Modelling overview for CO_2 storage

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BRGM in brief

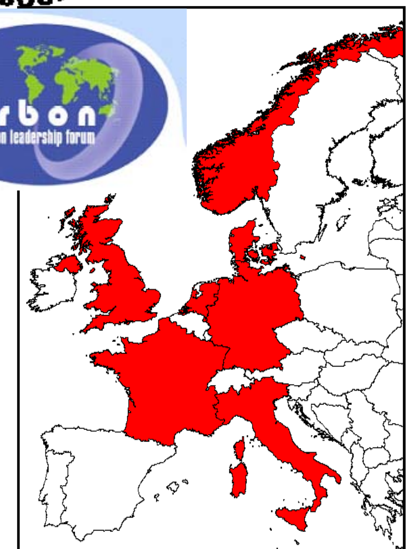
- BRGM is France's Public Institution responsible for mobilising the Earth Sciences in the sustainable management of natural resources and the subsurface domain.
- Since 1993, BRGM has been developing expertise on all aspects of CO_2 geological storage, i.e. site selection and characterisation, predictive modelling, monitoring, risk, safety criteria.
- BRGM has earned worldwide recognition for its skills in modelling the chemical interactions between injected CO_2 and the host rock.
- BRGM is a partner of CO_2GeoNet – the European Network of Excellence on CO_2 geological storage.
- As an expert or France's Representative, BRGM gives advice on CCS to French Ministries, national bodies and several international bodies or initiatives (CSLF, IEA-GHG, IEA-WPFF, ZEP, EURACOAL, IPCC, ECCP II, London and Ospar Conventions, G8/IEA/CSLF initiative…).

CO_2GeoNet Network of Excellence

CO_2GeoNet is the EU scientific body on CO_2 geological storage:

integrated community of researchers with multidisciplinary expertise, durably engaged in enabling the efficient and safe geological storage of CO_2

- 13 partners over 7 countries, more than 150 researchers
- Activities:
  - Joint research on all storage aspects
  - Training
  - Information / communication
  - Scientific advice
- Created as a FP6 Network of Excellence with EC initial support for 5 years (6 million €, April 2004 – March 2009).
- An Association, legally registered under the French law, has been launched in 2008.



Denmark: **GEUS**
France: **BRGM, IFP**
Germany: **BGR**
Italy: **OGS, URS**
The Netherlands: **TNO**
Norway: **NIVA, IRIS, SPR**
UK: **BGS, HWU, IMPERIAL**

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Outline (as in Joint Network Meeting in New York, June 2008)

1. Modelling is key for CO_2 storage implementation
2. Modelling is very complex
3. Modelling examples
4. Previous initiatives of code comparison
5. Additional efforts needed
6. Towards an IEA GHG modelling network?

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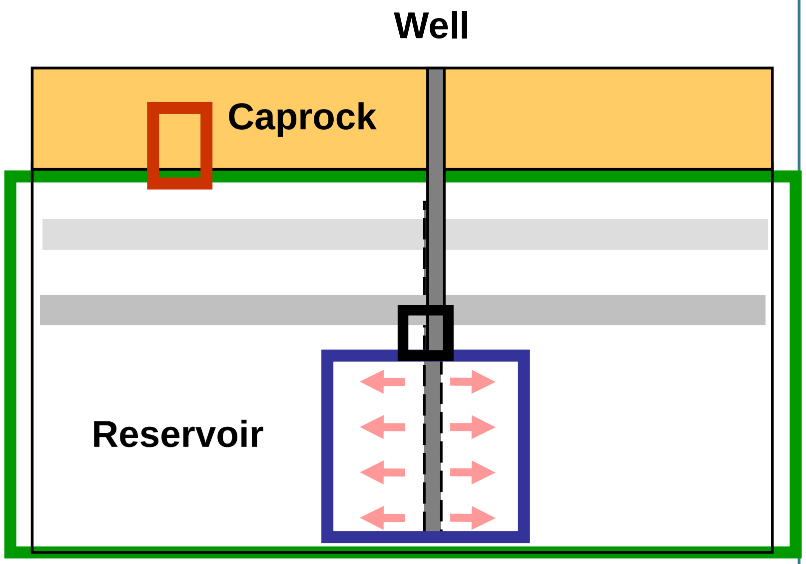
1- Modelling is key for CO_2 storage implementation

> **Top Necessity for:**
- Assessing the geological framework
- Assessing storage capacity, injectivity, integrity (caprock, faults, wells), risks (leakage, ground movement), impacts
- Advising monitoring (mutual impetus)

> **Only dynamic modelling enables practical conclusions**

> **Modelling will have a top importance in regulatory and legal frameworks**

e.g. EC Directive on CO2 geological storage (2008)



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EC Directive on CO_2 storage (Dec. 2008)

Annex 1 CRITERIA FOR THE CHARACTERISATION AND ASSESSMENT OF STORAGE SITES

> Step 1: Data collection

- Sufficient data shall be accumulated to construct a *volumetric and static three-dimensional (3-D)-earth model* for the storage site and storage complex

> Step 2: Building the 3D static geological earth model

- Using the data collected in Step 1, a *three-dimensional static geological earth model* shall be built using *computer reservoir simulators*.
- The uncertainty associated with each of the parameters used to build the model shall be assessed by developing a range of scenarios for each parameter and calculating the appropriate confidence limits. Any uncertainty associated with the model itself shall also be assessed.

