Multitrap folds	Closed dome	Anticline fold
No. wells	16 (2[1])	2	71[2] (241[3])	4	40
Site model, km^2	Regional c. 1000 Local: c. 10	c. 50	c. 5	c. 15	c. 20
Depth range, of potential storage layers	1100–1950 m	3700–4000 m	1100–2200 m	1400–1600 m	1380–1560 m
Age	E. Cretaceous-Jurassic	Early Triassic	Neogene	Jurassic	Cretaceous
Thicknesses of potential storage layers	4–55 m	13–40 m	20–30 m	140	0.6–21
Main rock type	Sandstone	Sandstone	Sandstone	Limestone/dolomite	Sandstone
Main seal rock type	Claystone Argillaceous limestone	Claystone	Marlstone Clay	Marl	Limestone Shale, marl
Porosity, %	20–29	5–10	20–28	12-17	16–20
Permeability, mD	10–4000	<10	15–500	n.d.	100–250

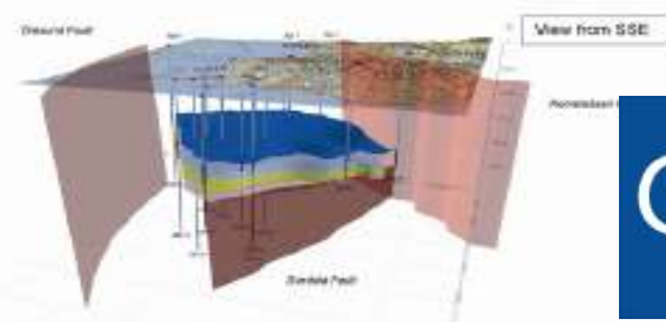
[1] In the local scale, [2]in the 3D parameter model, [3] Total wells with data

Example – South Scania Site Sweden









Contributing: UU, SGU

Mustang Test Sites – major field activity

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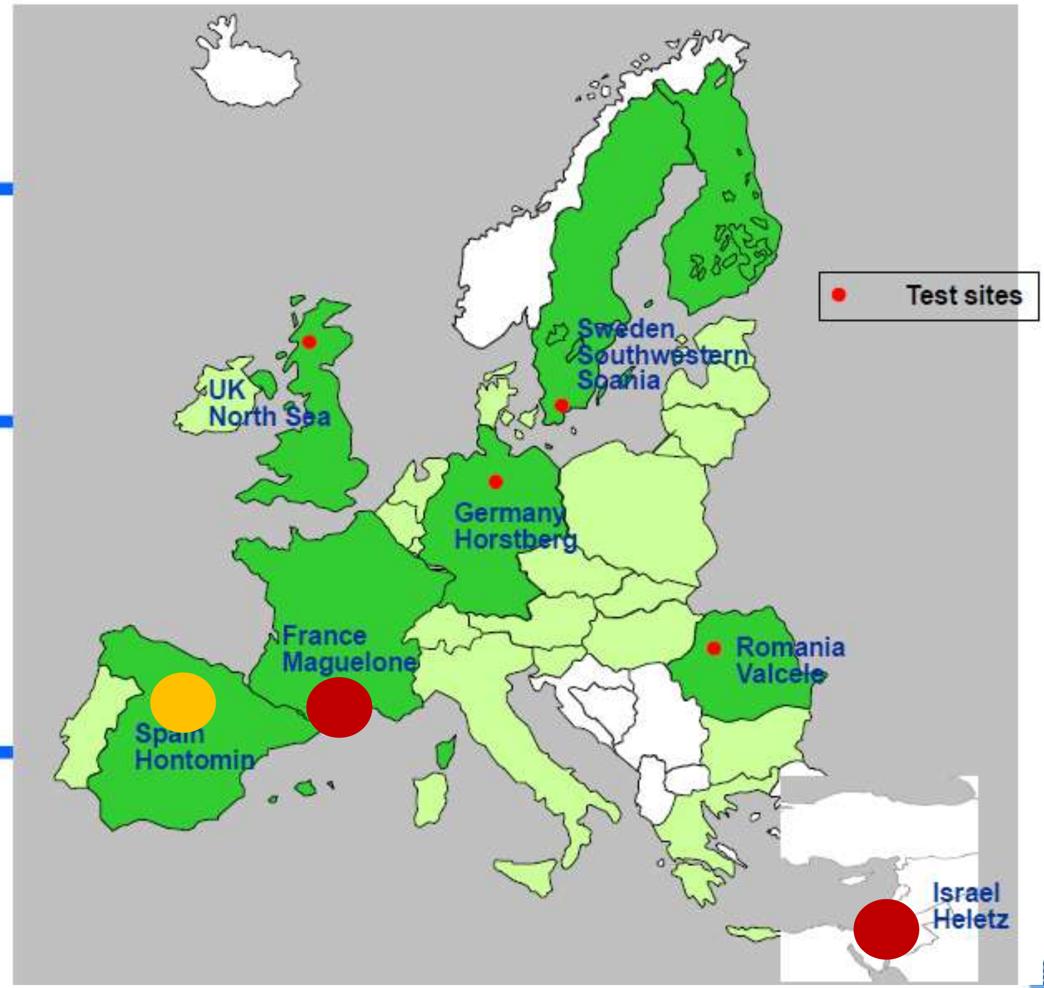
exchange with LBNL (Westcarb, Frio), natural analogue sites

Australia

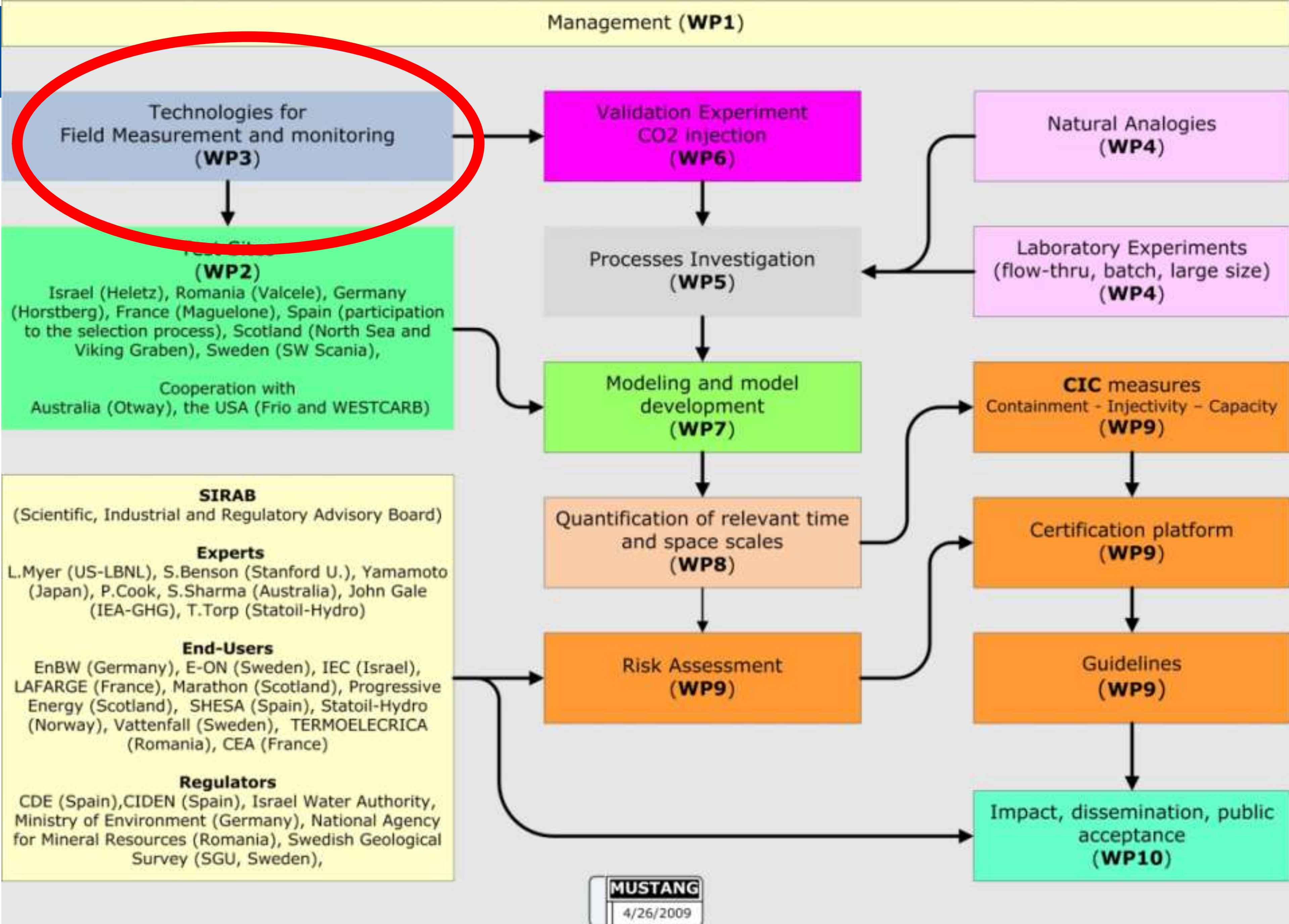
CO_2CRC, Otway site

Japan

Oil, Gas and Metals Corp, natural analogue studies



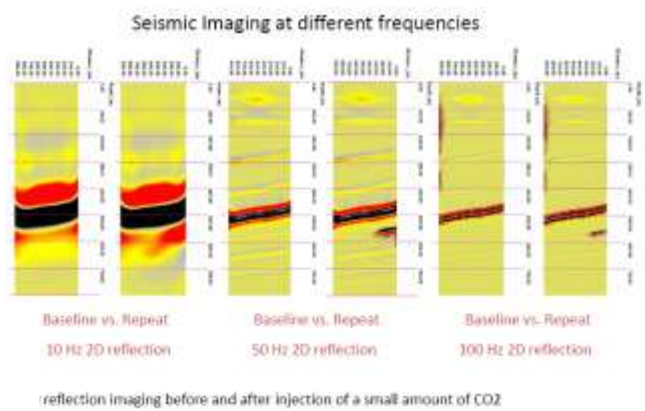
Contributing: UU, SGU, UNOTT, CSIC, LIAG, UGÖTT,GII, IIT, EWRE, UB, CNRS, UEDIN



