



High resolution monitoring, real time visualization and reliable modeling of highly controlled, intermediate and up-scalable size pilot injection tests of underground storage of CO<sub>2</sub>

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## Executive summary

TRUST aims at conducting CO<sub>2</sub> injection experiments at scales large enough so that the output can be extrapolated at industrial scales. It relies on four sites: the heavily instrumented sites of Heletz (Israel, main site) and Hontomin (Spain), access Miranga (Brazil) and the emerging site in the Baltic Sea region. The objectives are to: carry out CO<sub>2</sub> injection with different strategies, displaying characteristics representative of the large scale storage and with injection volumes that will produce extrapolable reservoir responses; Develop, use and implement characterization and MMV technologies for maximized safety and minimized risks, including real time visualization of the CO<sub>2</sub> containment and detection of possible failures; Develop optimal injection strategies that maintain realistic figures of injectivity, and capacity while simultaneously optimizing the use of energy; Detect and mitigate CO<sub>2</sub> leakage at an abandoned well; Produce comprehensive datasets for model verification and validation; Improve the predictive capacity and performance of computational models, as well as their capability to handle uncertainty and thermo-hydro-mechanical and chemical phenomena at different scales (at the scale of the experiments) and upscaling (extrapolation to industrial scale) simulations; Address critical non-scientific issues of public acceptance, community participation, communication, dissemination, liabilities and prepare templates for the preparation and application of injection licenses and communication with regulators; Establish on-site facilities for analysis of monitoring and measurement, providing training and capacity building; Address the risk assessment in a meaningful way; Prepare a platform for the exploitation of project findings and for knowledge and information sharing with planned, large scale, CCS projects. Allow open access to sites, and seek cooperation with large scale CO<sub>2</sub> injection projects both at the European and International levels.

Keywords	Large scale CO <sub>2</sub> Injection, Monitoring, Model validation, Injection strategies, risk assessment, communication, extrapolation, real time visualization, open access, capacity building, and training.
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# 1. Introduction

The training course “CO<sub>2</sub> sequestration in deep geological formations” was held in Montpellier from 19 until 21 October 2015 in the framework of the EC FP7 TRUST project. The course benefitted from the experience of two already EC finished projects on the topic: MUSTANG and PANACEA.

This training course presented an overview of the current status of CCS projects around the world, provided participants with the current state of the art knowledge concerning scientific and technical issues that need to be addressed for the successful operation of projects of CO<sub>2</sub> sequestration in deep, brine-containing geological formations. The course focused on the technical and scientific considerations of CO<sub>2</sub> injection, spreading, trapping in the target formations and on mathematical and numerical modeling of CCS projects. Experts lectured on site characterization and investigations of critical processes by laboratory studies and field techniques, as well as on planning of experimental projects and monitoring techniques aimed at verifying the conceptual models. An interactive exercise to address societal aspects was also performed during the course.

The course was targeted to students and professionals that wish to gain a greater understanding of current research findings in the field of CCS.



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## 2. Organization of the course and dissemination

The course was organized by the following institutions:

- CNRS: host organization of the event
- ITT: scientific organizer
- MERI: secretariat

The course had an additional charge of 75€ to cover costs incurred during the course (i.e. travel costs to the field site; coffee breaks; meals and beverages).

The course was published through a specific website (<https://trustco2course.wordpress.com/course/programme/>) linked to the TRUST website (<http://trust-co2.org>). The specific course website had a section for the registrations and information on payments.

A specific mailing list was created and used to circulate information on the course. Additionally, information was sent to UKCCS research Centre which announced the course and to the organizers of the PoroNet/SaltNet/BENet announcements.

A flyer with general information on the content of the course, the venue, contact information, scientific committee and registration was prepared and distributed to all contacts of the mailing list as well as to all partners of TRUST.

The final program and the list of participants was sent to all participants and lecturers before the beginning of the course. At the end of the course, all presentations and videos shown during the course were sent to the students via dropbox.

### 3. Lecturers

Fourteen lecturers were involved in the training course. Eleven of them are directly involved in the TRUST project. All lecturers have sound scientific and technical knowledge of the subject. The course lectures were divided in three sessions and there was an optional field trip to the Maguelone experimental site.

