

# Report from CO<sub>2</sub> storage workshop

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Longyearbyen, Svalbard, Norway, 3-7 August, 2009.

## 1. Introduction

The workshop “Modeling and risk assessment of geological storage of CO<sub>2</sub>”, was held in the Norwegian town of Longyearbyen, located on the archipelago of Svalbard. Beginning after lunch on Monday the 3<sup>rd</sup> of August, the workshop attracted 70 participants, engaging in oral and poster presentations, up until the final plenary discussion session before lunch on Friday the 7<sup>th</sup>. The participants came from three continents, with the largest delegations from Norway, Germany and the USA.

The scientific workshop consisted of oral lectures from 10 invited speakers, as well as 25 poster presentations. Each oral presentation was scheduled for 45 minutes, followed by 15 minutes discussion. The posters were posted for most of the conference, and a full afternoon was allocated to poster discussions. Three special sessions were organized as part of the scientific program:

- A two hour “Midnight Circus”, where short research ideas and perspectives were encouraged. The Circus was directed by Rainer Helmig, and lasted up until midnight the second day of the conference. A prize was awarded to the research group of Rainer Helmig from the Wasserbau at Stuttgart University for best Midnight Circus contribution.
- A one hour oral component of the poster session, where each poster had 3 minutes of oral presentation time in plenary. A prize was awarded to Halvor M. Nilsen for best poster.
- A two hour discussion session on the final day of the conference, chaired by Michael A. Celia and Karsten Pruess.

Outside of the scientific program, Tuesday saw the participants enjoy boat trips to the Russian mining town Barentsburg, and the abandoned Sovjet mining town Pyramiden. A short excursion to the site of test drilling for the CO<sub>2</sub> storage operation at Longyearbyen was also part of the program for Thursday.

The remainder of this report is structured in two parts. Section 2 will briefly report from the oral presentations of the invited speakers. Section 3 will recall some of the main points highlighted in the discussions that shaped the tone of the workshop, in particular those of the last day.

An overview of the program and related activities are to be found at the workshop home page

<http://org.uib.no/cipr/Workshop/2009/CO2/index.htm>

## 2. Summary of invited talks

The oral talks were presented by a diverse group, with affiliations from university, industry and government. We will here give a brief review of some of the main topics highlighted by the speakers.

*Jan Martin Nordbotten*, from the University of Bergen and Princeton University, spoke about the problem of CO<sub>2</sub> storage in geological formations from a general perspective. Considering simple questions such as “How much can we inject”, he discussed how the answer depends on critical factors such as modeling, numerics, user input, data interpretation, etc. Using recent benchmark studies as in depth illustrations, he initiated a discussion of the relative importance of the different sources of variability. As part of the talk, he also reviewed a recent benchmark proposed for this forum for the explicit purpose of evaluating uncertainty associated with modeling.

*Philip Ringrose*, from StatoilHydro, presented a talk in two parts. The first part took a look at multi-stage upscaling as part of the workflow in the petroleum industry. He emphasized the importance of upscaling separately to every length scale at which a representary elementary volume can be defined, but also the importance of choosing modeling scales based on physics, rather than computational limitations. For the second part of the talk, he gave a very interesting insight into the ongoing CO<sub>2</sub> storage operation at In Salah, led by BP. Particular attention was placed on the integration of recent observations into the subsurface model.

*Maria Toreblad*, from GassNova, presented CLIMIT – a research development and demonstration program set up by the Ministry of Petroleum and Energy with the aim to support technology development and with the ultimate aim to commercialize CCS. She talked about how the program is different from other research support schemes in that it covers the complete chain of development from research to pilot and demonstration. To support this wide range of different technologies she explained how CLIMIT is divided into CLIMIT – Research & Development (Research Council of Norway) and CLIMIT – Demo (Gassnova SF). She encouraged future applicants to visit [www.climit.no](http://www.climit.no)!

*Hamdi Tchelepi*, from Stanford University, presented mainly on two topics of particular interest for the community: Convective mixing due to buoyant instability, and order-of-magnitude predictions from simplified models. The latter topic is of particular relevance, as full complexity models are often too costly to be run over the length and time scales associated with carbon storage. When discussing convective mixing, a process that enhances storage security, Tchelepi mentioned both analysis of onset times, as well as high resolution numerical simulations of the unstable process. Convective mixing is an inherently unstable process, and it was of great interest to see the variability observed in even integrated measures from the numerical simulations performed.

*Ruben Juanes*, from MIT, elaborated in much more detail on predictions from simplified models. Using a classical sharp-interface approach, he presented results showing analytical solutions in 1D including both the effect of buoyancy and background aquifer flow. The approach was based on tracking solutions in the characteristic plane of the hyperbolic part of the governing equation. As an application, Juanes chose

to consider hypothetical large scale injections under the mainland US, and assess the spread of CO<sub>2</sub> during the post-injection period.