SEVENTH FRAMEWORK PROGRAMME

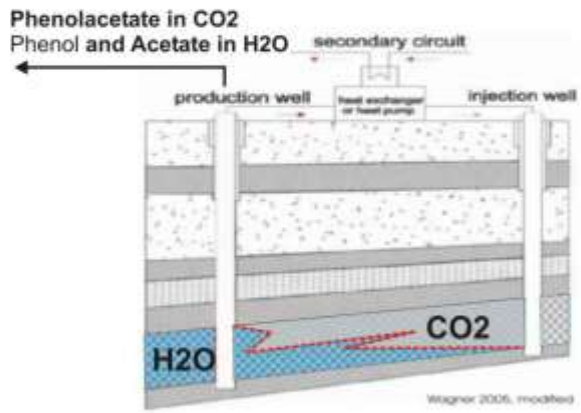
Improving the field testing methods

Geophysical methods



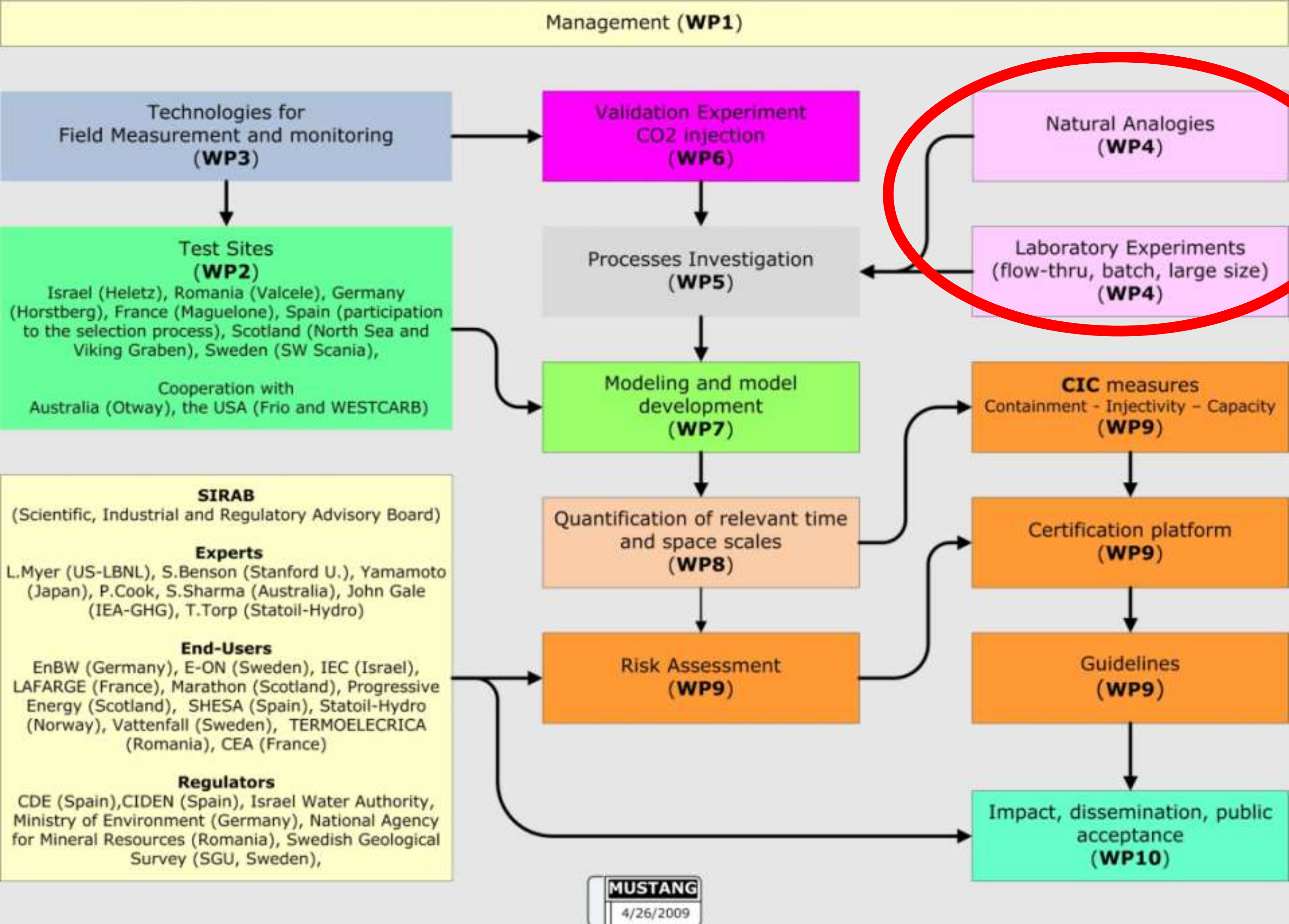
CO2 Injection-monitoring –sampling system

Spreading CO2 front and changing interface



Interface-specific tracers

Contributing: UU, UGÖTT,GII, EWRE, CNRS, Imageau, Solexperts, Vibrometric, CSIC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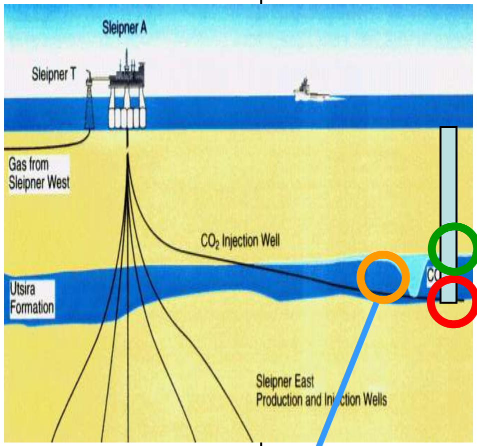
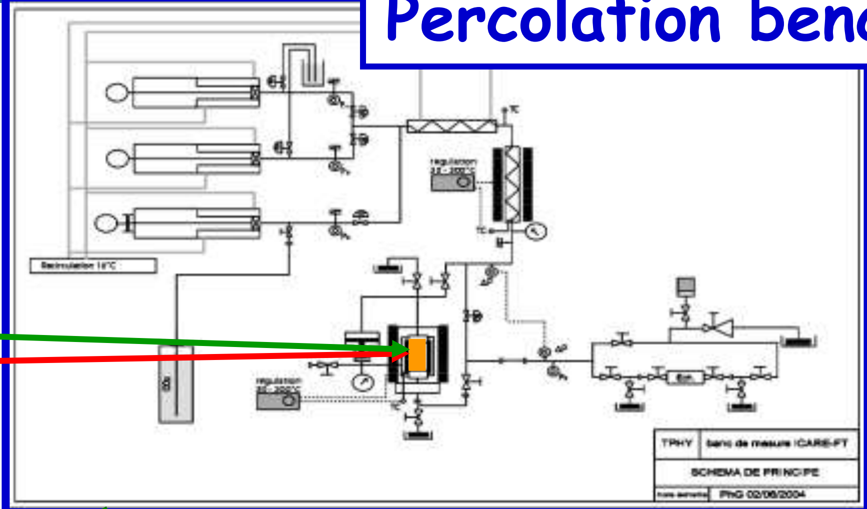
MUSTANG
4/26/2009