The three sessions focused on:

- General background
- Processes and modelling
- Characterization and monitoring.
- The list of lecturers is shown in the Table below.
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<b>Name</b>	<b>Affiliation</b>	<b>Country</b>
Bear, Jacob	Technion (WP9 leader)	Israel
Bensabat, Jacob	EWRE (TRUST coordinator and WP1 and WP2 leader)	Israel
Carrera, Jesús	CSIC (WP5 leader)	Spain
Dentz, Marco	CSIC	Spain
Kitron- Belinkov, Myra	Technion	Israel
Luquot, Linda	CSIC	Spain
Martell, Meritxell	Merience (WP8 leader)	Spain
Niemi, Auli	University of Uppsala (WP4 leader)	Sweden
Pezard, Philippe	CNRS (WP3 and WP6 leader)	France
Power, Henry	GeoEnergy Research Centre	UK
Van den Kerhof, Alfons	University of Göttingen (WP10 leader)	Germany
Zhan, Fengjiao	Uppsala University	Sweden
Zimmerman, Robert	Imperial College	United Kingdom

## 4. Programme

The final programme of the course is detailed below.

### 19 October 2015

8:30 – 9:00	Registration
9:00 – 9:45	Introduction to geological storage of CO <sub>2</sub> and examples of field projects (Auli Niemi, University of Uppsala, Sweden)
9:45 – 10:30	Experiences from natural analogues (Alfons van der Kerhof, University of Göttingen, Germany)
10:30 – 11:00	<i>Coffee break</i>
11:00 – 11:45	Capacity estimates of CO <sub>2</sub> geological storage sites (Jesús Carrera, CSIC, Spain)
11:45 – 12:30	Approaches to large scale problems (Auli Niemi, Uppsala University, Sweden)
12:30 – 13:30	<i>Lunch</i>
13:30 – 15:00	Mathematical models for CO <sub>2</sub> spreading and related processes (part 1; two-phase flow; part 2, non-isothermal transport, deformable porous media) (Jacob Bear, Technion, Israel)
15:00 – 15:30	<i>Coffee break</i>
15:30 – 17:00	Numerical Modeling of Geological Storage – part 1; Methodologies, part 2; Results and examples. Hontomin example (Jesús Carrera, CSIC, Spain)
17:00 – 17:30	Public perception and societal challenges associated with CCS (Meritxell Martell, Merience, Spain).

### 20 October 2015

9:00 – 9:45	Laboratory experiments for CO <sub>2</sub> geological characterization and leakage risks (Linda Luquot, CSIC)
9:45 – 10:30	Scale effects and upscaling (Marco Dentz, CSIC, Spain)
10:30 – 11:00	<i>Coffee break</i>
11:00 – 11:45	Fractured rock hydrology and implications for carbon storage / sequestration (Robert Zimmerman, Imperial College, UK)
11:45 – 12:30	Advanced methods for fracture propagation modeling (Robert Zimmerman, Imperial College, UK)
12:30 – 13:30	<i>Lunch</i>
13:30 – 14:15	Injection well-reservoir interaction (Myra Kitron-Belinkov, Technion, Israel)
15:00 – 15:30	<i>Coffee break</i>
15:30 – 16:15	Hydro-mechanical processes (Henry Power, Geo-Energy Research Centre, UK)
16:15 – 17:00	Geophysical monitoring of CO <sub>2</sub> geological storage sites, Ketzin case study (Fengjiao Zhang, Uppsala University, Sweden)

### 21 October 2015

9:00 – 9:45	Characterization and monitoring of an injection experiment – Example from Heletz, Israel (Jacob Bensabat, EWRE, Israel)
9:45 – 10:30	Hydro-geophysical monitoring methods: lessons from shallow injection experiments at Maguelone (Philippe Pezard, CNRS, France)
10:30 – 11:00	<i>Coffee break</i>
11:00 – 11:45	Risk assessment in geological storage of CO <sub>2</sub> (Jacob Bensabat, EWRE, Israel)
11:45 – 12:15	Closure of the course

The optional field trip to the Maguelone site was organized in the afternoon of 21<sup>st</sup> October 2015.

## 5. Participants

The course was attended by 29 participants from different countries and types of organisations. The list does not include the name of the lecturers that stayed during the whole course duration.

