



High resolution monitoring, real time visualization and reliable modeling of highly controlled, intermediate and up-scalable size pilot injection tests of underground storage of CO₂

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Executive summary

This training course presented an overview of the current status of CCS operations and research, with the objective of providing the participants with a basic understanding of the scientific and technical issues that need to be address for the successful injection of CO₂ into saline formations. The course focused on the technical and scientific considerations for CO₂ injection, the exploration of critical process in laboratory studies and by field techniques, as well as the related numerical modeling. The training course was intended for students and professionals that wish to gain a greater understanding of current research findings in the CCS field. Days 1 and 2 focus on general topics, while Days 3 and 4 provides a short introductory training course to parallel CO₂ simulation capabilities of the PFLOTRAN software.

The course was jointly organized by three ongoing EU FP7 Research and Development projects working on the topic (MUSTANG, PANACEA and CO₂TRUST).

Keywords	Training course, PFLOTRAN, CCS operations
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1. Course description

Carbon capture and storage (CCS) is a rapidly developing field with scientific and technical challenges that are being addressed globally. This training course presented an overview of the current status of CCS operations and research, with the objective of providing the participants with a basic understanding of the scientific and technical issues that need to be address for the successful injection of CO₂ into saline formations. The course focused on the technical and scientific considerations for CO₂ injection, the exploration of critical process in laboratory studies and by field techniques, as well as the related numerical modeling. The training course was intended for students and professionals that wish to gain a greater understanding of current research findings in the CCS field. Days 1 and 2 focus on general topics, while Days 3 and 4 provides a short introductory training course to parallel CO₂ simulation capabilities of the PFLOTRAN software.

The course was jointly organized by three ongoing EU FP7 Research and Development projects working on the topic (MUSTANG, PANACEA and CO₂TRUST).

Lectures during the first two days of the training course covered the following topics:

- Overviews of the current status of CCS projects and the main challenges
- Information needed and data assembly for characterization of storage sites
- Field techniques for site characterization
- Field techniques for monitoring
- Laboratory experiments of critical properties and processes
- Processes taking place during CO₂ injection and storage, their conceptual and numerical modeling

The last two days were devoted to training on the use of the PFLOTRAN software. The training will be delivered by the developers of this software.

PFLOTRAN is an open source parallel, multiphase, multicomponent and multiscale code for the modelling of subsurface processes. It has the capabilities to model CO₂ storage problems, including thermal, chemical and mechanical effects.

The main goal of this course was to give you the essential understanding and tools to start applying the software to your models. Participants were guided from the software installation to the first simulation cases on a number of hands-on problems.

The course was held over two days, and will be given by the software developers. Participants were required to bring their own laptops.

2. Teaching Staff and Organizers

The tutors of the course are directly or indirectly involved in the MUSTANG, PANACEA or CO₂ TRUST projects and have an excellent scientific and technical knowledge of the subject. The list of teaching staff and organizations involved in the training course is shown in the Table below.

Jacob Bear (co-chair)	Technion Israel Institute of Technology	Israel
Auli Niemi(co-chair)	Uppsala University	Sweden
Jacob Bensabat	EWRE Ltd	Israel
Jésus Carrera	CSIC	Spain
Calin Cosma	Vibrometric	Finland
Marco Dentz	CSIC	Spain
Katriona Edlman	University of Edinburgh	Scotland
Mikael Erlström	Swedish Geological Survey	Sweden
Philippe Gouze	CNRS	France
Stuart Hazeldine	University of Edinburgh	Scotland
Monika Ivandic	Uppsala University	Sweden
Christopher Juhlin	Uppsala University	Sweden
Satish Karra	LANL	USA
Peter Lichtner	LANL	USA
Chris McDermott	University of Edinburgh	Scotland
Johannes Miocic	University of Edinburgh	Scotland
Philippe Pezard	CNRS	France
Henry Power	University of Nottingham	England
Martin Sauter (co-chair)	Georg-August-Universität Göttingen	Germany
Richard Tran Mills	Oakridge National Laboratory	USA

Table 1. Teaching staff



3. Program

The course was programmed as a 3 days course. It was organized as theoretical presentations and following practical exercises with the delivered tutorials. Presentations are annexed and organized per each day course, at the end of the report.