Laboratory Experiments - Synopsis



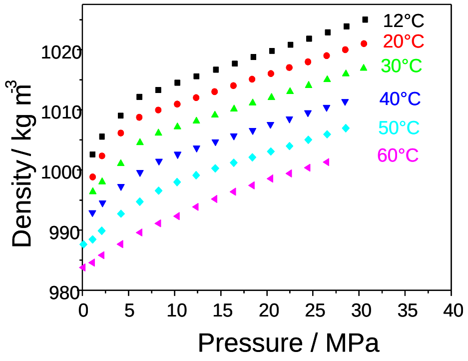
Percolation bench



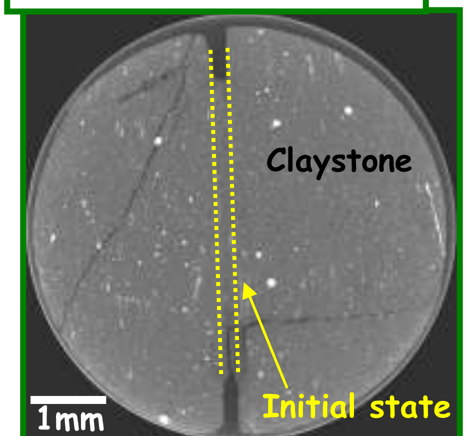
Caprock samples

Reservoir rock samples

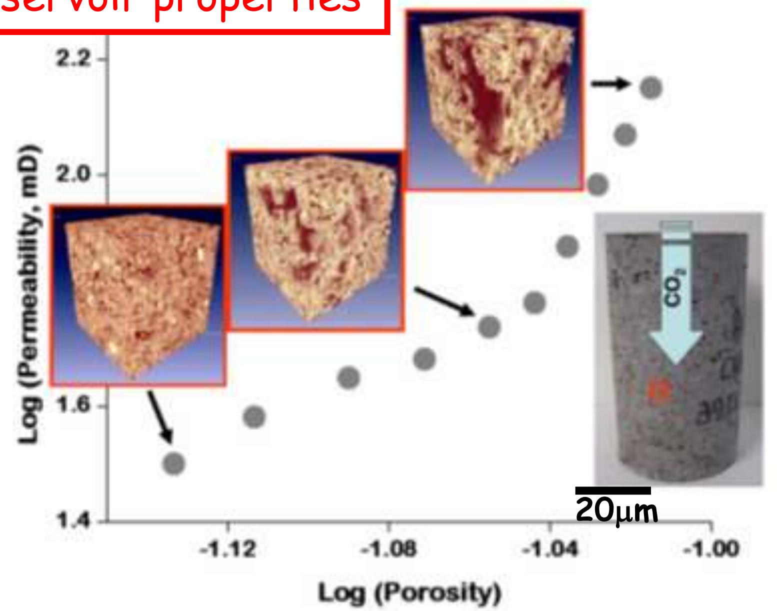
Brine-CO_2 mixture properties



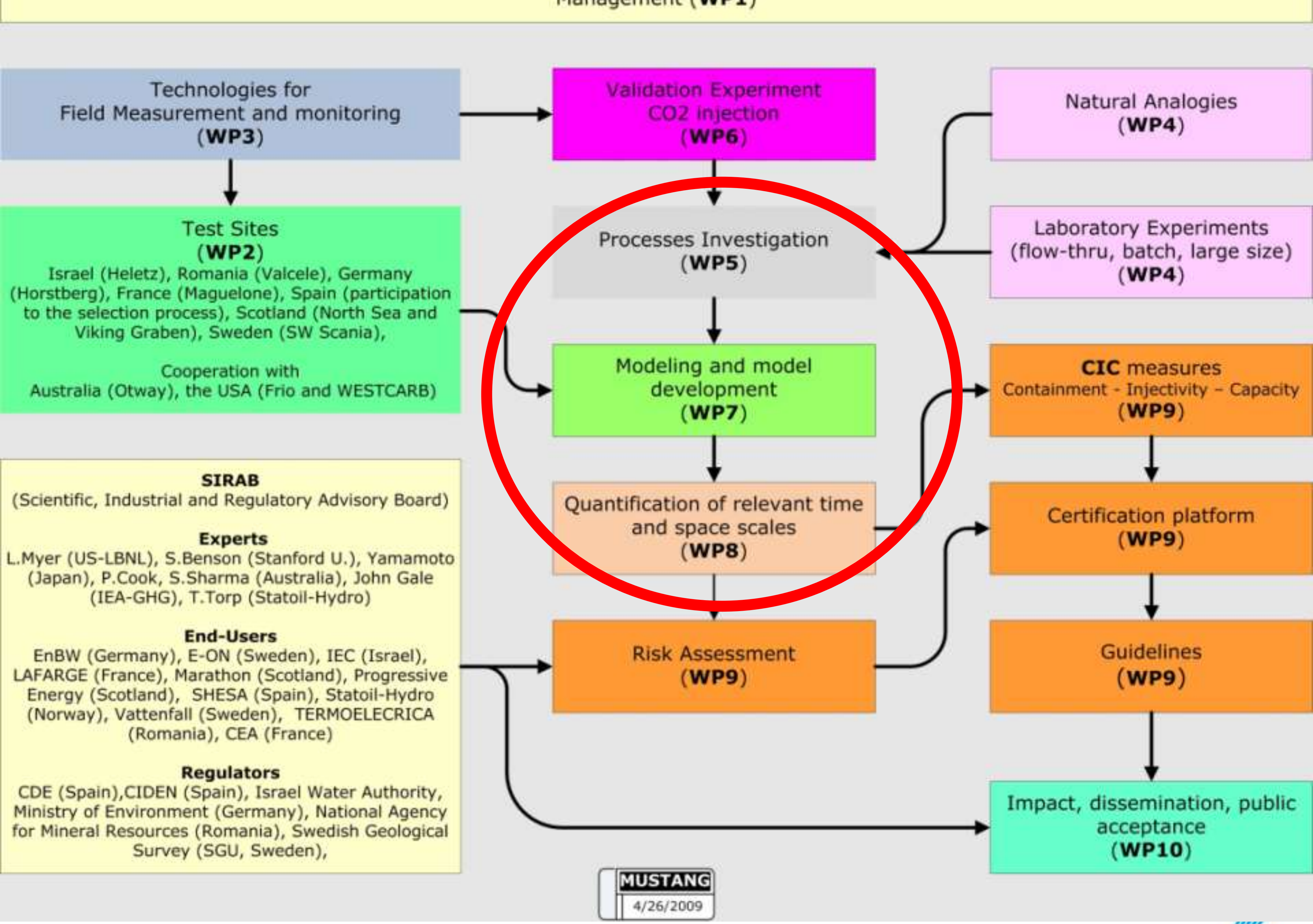
Fractured caprock alteration



Reservoir properties



Contributing: CNRS, UGÖTT, KIT, UEDIN, UU

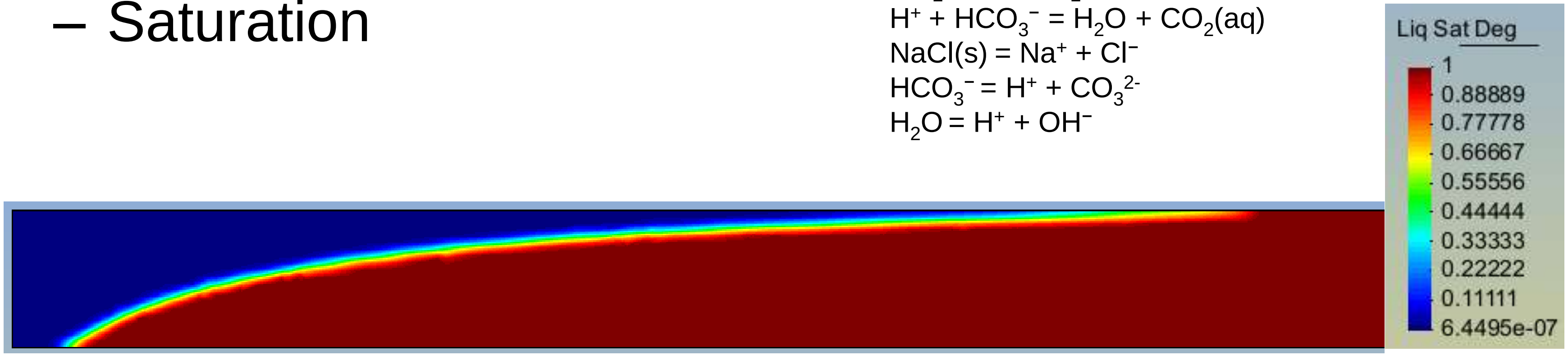


SEVENTH FRAMEWORK PROGRAMME

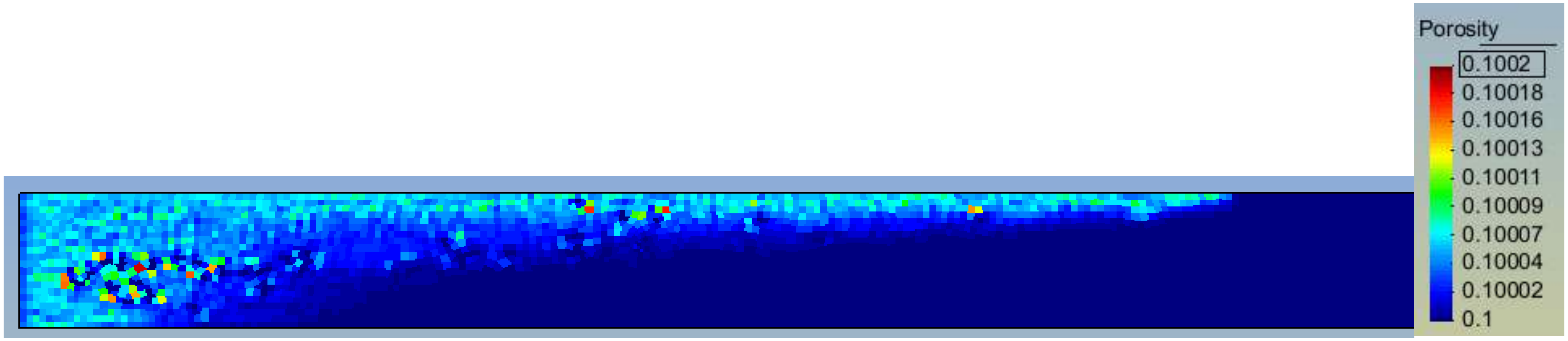
Example - Adding chemistry to Code-Bright

$CaCO_3(s) + H^+ = Ca^{2+} + HCO_3^-$
$CO_2(aq) = CO_2(g)$
$H^+ + HCO_3^- = H_2O + CO_2(aq)$
$NaCl(s) = Na^+ + Cl^-$
$HCO_3^- = H^+ + CO_3^{2-}$
$H_2O = H^+ + OH^-$

– Saturation

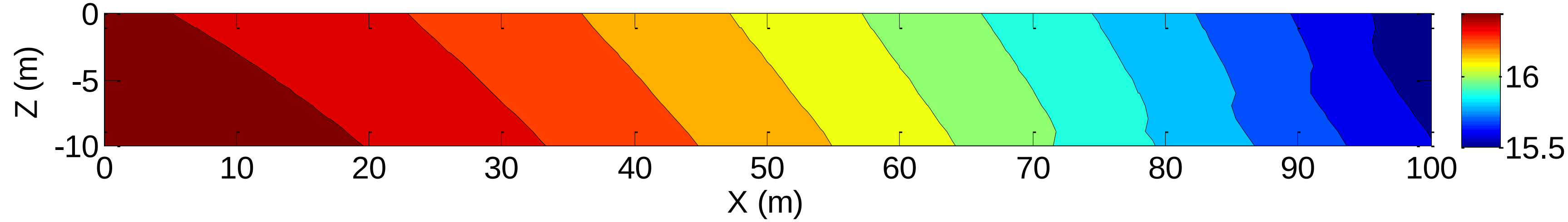


– Porosity after calcite dissolution

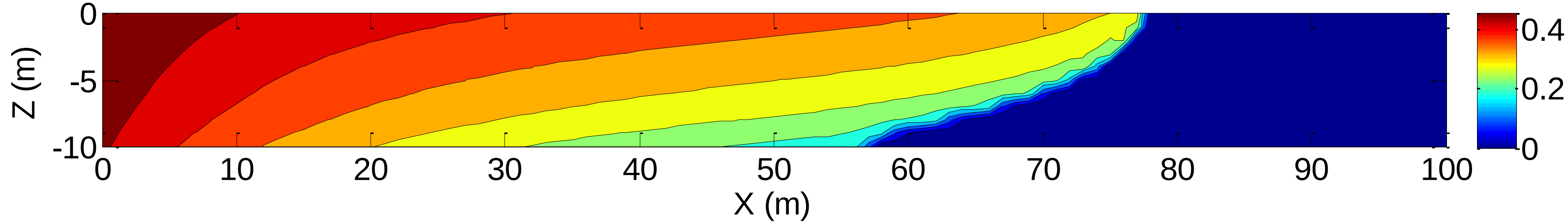


Saaltnik et al, 2012

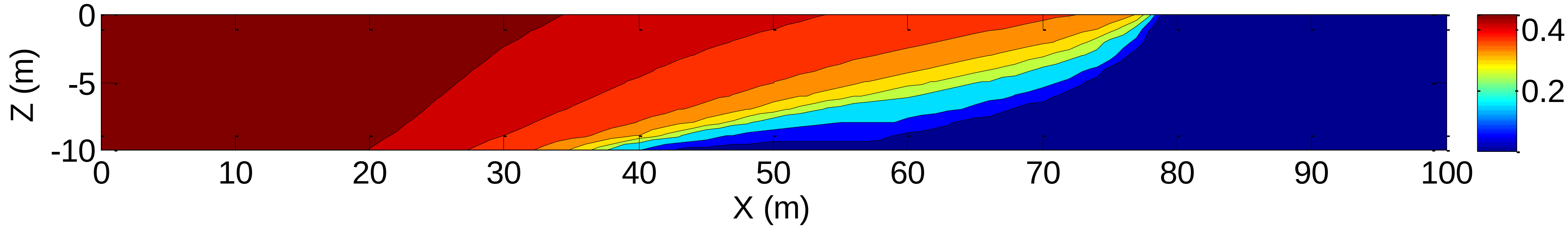
Example: two-phase flow and transport with time dependent tracer reaction/partitioning between the phases



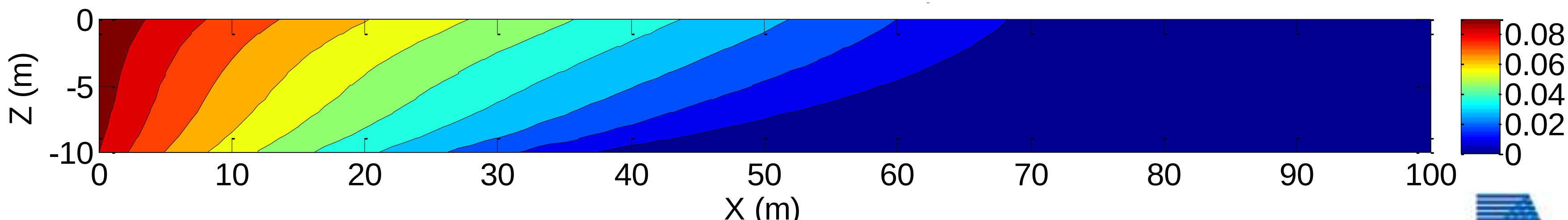
Spatial distribution of simulated CO2 pressure at 16 days (unit: MPa)