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EC Directive on CO_2 storage (Dec. 2008)

Annex 1 CRITERIA FOR THE CHARACTERISATION AND ASSESSMENT OF STORAGE SITES

> **Step 3: Characterisation of the storage dynamic behaviour, sensitivity characterisation, risk assessment**

- The characterisations and assessment shall be based on dynamic modelling, comprising a variety of timestep simulations of CO_2 injection into the storage site using *the three-dimensional static geological earth model(s)* in the computerised storage complex simulator constructed under Step 2.
- Multiple simulations shall be undertaken to identify the sensitivity of the assessment to assumptions made about particular parameters. The simulations shall be based on altering parameters in the *static geological earth model(s)*, and changing rate functions and assumptions in the dynamic modelling exercise. Any significant sensitivity shall be taken into account in the risk assessment.
- The risk assessment shall comprise hazard characterisation, exposure assessment, effects assessment and risk characterisation, which includes an assessment of the worst-case environment and health impacts. It shall include an assessment of the sources of uncertainty.

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EC Directive on CO_2 storage (Dec. 2008)

Annex 2 CRITERIA FOR ESTABLISHING AND UPDATING THE MONITORING PLAN

- The data collected from the monitoring shall be collated and interpreted. The observed results shall be compared with the behaviour predicted in dynamic simulation of the 3-D-pressure-volume and saturation behaviour undertaken in the context of the security characterisation.
- Where there is a significant deviation between the observed and the predicted behaviour, the 3-D-model shall be recalibrated to reflect the observed behaviour.
- Where new CO_2 sources, pathways and flux rates or observed significant deviations from previous assessments are identified as a result of history matching and model recalibration, the monitoring plan shall be updated accordingly.
- Post-closure monitoring shall be based on the information collected and modelled during the implementation of the monitoring plan

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1- Modelling is Key for CO_2 storage implementation

But « how confident are we in the modelling results we are generating for CCS projects? »

(Quotation from Risk Assessment network)

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2- Modelling is very complex

- Large timescale range of interest: from hours to thousands of years
- Large spatial scales of interest: from cms to tens of kms
- Various compartments: reservoir, caprock, overburden, faults, wells, surface
- Natural heterogeneities, poor knowledge of the subsurface
- Various dynamic (& coupled) processes: Fluid flow – Geochemistry – Thermics – Geomechanics – Microbiology
- Uncertainty and sensitivity
- Site specificity

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> Only modelling can address such complex issues for enabling to make predictions

- Numerical & Analytical approaches
- Need for efficient computing algorithms and machines
- Conceptual modelling is very important
- Mutidisciplinary teams are needed (all fields of geosciences, mathematics, computer sciences)

> But real data is necessary for model calibration and benchmarking

- Lab & Field experiments
- Field monitoring
- Comparison analytical / numerical models
- Comparison between various numerical codes

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3- Modelling examples

(as shown in Joint Network Meeting in New York, June 2008)

To illustrate why we need models, how complex they are, why we should improve them to increase confidence

- Static geological model
- Fluid flow
- Chemical reactivity
- Geomechanical behaviour
- CO_2 leakage through a well – analytical model

See examples at this Orleans Workshop

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4- Previous initiatives of code comparison

- 2002 Workshop at LBNL, Berkeley, USA: Inter-comparison of numerical simulation codes for geologic disposal of CO2 report (reported in Pruess et al. 2004)

  "Code intercomparison builds confidence in numerical simulation models for geologic disposal of CO2"

  Energy 29 (2004) 1431–1444

- 2008 Workshop at University of Stuttgart, Germany: Numerical Models for Carbon Dioxide Storage in Geological Formations (report to be issued)

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LBNL code intercomparison exercise (2002)

> Participants:

Research Institute	Code(s)
LBNL, USA	TOUGH2 Family
University of Stuttgart, Germany	MUFTE_UG
CSIRO Petroleum, Australia	TOUGH2/ECO2
IFP, France	SIMUSCOPP
University of Stanford, USA	NON BAPTISE
Alberta Research Council (ARC), Canada	GEM
LANL, USA	FLOTRAN, ECLIPSE 300
LLNL, USA	NUFT
Industrial Research Limited (IRL), NZ	CHEM-TOUGH
PNNL, USA	STOMP

> 8 very simplified exercises (1D, 2D radial, schematic & homogeneous media) that probed advective and diffusive mass transport in multiphase conditions, with partitioning of CO2 between gas and aqueous phases; two problems also involved solid minerals and oil phases.

> broad agreement in most areas; bugs corrected, some unexpl. discrepancies

> also points out sensitivities to fluid properties and discretization approaches that need further study.