Wednesday 9th October

08:30 - 9:00 Registration

9:00 - 9:15 Introduction to the course and practicalities (Auli Niemi, Martin Sauter, Alexandru Tatomir)

Part I – General Background

Background to CO₂ geological storage, Experiences from field injection projects, Experiences from natural analogues, Capacity estimates of CO₂ geological storage sites.

9:15- 9:45 Introduction to geological storage of CO₂ and examples of field projects (Auli Niemi)

09:45-10:30 Experiences from natural analogues (Johannes Miocic)

10:30-10:45 Coffee break

10:45-11:30 Capacity estimates of CO₂ geological storage sites (Johannes Miocic)

Part II– Processes and modeling

Overview of the processes and their relevance to different key questions in geosequestration, Mathematical models for CO₂ spreading and related processes, Numerical Modeling of CO₂ geological storage.

11:30-12:30 Mathematical models for CO₂ spreading and related processes (part 1; two-phase flow) (Jacob Bear)

12:30 – 13:30 Lunch

13:30-15:30 Mathematical models for CO₂ spreading and related processes (part 2, nonisothermal transport, deformable porous media) (Jacob Bear)

15:30 -15:45 Coffee

15:45-16:45 Hydro-mechanical processes (Henry Power)

Part III - Experimental Characterization and Monitoring



Numerical Modeling of CO₂ geological storage continued, Scale effects and upscaling

16:45-17:45 Laboratory experiments for CO₂ geological characterization (Katriona Edlmann) 17:45-18:00 *Closing of Day 1*

Thursday 10th of October

Part III - Experimental Characterization and Monitoring (cont.)

9:00-9:45 Characterization and monitoring of an injection experiment – Example Heletz, Israel (Jacob Bensabat)

9:45-10:30 Characterization and monitoring of an injection experiment – Example Hontomin, Spain (Jesus Carrera)

10:30-10:45 Coffee break

10:45-11:45 Geophysical monitoring of CO₂ geological storage sites, case study Ketzin (Monika Ivandic)

Part IV– Risk Assessment

Field Characterization of CO₂ storage sites, Monitoring of CO₂ storage sites, Laboratory experiments for characterizing injection sites and for evaluating the influence of CO₂ on rock and fluids

11:45-12:30 Risk assessment in geological storage of CO₂ (Katriona Edlmann)

12:30-13:30 Lunch

Part V - Numerical modeling of geological storage of CO₂

13:30-14:15 Numerical Modeling of Geological Storage – part 1; Methodologies (Jesus Carrera)

14:15 – 15:15 Numerical Modeling of Geological Storage – part 2; Results and examples (Jesus Carrera)

15:15 – 15:30 Coffee

15:30 – 16:30 Scale effects and upscaling (Marco Dentz)

16:30 – 17:00 Approaches to deal with large scale problems (Auli Niemi)

17:00-17:15 Closing of day one and introduction to days 3 and 4



Friday 10th and Saturday 11th of October

These two days were devoted to an in depth training on the use of the PFLOTRAN simulator. The teachers of this course were Prof. Richard Lichtner and Dr. Richard Tran Mills from LANL, Los Alamos, USA.

4. Links to the contents of the course

4.1 Part I – General Background

[Introduction to geological storage of CO₂ and examples of field projects \(Auli Niemi\)](#)

[Experiences from natural analogues \(Johannes Miocic\)](#)

[Capacity estimates of CO₂ geological storage sites \(Johannes Miocic\)](#)

4.2 Part II– Processes and their mathematical modelling

[Mathematical models for CO₂ spreading and related processes \(Jacob Bear\)](#)

[Hydro-mechanical processes \(Henry Power\)](#)

4.3 Part III– Experimental Characterization and Monitoring

[Laboratory experiments for CO₂ geological characterization \(Katriona Edlmann\)](#)



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[Characterization and monitoring of an injection experiment – Example Heletz, Israel \(Jacob Bensabat\)](#)

[Characterization and monitoring of an injection experiment – Example Hontomin, Spain \(Jesus Carrera\)](#)

[Geophysical monitoring of CO₂ geological storage sites, case study Ketzin \(Monika Ivandic\)](#)