Spatial distribution of simulated degree of CO2 saturation at 16 days



Spatial distribution of simulated tracer concentration in CO2 at 16 days



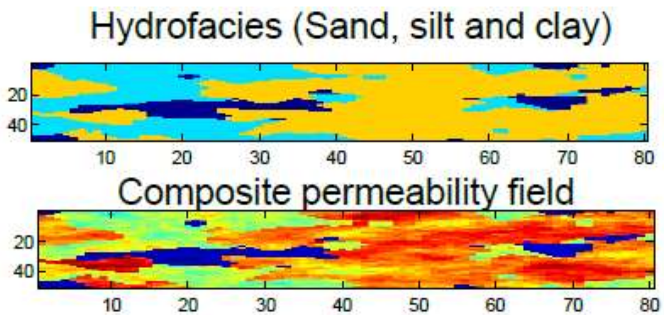
Spatial distribution of simulated tracer concentration in water at 16 days

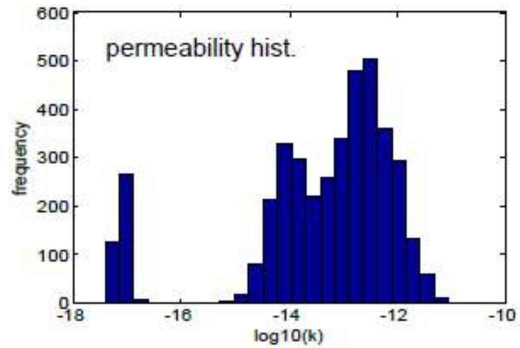
Tong et al, TiPM, 2013

Upscaling

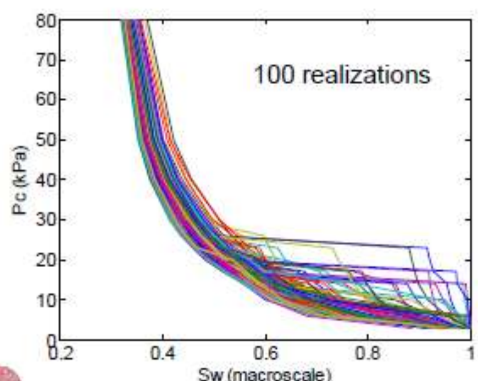
•**Analytical approaches** (Denz et al)

•**Numerical** approaches (effective parameters, telescopic mesh refinement , dual/multi-porosity approaches)

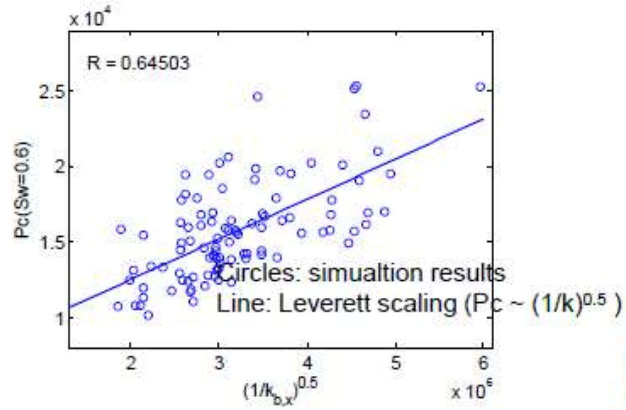


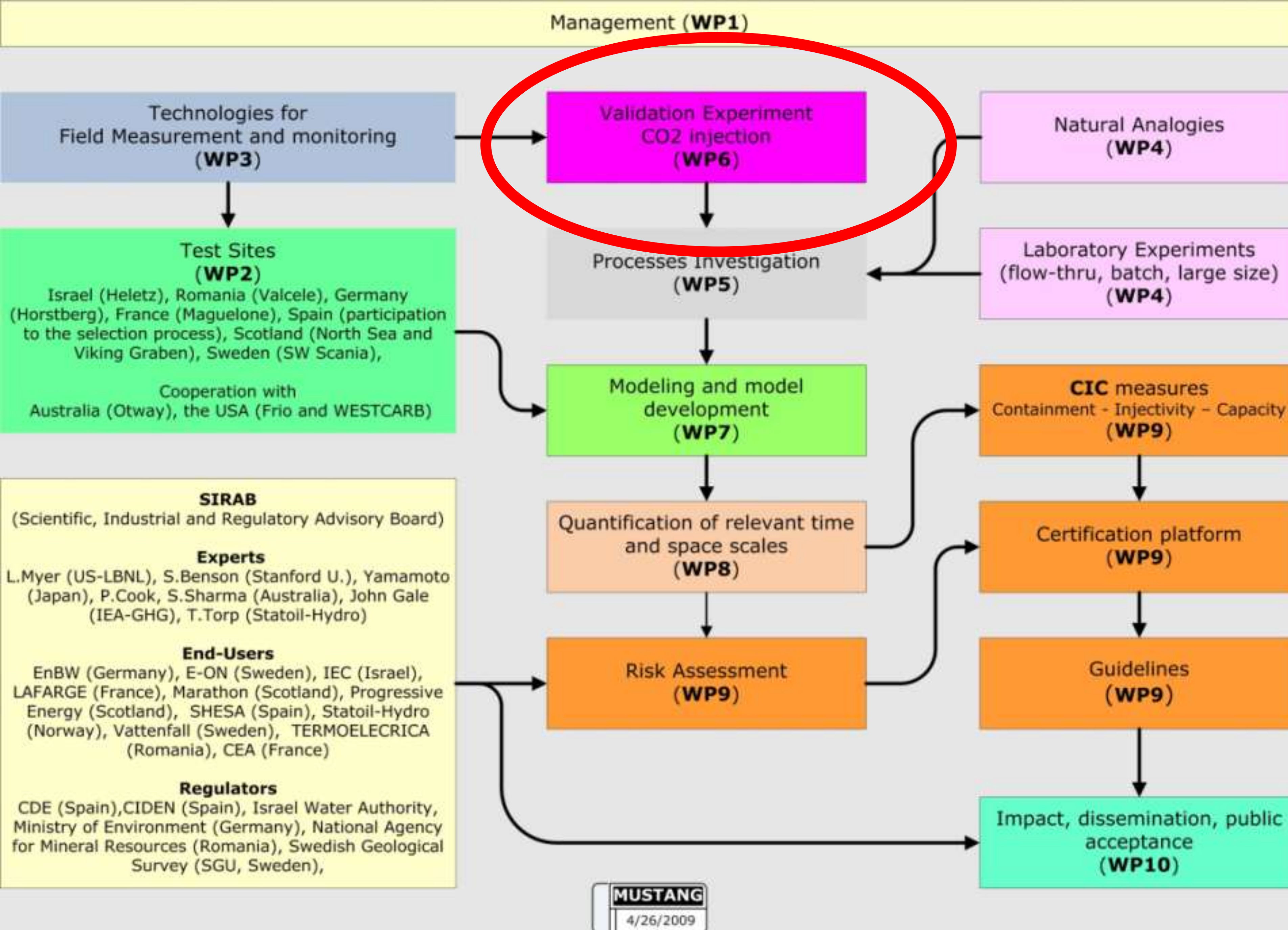


Examples of upscaled dependencies



Yang et al, IJGHGC, 2013





SEVENTH FRAMEWORK PROGRAMME

MUSTANG CO2 injection experiments

Shtivelman, GII

Deep injection of supercritical CO_2 Heletz, Israel

- extensive monitoring and modeling

- major financial component of the project

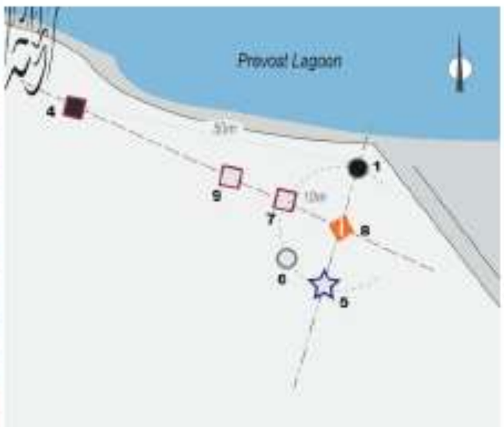
Shallow injection of gaseous CO_2 Maguelone, France

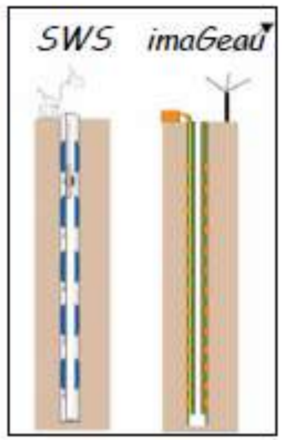
- cross-validation of certain geophysical methods, especially geoelectric, co-financing by CNRS

Pezard, CNRS

Maguelone shallow injection experiment

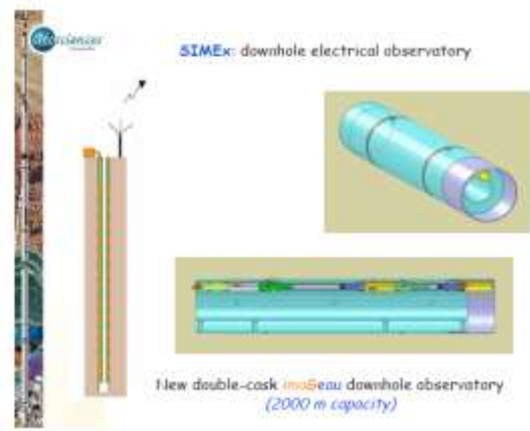
Maguelone experimental site :
downhole monitoring lab (**SIMEx-2010**)





- Downhole set-up :
  - injection (13-16 m)
  - electrical (3 holes)
  - seismic (1 hole)
  - hydro (WestBay)
  - PVC hole for logging
- Surface set-up :
  - electrical (2 lines)
  - seismic(2 lines)

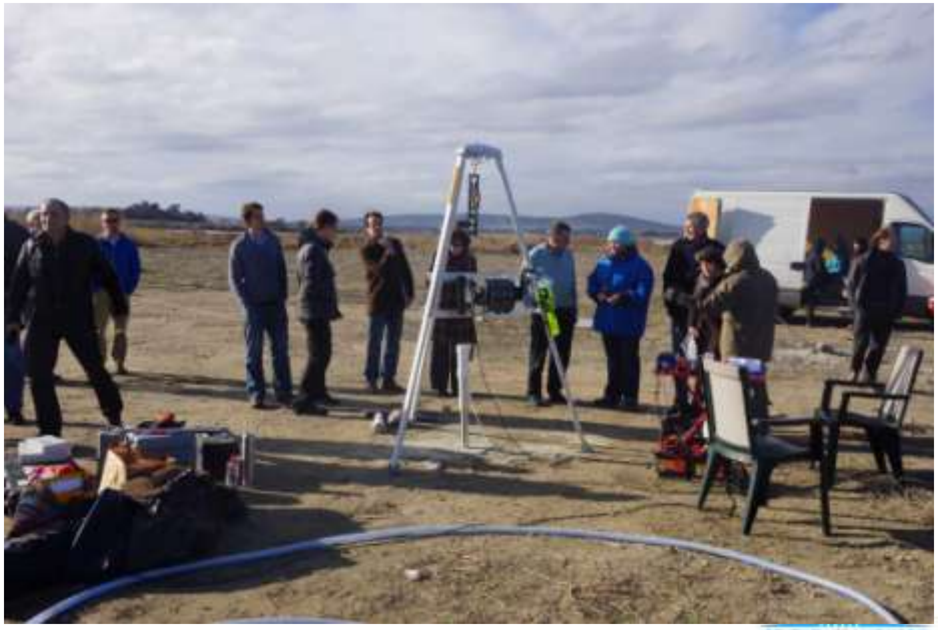
- **Multi-method approach** :
  - electrical (imaGeau), acoustical (GM) hydrodynamic with fluid sampling (SWS), time-lapse logging (GM).
- Surface-to-downhole & crosshole tomography (GM)
- Push-pull experiments (GM) with progressive injection protocol (water, N_2 , CO_2)
- Inversion and modelling protocol still to be defined



