TIME TABLE

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	June 21	June 22	June 23	June 24	June 25
09.00 - 09.45	Registration	Jimenez-Martinez	Boon	Boon	Gasda
09.45 - 10.30	De Paoli	Jimenez-Martinez	Boon	Boon	Gasda
11.00 - 11.45	Both	De Paoli	Jimenez-Martinez	Gasda	Both
11.45 - 12.30	Both	De Paoli	Jimenez-Martinez	Gasda	Both
14.00 - 14.45	Boon	Gasda	Visit to the	De Paoli	
14.45 - 15.30	Boon	Gasda	borehole	De Paoli	
16.00 - 16.45	Franceschini	Both	geophysics test	Franceschini	
16.45 - 17.30	Franceschini	Both	site PiTOP	Franceschini	
18.00	Welcome aperitif	Poster Session			

ADMISSION AND ACCOMMODATION

The course is offered in a hybrid format, allowing participants the flexibility to attend either in person or remotely via the Microsoft Teams platform. Admission to on-site attendance is granted on a first-come, first-served basis to comply with the capacity of the lecture room.

Registration fees:

- **Early Bird On-Site Participation: € 650.00 + VAT***
  Deadline: April 21, 2027
- **Late On-Site Participation: € 800.00 + VAT***
  Deadline: June 9, 2027
- **Live Streaming Online Participation: € 250.00 + VAT***
  Deadline: June 9, 2027

On-site participation includes a complimentary bag, five fixed menu buffet lunches, hot beverages, downloadable lecture notes.
Online participation includes downloadable lecture notes.

Application forms should be submitted online through the website: http://www.cism.it. A confirmation message will be sent to participants whose applications are accepted.
Upon request, and subject to availability, a limited number of on-site participants can be accommodated at the CISM Guest House for € 35 per person per night. To request accommodation, please contact: foresteria@cism.it

** where applicable; bank charges are not included - Italian VAT is 22%.*

CANCELLATION POLICY

Applicants may cancel their registration and receive a full refund by notifying the CISM Secretariat in writing (via email) no later than:
- April 21, 2027, for early bird on-site participation;
- May 21, 2027, for late on-site participation;
- June 9, 2027, for online participation.

No refunds after the deadlines. Cancellation requests received before these deadlines and incorrect payments will be subject to a € 50.00 handling fee.

CISM GRANTS

A limited number of participants from universities and research centers who do not receive support from their institutions can request a waiver of the registration fee and/or free lodging.
Requests must be submitted via the CISM website by **April 21, 2027**. Applicants should select the relevant option in the online application form and provide a curriculum vitae and a letter of recommendation from their department head or supervisor confirming that their institution is unable to provide financial support. Preference will be given to applicants from countries that sponsor CISM.

For further information please contact:

CISM (Seat of the course)
Palazzo del Torso - Piazza Garibaldi 18 - 33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
e-mail: info@cism.it | www.cism.it

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

ACADEMIC YEAR 2027
Andreas Acrivos Session

FLUID MECHANICS OF CO2 AND HYDROGEN STORAGE IN GEOLOGICAL FORMATIONS

CISM Advanced School
coordinated by

Jakub Wiktor Both
University of Bergen, Norway

Marco De Paoli
TU Wien, Austria

Udine *June 21 - 25* 2027

FLUID MECHANICS OF CO2 AND HYDROGEN STORAGE IN GEOLOGICAL FORMATIONS

The geological storage of carbon dioxide (CO_2) and hydrogen is a key technology for climate change mitigation and the transition to a low-carbon energy system. Both applications involve complex multiscale transport phenomena in porous geological formations, where fluid flow, heat and mass transfer, geochemistry, geomechanics, and biological processes interact across pore, reservoir, and basin scales. Developing predictive models that consistently connect these scales remains a major challenge in mechanics and applied mathematics.

This CISM course provides a rigorous introduction to the mechanics and mathematical modelling of geological CO_2 sequestration and underground hydrogen storage. It combines fundamental theory with modern applications, emphasizing multiscale modelling, transport processes, stability analysis, and numerical simulation. Participants will develop a unified understanding of the governing physical mechanisms controlling multiphase flows in porous media, from pore-scale dynamics to Darcy-scale and regional-scale descriptions.

The course begins with the governing equations for single- and multiphase flow in porous media, including conservation laws, constitutive relations, and closure models. Buoyancy-driven convection, dissolution trapping, mixing, and transport enhancement are analysed through scaling arguments, stability theory, and nonlinear flow dynamics. These concepts are complemented by hands-on FluidFlower experiments that visualize convective instabilities and CO_2 dissolution under ambient laboratory conditions.