<b>Title</b>	<b>Name</b>	<b>Affiliation</b>	<b>City / Country</b>
Mr.	Bezos, Víctor	CSIC	Barcelona / Spain
Mr.	Bonet Gil, Enric	CSIC	Barcelona / Spain
Dipl.-Math	Büsing, Henrik	EON Energy Research Centre Aachen University	Aachen / Germany
Mr.	March Castaneda, Rafael	Herriot-Watt University	Edinburgh /UK
Post-Doc	De Gaspari, Francesca	CNRS	Montpellier / France
MSc	De Simone, Silvia	CSIC	Barcelona / Spain
Dr.	El Ossmani, Mustapha	UPPA	Pau / France
Dr	Elias, Antonio	CNRS	Montpellier /France
Miss	Escario, Sofia	CNRS	Montpellier / France
Dr	Garcia Rios, Maria	CNRS	Montpellier/ France
Mr.	Gheibi, Sohrab	NTNU	Trondheim /Norway
Dr	Gran, Meritxell	CSIC	Barcelona /Spain
Ms.	Hume, Laurène	UPPA	Pau /France
Mr.	March Castaneda, Rafael	Heriot Watt University	Edinburg /UK
Dr.	Martínez Landa, Lurdes	UPC	Barcelona / Spain
Ms.	Martínez Pérez, Laura	CSIC	Barcelona / Spain
Ing.	Mendoza Miranda, Angela Norma	UJV Rez	Prague/ Czech Republic
Miss	Noel, Julie	Université Montpellier	Montpellier/ France
PhD	Oulebsir, Fouad	UPPA	Pau / France
PhD	Puyguiraud, Alexandre	CNRS	Montpellier / France
Mr.	Rabiu, Kazeem	Loughborough University	Loughborough / UK
Dr.	Salimzadeh, Saeed	Imperial College London	London /UK
Mr.	Sami, Irfan	Xodus	London / UK
Dr.	Schuszter, Gabor	ULB	Brussels / Belgium
PhD	Smal, Pavel	CNRS	Montpellier / France



PhD	Soler Segarra, Joaquim	UPC CSIC	Barcelona / Spain
Dr.	Stevar, Mihaela	Imperial College London	London /UK
Ms	Thomas, Carelle	ULB	Brussels / Belgium
Mr.	Tsarfis, Igal	EWRE	Haifa /Israel

## 6. Evaluation

An anonymous on-line survey through JotForm was sent to all participants of the course, requesting their feedback. The questionnaire included the following questions:

- Did the course contribute to increase your knowledge on CCS?
- If yes, how?
- Do you think you will be working in the field of CCS in the next 5 years?
- Do you think you would attend another workshop on CCS?
- In which specific fields would you be interested?
  - o Descriptive status of CCS globally (sites, injection activities)
  - o Modeling and processes
  - o Field Experiments
  - o Industrial injection
  - o Monitoring and measurements
  - o Public perception, communication and acceptance
  - o Site characterization
  - o Others
- Level of satisfaction: overall, duration, content, price, speakers, applicability for your own work, field trip.
- Any further observations on how to improve future courses.

A total of 21 answers to the survey were received, around 73% of the total number of participants. All of them state that the course contributed to increase their general knowledge on CCS, except one. From basic to more advanced information was provided as well as different points of view to address the same problem. Another comment from one respondent was that the schedule of lectures was perfect as they were in a good logical sequence. The majority of respondents (17 out of 21) state that they think they would be working in the field of CCS in the next 5 years.

More than 90% of the students state that they would attend another course on CCS.

When asked about in which specific field they are interested, the results are shown in the Table below:

Topic	Number of positive responses (%)
Descriptive status of CCS globally (sites, injection activities)	7 out of 21 (33%)
Monitoring and measurements	9 out of 21 (43%)
Industrial injection	5 out of 21 (24%)
Field Experiments	10 out of 21 (48%)
Modeling and processes	13 out of 21 (62%)
Public perception, communication and acceptance	2 out of 21 (9.5%)
Site characterization	5 out of 21 (24%)
Others	Molecular simulation of processes Geochemistry of CCS Precipitation pattern formation during CO <sub>2</sub> sequestration

All students are very satisfied or satisfied with the training course, the duration, content, price and the speakers, except one who was unsatisfied. There was one observation from two participants stating that some courses were too specific and speakers gave too much detail and were not really understandable by a broad audience. As a result, these presentations were hard to follow for people from different backgrounds. Keeping in mind the different background of the participants would improve the course.