Pezard et al. 2011

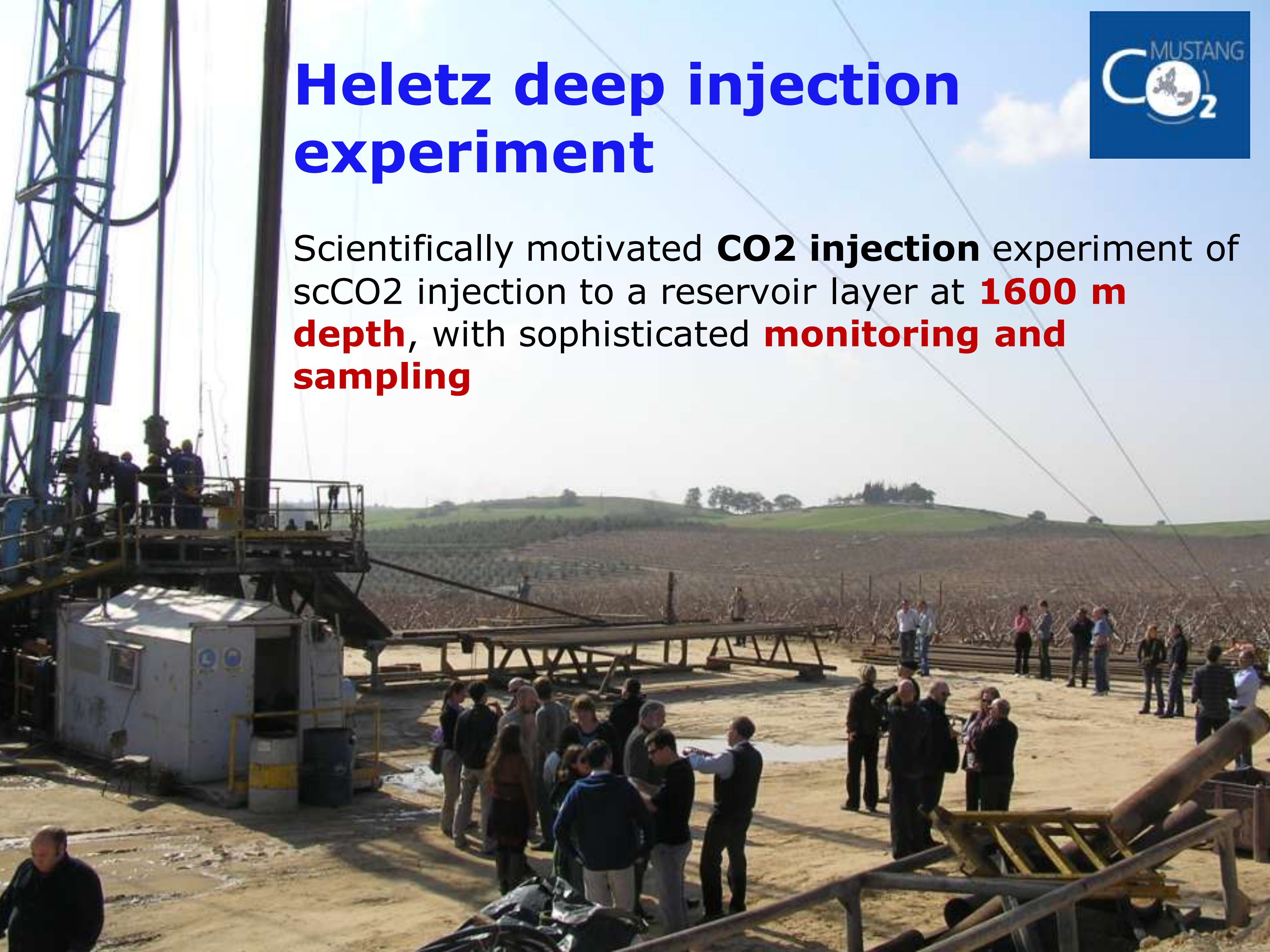
Maguelone shallow experiment

- Injection of CO_2 into a shallow reservoir (13-16 m deep)
- Monitoring both from surface and downhole, including high frequency seismic and electrical resistivity, pressure recording and fluid sampling
- Three N_2 injections during 2012 for tuning the field monitoring strategy
- CO_2 injection took place in January 2013
- Project leader CNRS/ P. Pezard
- For more info, see www.co2mustang.eu



Heletz deep injection experiment

Scientifically motivated **CO2 injection** experiment of scCO2 injection to a reservoir layer at **1600 m depth**, with sophisticated **monitoring and sampling**

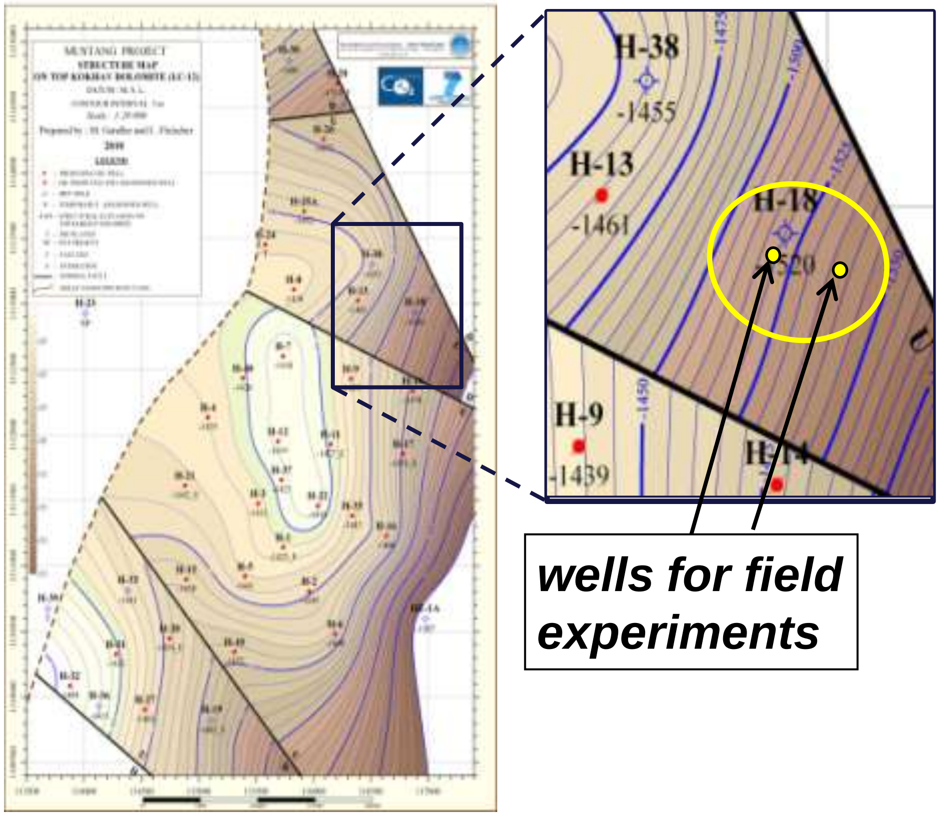


Heletz CO2 injection experiment

Objectives

- To gain understanding and develop methods to determine the **two key trapping mechanisms** of CO_2 (residual trapping and dissolution trapping) **at field scale,** impact of heterogeneity
- **Validation of** predictive **models, measurement and monitoring techniques**

Site: a well-investigated depleted oil reservoir with saline water on the edges (Heletz, Israel)