*Herbert Huppert*, from Cambridge University, took a more physical approach to simplified models. Using them primarily as a tool to understand the qualitative behavior of the problem, he looked at the available data and experiments on real porous media. Three setups formed the core of the talk, with the first data set coming from the Utsira injection site in the North Sea. Here the data showed strong qualitative correlation to the simple models. The two second setups were laboratory experiments, which Huppert had brought along for illustration purposes. Using a Hele-Shaw cell and a simple porous medium, he showed how simple experiments can capture many of the flow scenarios we expect to be important when assessing leakage risk.

*Steven Bryant*, from UT at Austin, discussed the importance of heterogeneity on gas trapping by capillary effects. He created several different geological systems using random permeability fields, and then correlated the capillary entry pressure permeability in each cell using different functions. By changing the reference capillary pressure and the correlation, he was able to create vastly different and interesting results. His work shows that it is possible to maximize the amount of gas trapped, which is very exciting for managing the risk of carbon sequestration operations.

*Alvar Braathen*, from UNIS, Svalbard, presented the Longyearbyen CO<sub>2</sub>-storage project. Longyearbyen is a closed energy-system based on coal and is also a key area to study effects of climate change. The Svalbard pilot project is therefore a unique location for such a project. He then continued to describe the basic geology of the storage site. Currently three wells have or are going to be drilled which provide information about the target aquifer approximately 1000 meters below the surface. He also described the main sealing properties of this target, including the permafrost.

*Erik Lindeberg*, from SINTEF Petroleum, set out to discuss the dominating mechanisms at the different time-scales associated with CO<sub>2</sub> storage. To limit the scope, he a priori discounted residual trapping as being too case specific, and proceeded to consider the other main physical trapping mechanism, dissolutions. Using different setups, he emphasized how simulated dissolution rates are highly dependent on numerical resolution, indicating that at too coarse resolutions, a better approximation is obtained by neglecting dissolution rather than including it.

*Holger Class*, from Stuttgart University, presented their experiences in using benchmark studies as a means to understanding model predictions for CO<sub>2</sub> studies. Using the benchmarks prepared for the last CO<sub>2</sub> workshop in Stuttgart as a foundation, he addressed modeling and numerical uncertainties. In the second half of the talk, he argued that numerical or modeling aspects may dominate in importance during different times in the simulation, and presented a recent strategy they had developed to address within a numerical simulator.

### 3. Discussion points

Several topics were repeatedly discussed at the workshop, and we will outline three of them here: Simplified models and upscaling; Purpose and value of benchmarks; Inclusion of realistic geological descriptions. These topics were a natural consequence of the interests of participants, and our review of these discussions should be seen in that light. In particular, most participants were mathematicians, numerical modelers, porous media flow researchers, or geologists. Thus e.g. geochemical processes were not discussed, although such process may be of importance from the perspective of long term storage security.

Several of the invited speakers discussed *simplified models* and *upscaling* in their talks. This reflects the realization that the governing physical processes together with relevant temporal and spatial scales form a computational problem that is intractable. Thus we either need to define suitable simplified models, or more generally, appropriate upscaled models. The main current question revolves around whether vertically averaged models (often using a sharp interface approximation), have sufficient complexity to capture the dominant flow mechanisms. If they have, it allows for reduction of one spatial dimension, with great computational gain. Challenging this view is the desire to resolve the intrinsically vertical structure imposed by geology, together with the important physics associated with vertical processes such as convective mixing and capillary dispersion.

At the final plenary discussion, the *purpose and value of benchmarks* became the topic of extensive and intense exchanges. Two fairly diverse points of view emerged, which we refer to as the mathematics viewpoint and the realism viewpoint. The mathematical (or numerical) view is that a benchmark should be precisely defined in all details. This view allows benchmarks to be tools with which we build confidence in our numerical solutions, and serve as a test bed for subsequent simplifications. The realist view is that the benchmark should reflect the type of information typically available for a CO<sub>2</sub> storage project, where the exact physical model or boundary conditions will not be precisely specified. This latter view aims at gaining appreciation of the range of uncertainty we may expect from our predictions, and may ultimately provide insights into what questions state of the art modeling can answer. The group generally recognized the strong value in both of these approaches, and possible future activities under each viewpoint were discussed.

Finally, the workshop participants were acutely aware of the challenge in adequately *incorporating geologic uncertainty*. It is clear that detailed geology, which will almost always be unknown, governs the local flow paths of CO<sub>2</sub> in an aquifer. However, questions remain both as to how to integrate this unknown geology effectively into simulations, as well as to the impact of fine scale flow paths on the larger questions raised in CO<sub>2</sub> storage.