Subsequent lectures address the influence of heterogeneity, anisotropy, and dispersion on flow and mixing, and present multiscale approaches linking pore-scale experiments and simulations to continuum and field-scale models through upscaling techniques. Coupled flow-geomechanics problems, including poroelasticity, stress evolution, fault stability, and reservoir integrity, are introduced together with advanced numerical methods and high-performance computing approaches. The course also covers reactive transport, microbial processes, and biofilm formation, illustrating how biochemical phenomena modify the hydraulic and mechanical properties of porous media.

A dedicated module focuses on underground hydrogen storage, highlighting similarities and differences with CO_2 sequestration, including multiphase behaviour, reactivity, and mechanical effects. Current research challenges and industrial applications are discussed throughout the course. A visit to a borehole geophysics test site, part of the FUSE project - Open Infrastructure on Future Underground Hydrogen Storage - complements the lectures.

The course is intended for graduate students, PhD candidates, postdoctoral researchers, and faculty in applied mathematics, fluid mechanics, geophysics, computational science, and engineering, as well as industrial practitioners seeking a rigorous understanding of multiscale modelling, simulation, and experimentation for geological energy storage.

PRELIMINARY SUGGESTED READINGS

De Paoli, M. (2023). Convective mixing in porous media: a review of Darcy, pore-scale and Hele-Shaw studies. The European Physical Journal E, 46(12), 129.

Nordbotten, J. M., & Celia, M. A. (2011). Geological storage of CO_2: Modeling approaches for large-scale simulation. John Wiley & Sons.

Flemisch, B. et al. (2024). The FluidFlower Validation Benchmark Study for the Storage of CO_2. Transport in Porous Media, 151(5), 865–912.

Jiménez-Martínez, J. et al. (2015). Pore-scale mechanisms for the enhancement of mixing in unsaturated porous media and implications for chemical reactions. Geophysical Research Letters. https://doi.org/10.1002/2015GL064513

Jiménez-Martínez, J. et al. (2020). Homogenization of dissolution and enhanced precipitation induced by bubbles in multiphase flow systems. Geophysical Research Letters.

Zhang et al. (2025). Enhanced reaction kinetics in stationary two-phase flow through porous media. Environmental Science & Technology.

Kurz et al. (2022). Competition between growth and shear stress drives intermittency in preferential flow paths in porous media biofilms. Proceedings of the National Academy of Sciences.

Salek, M. M. et al. (2024). Multiscale porosity microfluidics to study bacterial transport in heterogeneous chemical landscapes. Advanced Science.

Rutqvist, J. et al. (2016). Fault activation and induced seismicity in geological carbon storage – lessons learned from recent modeling studies. Journal of Rock Mechanics and Geotechnical Engineering.

Hosseini et al. (2026). A decade of progress in the modeling and simulation of geologic carbon storage. International Journal of Greenhouse Gas Control.

Ougier-Simonin et al. (2026). The pressure balancing act in geological storage: sharing the subsurface for the common good. International Journal of Greenhouse Gas Control.

INVITED LECTURERS

Maartje Boon - University of Stuttgart, Germany
6 lectures on:
Underground H2 storage (multiphase flow and trapping), wettability, capillary pressure and relative permeability, heterogeneity, phase redistribution, and bio-geochemical reactions. Experimental observations and implications for field-scale behavior.

Jakub Wiktor Both - University of Bergen, Norway
6 lectures on:
Multiphase flow in geological formations incl. CCS trapping mechanisms; hands-on FluidFlower CCS experiments under ambient conditions, incl. visualization of dissolution and buoyancy-driven flows; and image-based model validation.

Marco De Paoli - TU Wien, Austria
5 lectures on:
General introduction. Modelling of convective flows in porous media; application to CO_2 sequestration. From pore-scale to Darcy flows. Effect of porous media properties on convection. Review of theoretical approaches: challenges and perspectives.

Andrea Franceschini - University of Padova, Italy
4 lectures on:
Numerical modelling of coupled hydro-mechanical processes in porous and fractured/faulted media and fault stability analysis for geological CO_2 storage. Scalable parallel solvers for large heterogeneous reservoirs; selected case studies.

Sarah E. Gasda - NORCE Research, Bergen, Norway
6 lectures on:
Field-scale simulation for CO_2 storage, including upscaling and integration of machine learning to resolve subscale mechanisms. Regional-scale modelling including the meaning and implications of gigaton-scale CO_2 storage.

Joaquín Jiménez-Martínez - ETH Zürich, Switzerland
4 lectures on:
General introduction to subsurface flows, mixing and dissolution in multiphase systems, microbial behavior (chemotaxis and biofilm formation) in porous media, and description of pore scale experimental techniques.

LECTURES

All lectures will be given in English.
Lecture notes can be downloaded from the CISM web site.
Instructions will be sent to accepted participants.