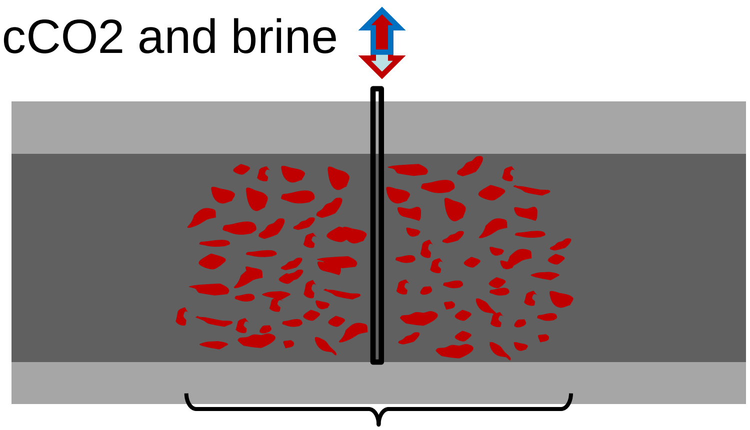


Experiment scenarios

❑ **Determine in-situ trapping parameters: residual & dissolution trapping**

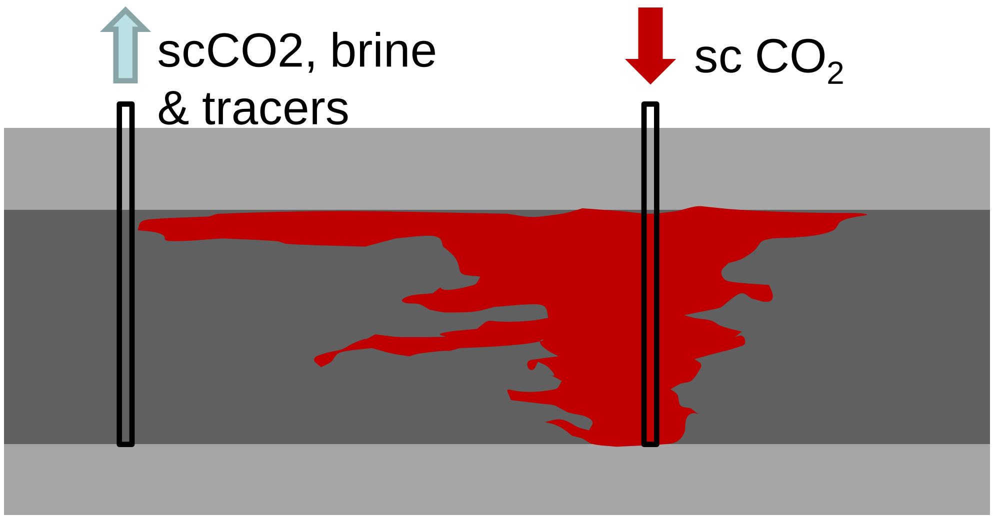
1. push-pull

injection-withdrawal
of $scCO_2$ and brine



zone of residual trapped $scCO_2$

2. dipole

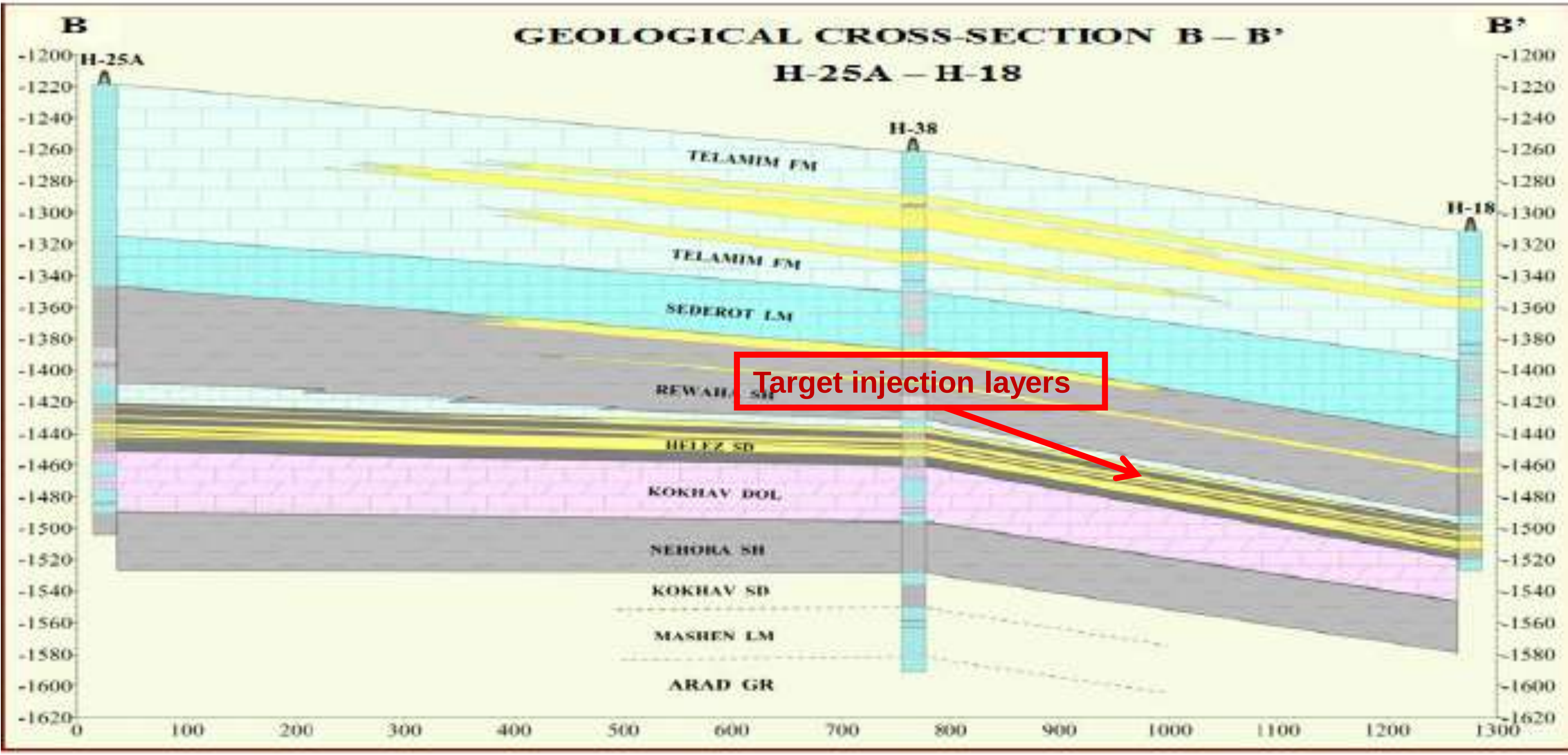


❑ Reduced influence of formation heterogeneity

❑ Heterogeneity affects migration and trapping

❑ Hydraulic tests	⇨	residual trapping
❑ Thermal tests	⇨	residual trapping
❑ Tracer tests	⇨	residual & dissolution trapping, (& interfacial area)

Heletz geology



- Intenisve planning, design and predicitive modeling underway since start of project

- Field activities underway since Jan 2011

- Well opening attempts (Jan 2011-July 2011) in two existing wells failed > re-evaluation of the plan + additional fund raising (esp. Lapidoth company contributions)

- **drilling of two new wells** during 2012

Cones of the caprock coming up at Heletz injection well

Time table of Heletz experiment

- Drilling activities

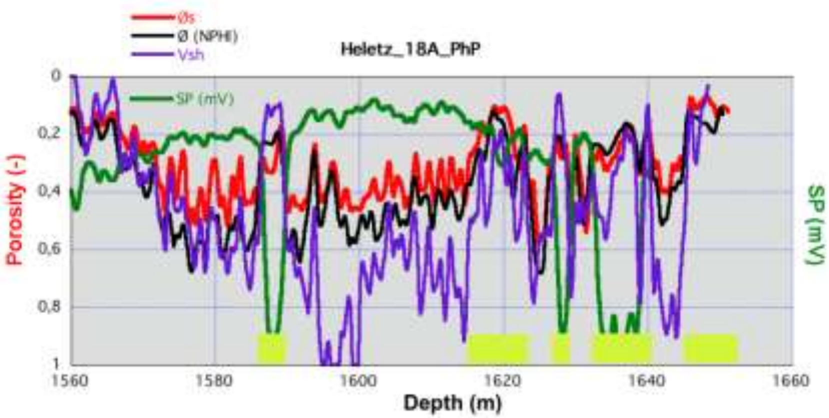
Well 1: drilling Feb-May 2012, cementing and casing May 2012, perforating Sep 2012

Well 2: drilling July-Sept 2012, cementing and casing completed Feb 2013

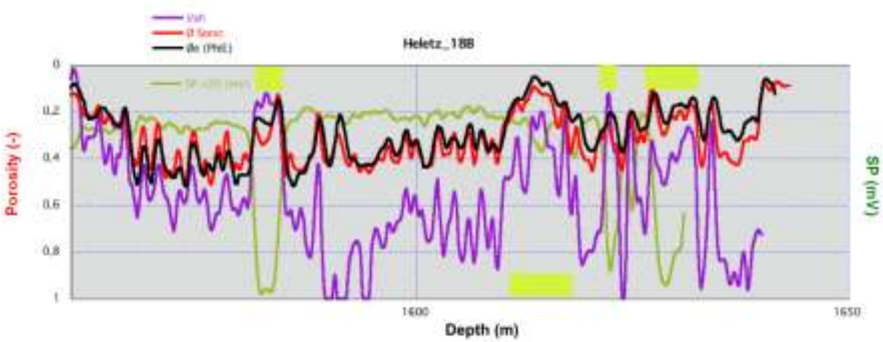
- Core samples for testing September 2012
- Geophysical baseline Dec 2012
- Pre-injection hydraulic and thermal testing to start May 2013
- CO_2 injection next autumn

SEVENTH FRAMEWORK PROGRAMME

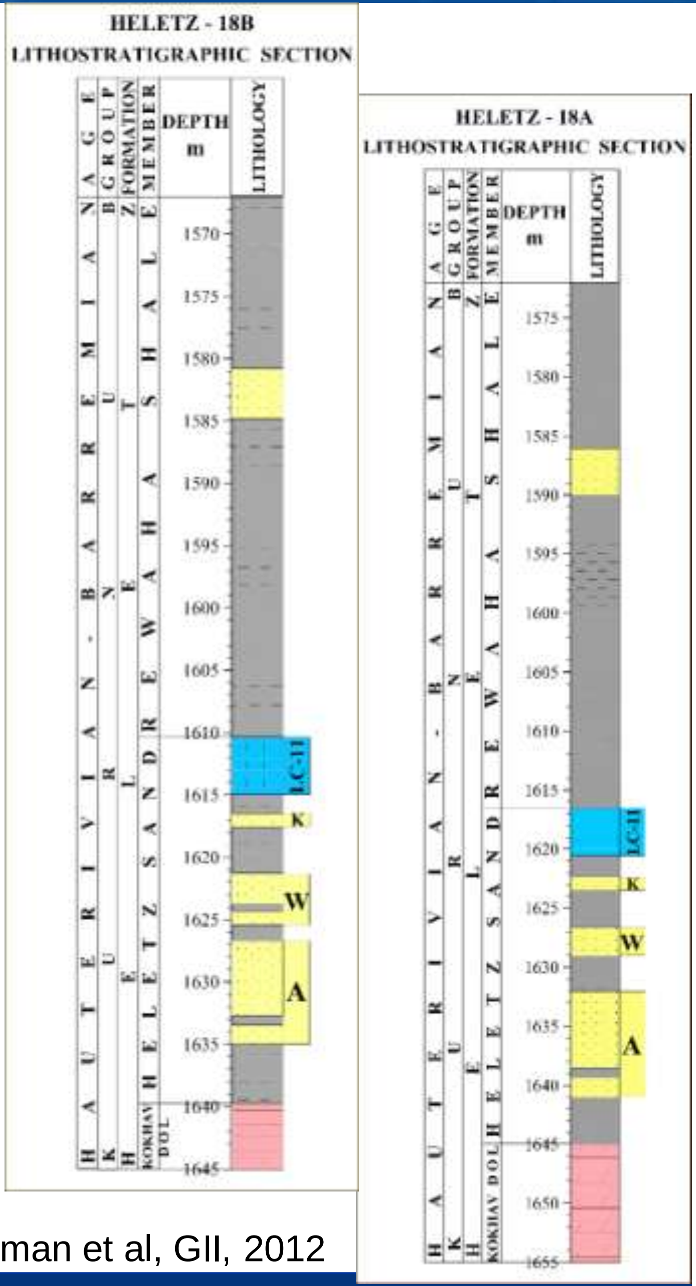
Heletz site – Caprock and Target layers



Heletz 18A (Pezard, 2012)