> It is hoped that future code intercomparisons will address coupled processes in fully 3D heterogeneous media, constrained by actual field observations.

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Univ. of Stuttgart code intercomparison exercise (2008)

> Participants:

Research Institute	Code(s)
University of Bergen/Princeton, Norvège/USA University of Texas/Austin, USA IFP Rueil Malmaison, France University of Stuttgart, Germany RWTH Aachen, Germany BGR Hannover, Germany LANL, USA	Semi-analytical solutions IPARS-CO2 COORES MUFTE TOUGHREACT ROCKFLOW FEHM
University of Stuttgart, Germany	DuMux
BRGM Orléans, France	RTAFF2
HW Edinburgh, UK	ECLIPSE 300
Schlumberger Carbon Services, Paris	ECLIPSE 300
University of Stanford, UK	GPRS

> 3 exercises: focused on fluid flow and numerical aspects, 3D geometries

> Fairly good agreement, but some big discrepancies that need to be further analysed (discretization, numerical algorithm, etc.)

5- Additional efforts needed

> Needs expressed by IEA GHG Wellbore Integrity Network

- Numerical models of wellbore geochemistry and geomechanics need additional development for providing long-term predictions
- Numerical models incorporating realistic permeability distributions for wells are needed to evaluate the leakage potential of fields with multiple wells
- Integrated geomechanical and geochemical experiments/numerical models are needed to capture full range of wellbore behavior
- Long-term numerical modeling grounded in enhanced field and experimental data

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5- Additional efforts needed

> Needs expressed by IEA GHG Monitoring Network

- Recognizes the importance of modelling in the various phases of CO_2 storage (site investigation, drilling & well testing, storage operation, site closure)
- "The monitoring measurements should be history matched against the predictive flow modelling"
- "The main gap is a lack of a "matrix" presenting the common interests among the three networks and the perspective they are dealt within each individual network. The objective should be to converge to a common outcome. For example, when a CO_2 risk pathway is identified, is /are the simulation tools able to calculate it? Which output they provide? How this output can be then translated in probability of occurrence or severity of consequences".

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5- Additional efforts needed

> Needs expressed by IEA GHG Risk Network

- How confident are we in modelling results?
- Need for modelling physical/chemical/mechanical phenomena in a way that can be useful for risk assessment

> Needs expressed by ZEP - the European Technology Platform for Zero Emissions Fossil Fuel Power Plant:

- R&D area: Long-term modelling of CO_2 storage in deep saline aquifers: “Modelling is used to characterise both short-term and long-term storage performance in terms of injectivity, capacity, containment, and quantitative estimation of potential leakage. A dedicated project is needed to develop and demonstrate the capacity of models to adequately predict the storage behaviour and CO_2 fate. This will increase confidence in the safe implementation of storage sites and will be useful for optimising the injection operations and the short/long term monitoring strategies”.

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6- Towards a IEA GHG modelling network? – Feedback from questionnaire (18 received, 16 with opinion)

> FOR (13), e.g.:

- YES. Modelling is a key component of all CCS projects and thus determining best practises in this area would be very useful.
- YES, it is important to create a place where this community can meet, especially to perform benchmarking
- YES - Definitely. Modelling needs to be performed at several levels, which transcends the scope of the individual networks at present. Our confidence in our ability to model both the small scale and large scale phenomena in the system will be greatly enhanced if we focus effort on this problem and share information that is currently within the domain of the individual network groups.

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6- Towards a IEA GHG modelling network?
– Feedback from questionnaire (18 received, 16 with opinion)

> FOR (13), e.g.:

- YES. I think the results of work done in the other networks can feed the modelling to develop better models, but that this topic is a stand alone issue.
- Simulation and modelling is very important for CCS. So, new network should deal with modelling and simulation
- YES, a new network would be useful on this topic … but Modellers shouldn't be allowed to have more than 2 meetings in a row by themselves! Too susceptible to becoming remote from the "real world"; that is, from addressing issues that matter to other people.

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6- Towards a IEA GHG modelling network?
– Feedback from questionnaire (18 received, 16 with opinion)

> AGAINST (2):

- No. I'd rather see effort put into identifying economic monitoring methods that will work when the plants are at full capacity and the years after abandonment (Tools like InSAR).
- NO. Modeling is a crosscutting activity that pertains to all the existing networks.

> MAY BE (1):

- Maybe to some extent

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6- Towards a IEA GHG modelling network?

Conclusion is best summarised by one of the answers to the questionnaire:

- "**YES**, I believe there would be a lot of benefit from a modelling network. Significant components of the practice of CO2 injection and geologic storage can be described only by modelling (e.g., estimated injectivity, injection field design and injection rates, total storage capacity, plume fate and tracking, etc.). Modelling of these technical components will be important in preparing carbon storage permits, and convincing regulators and the public of storage safety and viability. Therefore, a modelling network would contribute to more directly integrating modelling developments with developments in WI, M, and RA, and would also promote accurate, dependable, and practical modelling as applied to permitting and monitoring CO2 geologic storage".

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