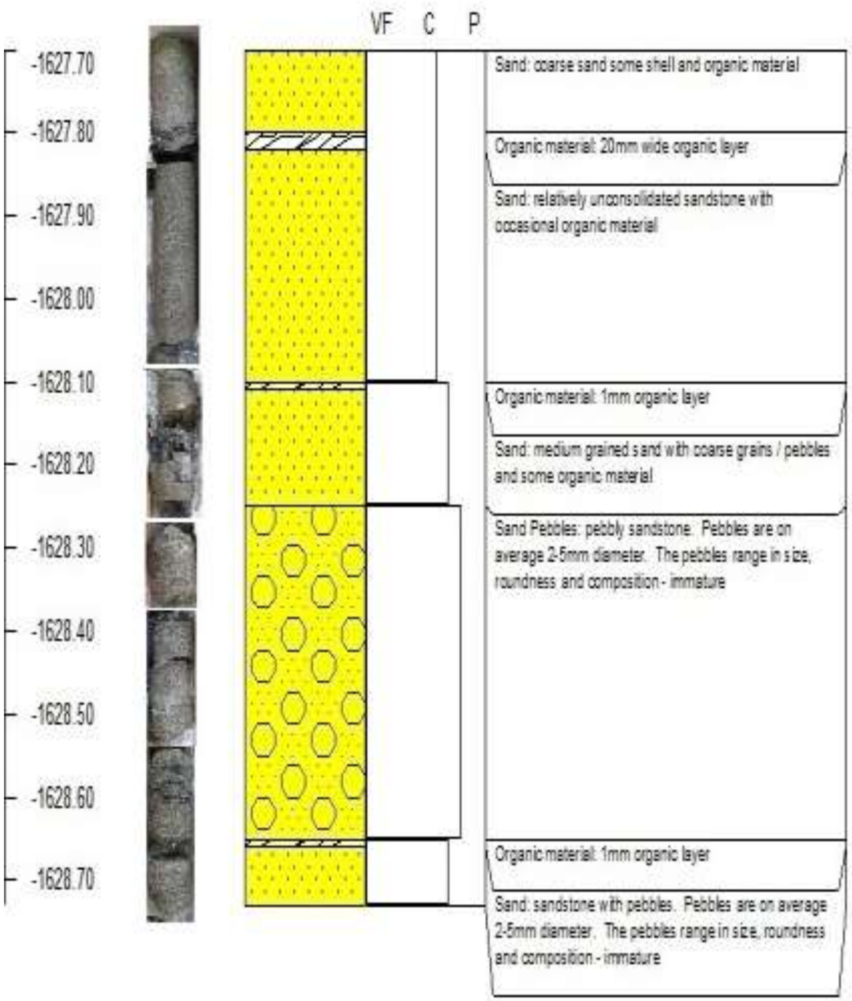


Heletz 18B (Pezard, 2012)



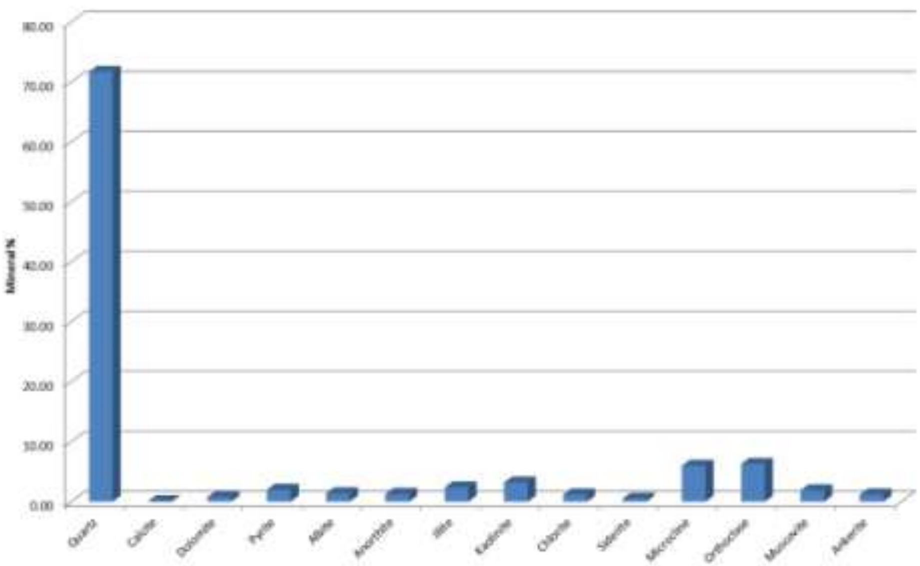
Shtivelman et al, GII, 2012

Heletz Well 18B core run 1627.70 - 1628.73

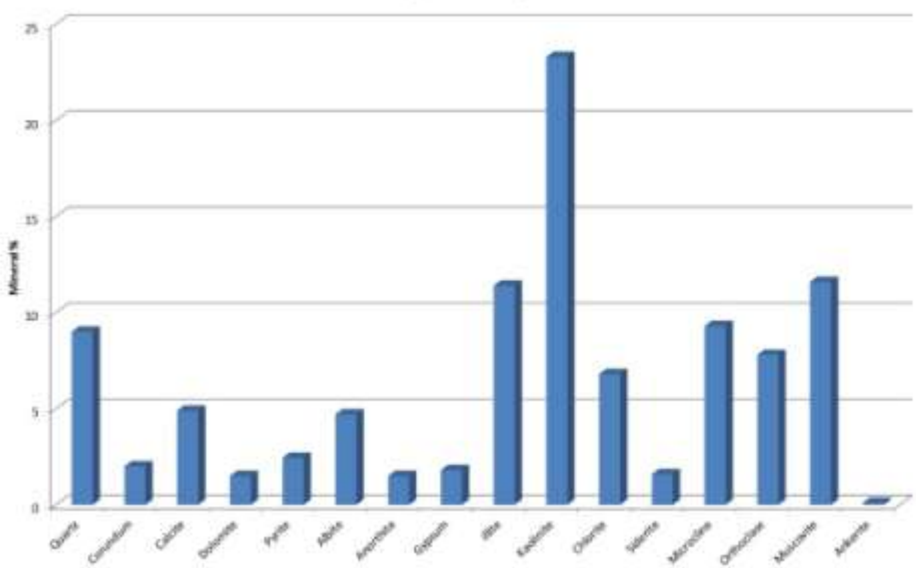


SEVENTH FRAMEWORK PROGRAMME

Example XRD results from Heletz H-18



Typical Heletz Well H-18 sandstone core



Typical Heletz Well H-18 caprock core

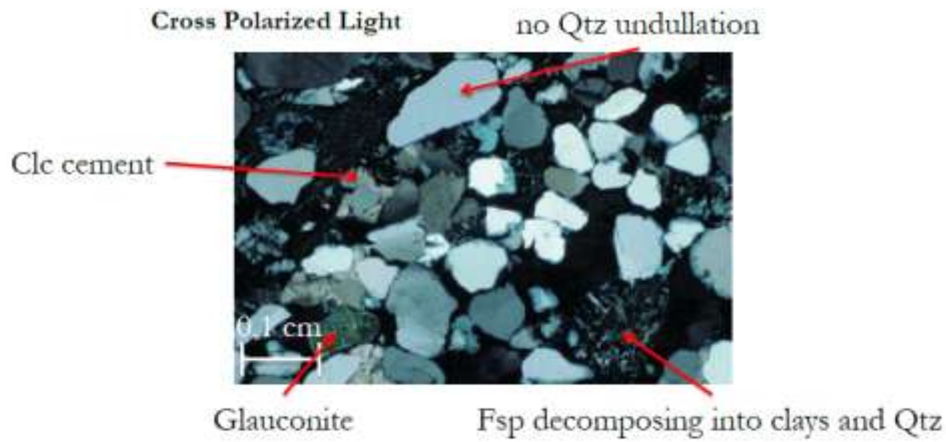
Edlmann et al, Edinburgh Univ

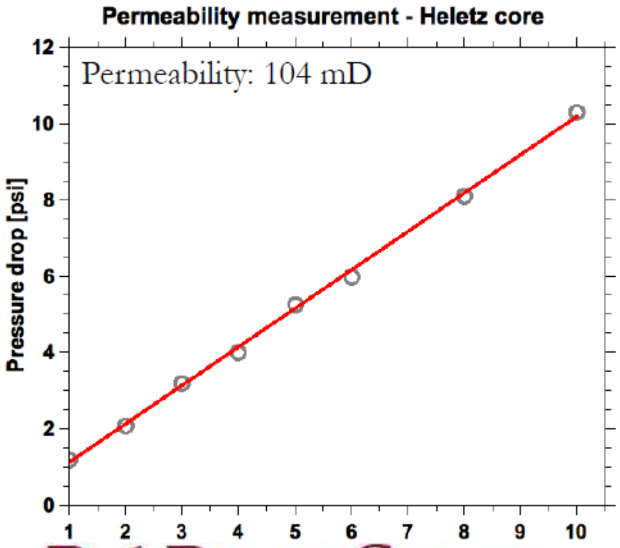
SEVENTH FRAMEWORK PROGRAMME

Laboratory testing of the rock samples

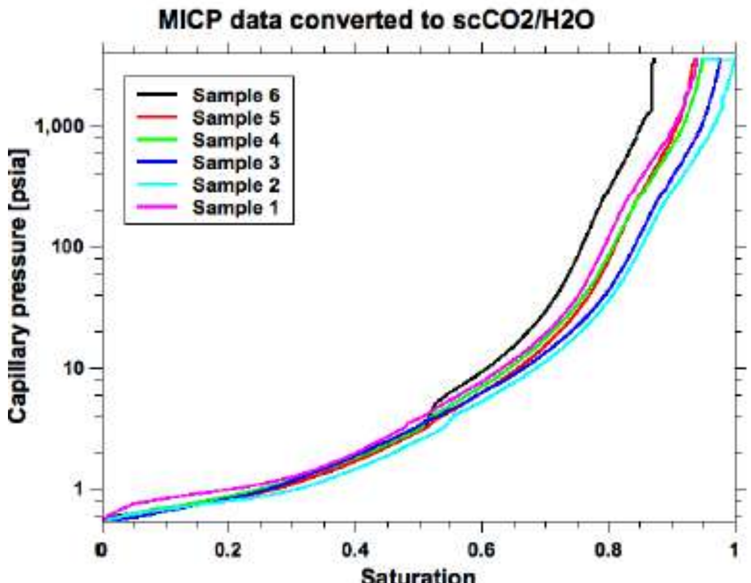
- petrophysical properties, permeability, relative permeability, capillary pressure
- Mineral composition
- Behavior of rock (and fractures) when in contact with CO2 and/or CO2/brine mixtures
- Rock mechanical properties

Laboratories: CNRS, Univ. of Edinburgh, University of Göttingen, Stanford University, Luleå University of Technlogy, Uppsala University



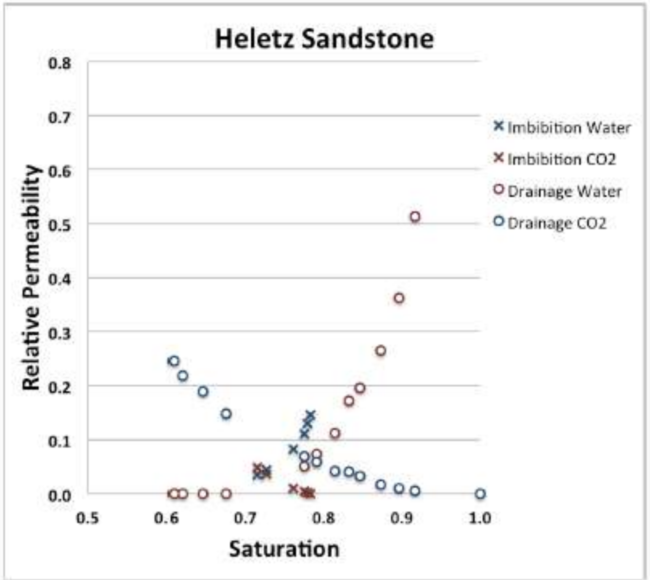


Capillary pressure



Benson et al, 2013 (Stanford Univ)

Rel Perm Curves



Hydraulic/tracer testing commenced

- **Water pulse and pumping tests** > for determining larger scale hydraulic properties, boundaries (bounding fracture zones)
- **Flowing Fluid Electrical Conductivity** (FFEC) logging > vertical variability of the reservoir permeability in the vicinity of the injection well
- **Thermal test** > heat transfer coefficient
- **Chemical sampling**
- **Tracer tests**

➢ **CO2 injection in late autumn**

MUSTANG

CO_2

A multiple space and time scale approach for the quantification of deep saline formations for CO2 stor

LATEST NEWS

A 'MUSTANG' PhD Thesis completed (July 2012)

Victor Vilarrasa from CSIC/UPC (Spain) defended his PhD Thesis on 'Thermo-Hydro-Mechanical Impacts of Carbon Dioxide Injection in Deep Saline Aquifers' at UPC, Barcelona on July 20th 2012. The supervisors of the work are Jesus Carrera (CSIC) and Sebastia Olivella (UPC). The warmest congratulations to Victor for the work well done!

Victor Vilarrasa from CSIC/UPC (Spain) in his Thesis Defense (July 2012)

The Thesis can be downloaded **HERE**

MUSTANG visit to CO2CRC and the Otway Project injection site in Australia (May 2012)

As part of the preparations for the Heletz CO_2 injection experiment, a group of MUSTANG partners visited the Otway injection site in Australia in May 2012. Hosted by MUSTANG SIRAB representative Dr Matthias Raab from CO2CRC, the group visited both the CO2CRC offices in Melbourne, the CSIRO research institute as well as the Otway injection site. **More info...**

SEVENTH FRAMEWORK PROGRAMME

www.co2mustang.eu

FRAMEWORK
GRAMME

Continuation FP7 projects

Heletz experimental CO2 injection site is being developed within EU FP7 project MUSTANG and be continued in subsequent EU FP7 projects

MUSTANG – methods for quantifying Saline Aquifers for CO2 Geological Storage (2009-2014)

Panacea – project focusing on **long term effects** of CO2 Geological Storage, is a modeling project (2012-2014) (led by EWRE, Israel)

TRUST – project continuing and **expanding the field experiment** of MUSTANG (sizeable injection, testing different modes of injection etc.) (Nov. 2012-Nov 2017)(led by EWRE, Israel) – formal **collaboration with Bastor and SwedstoreCO2**

CO2QUEST – project focusing on effect of **impurities** of CO2 stream (March 2013- Feb 2016) (led by UCL, England)

Why a Swedish national test site for CO2 storage: SwedSTORE^{CO2}

Christopher Juhlin (Uppsala University, UU)

with

Maria Ask (Luleå Technical University, LTU), Mikael Erlström (Geological Survey of Sweden, SGU), Auli Niemi (UU), Peter Lazor (UU) and Jan-Erik Rosberg (Lund University, LU)

SwedSTORE^{CO2} Goals

- Develop methods for site characterization of a Swedish land based CO2 storage test site
- Answer the question:Do suitable aquifers and caprocks exists for CO2 storage in the southern Baltic Sea?
- Build up national competence in geological storage of CO2 concerning evaluation of deep saline aquifers and their caprocks

SwedSTORE CO2

Energimyndigheten Vetenskapsrådet

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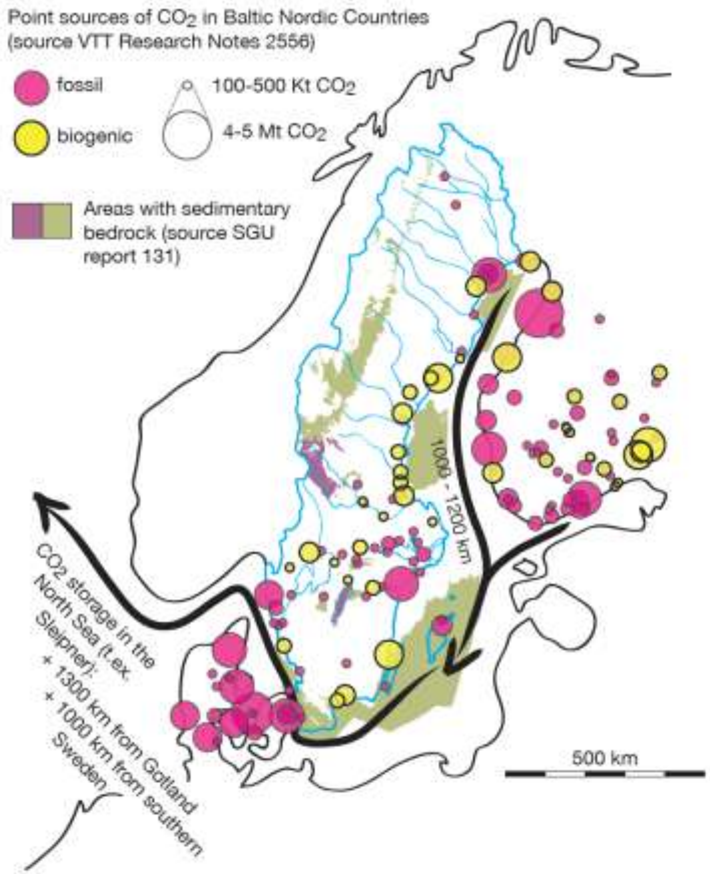
Swedish CO2 sources



- A large portion of Swedish emissions from biogenic sources
  - Storage of biogenic CO2 allows the amount of CO2 in the atmosphere to be reduced
  - Many biogenic sources are locatied along the east coast of Sweden, making CO2 storage below the Baltic Sea an attractive option
- Possible storage areas
  - Cambrian sandstones, the southern Baltic Sea
  - Younger Mesozoic sandstones south of Skåne and and in the Skagerrak-Kattegat area
- A Swedish test site should be relevant for these areas

SwedSTORE CO2

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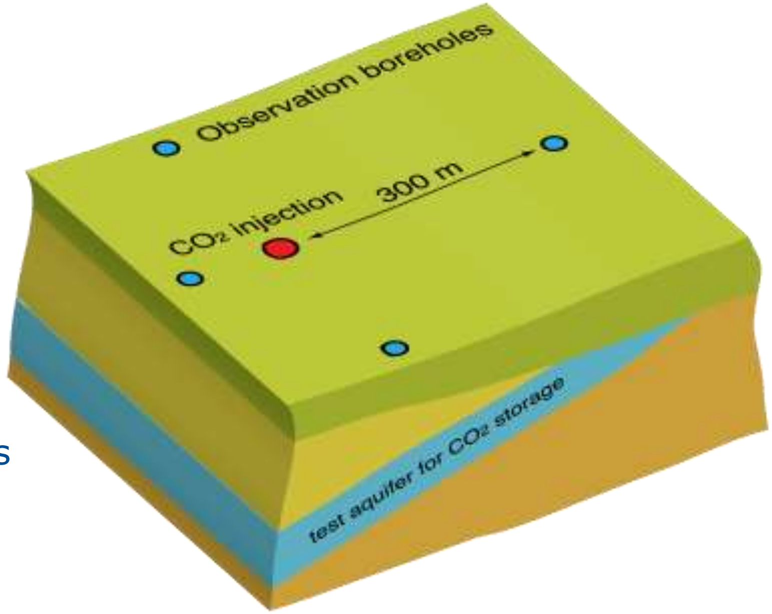
SGU Sveriges geologiska undersökning Geological Survey of Sweden

Project plans

- SwedSTORE^{CO2} is in a feasibility study stage (phase 1) investigating the potential to build a test site with monitoring of the highest quality
- The test site will consist of 4-5 boreholes, one of which is for CO2 injection
- SwedSTORE^{CO2} contains 3 +1 phases
  - Phase 1 (current phase): planning and cost estimates
  - Phase 2 (2014-2015): Site characteriziation and testing of a suitable site
  - Phase 3 (2016-2019): Test site construction and injection of CO2
  - Phase 4: (2020-?) Abandonment



SwedSTORE^{CO2}

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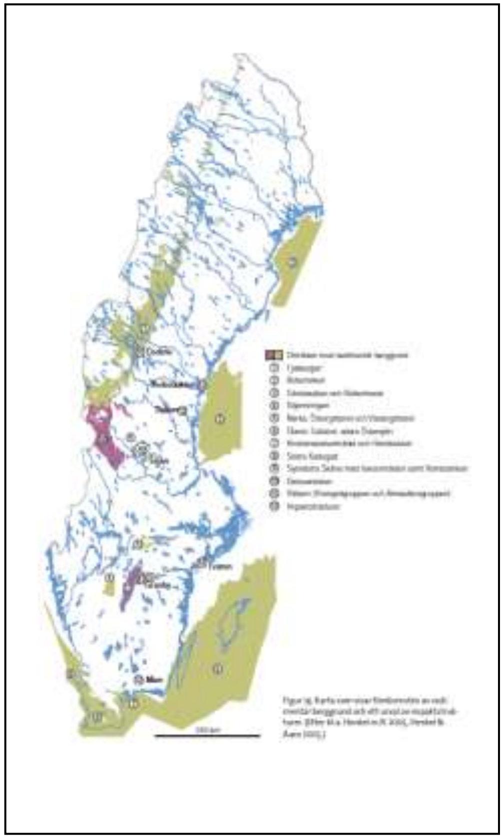
SGU Sveriges geologiska undersökning Geological Survey of Sweden

Potential sites

- "Shallow site"
  - Injection at about 700 m
- "Deep site"
  - Injection at 1500-1700 m
- Phase 1 consists of studies of both types of sites
- Test site will be on land with a maximum injection of 100,000 tons of CO_2



Phase 2: Site characterization

- Detailed site characterization
- Drilling of two fully cored boreholes
- Hydraulic testing
- Core analysis
- Numerical modeling of CO_2 injection based on drilling and coring results
- Planning of phase 3 if site is suitable

Phase 3: Test site

- Drilling of the injection borehole and two more monitor boreholes
- Establishment of infrastructure for CO_2 injection
- Establishment of monitoring systems
- Test injection
- Running of the site
- Transfer of knowledge and expertise to academia, industry and the general public

SwedSTORE CO2

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Spin-offs

- Phase 2 and Phase 3 will also increase our knowledge on the potential of using geological formations of southern Sweden for
  - Geothermal energy production
  - Storage of hydrogen generated from renewable energy sources

Excerpt from SANDIA REPORT: SAND2009-5878

"The storage of hydrogen within the same type of facilities, currently used for natural gas, may add new operational challenges to the existing cavern storage industry, such as the loss of hydrogen through chemical reactions and the occurrence of hydrogen embrittlement. Currently there are only three locations worldwide, two of which are in the United States, which store hydrogen. All three sites store hydrogen within salt caverns."

SwedSTORE CO2

Energimyndigheten Vetenskapsrådet

Uppsala Universitet Luleå University of Technology Lunds Universitet SGU Sveriges geologiska undersökning Geological Survey of Sweden

Thank you!

- Sweden needs to increase its competence concerning geological storage of CO_2
- Sweden needs to know if CO_2 can be stored in the southern part of the country
- We have a unique opportunity in Sweden to show that we can reduce CO_2 in the atmosphere by demonstrating we can store biogenic CO_2
- Work towards a national test site will have several positive spin-off effects concerning energy questions
- Potential new partners please contact us

SwedSTORE CO2

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Thank you for your attention!

www.co2mustang.eu

www.swedestoreco2.se