Annex 2 – Educational plan of Master di II level
International Master in "**CO_2 Geological Storage**"
Dipartimento Scienze della Terra,
Facoltà_Scienze MM., FF., NN.

Director del Master:	*Prof. E. Carminati*
Educational-scientific council	*The Educational-scientific council includes professor from the Partner Universities:* - Prof. E. Carminati - Prof. S. Bigi - Prof. M. Cercato - Prof. P. Ballirano - Prof. M. Battaglia - Prof. Bruno Saftic (Zaghreb University) - Prof. Domagoj Vulin (Zaghreb University) - Prof. Iva Kolenković Močilac (Zaghreb University) - Prof. Bruno Tomljienovic (Zagreb University)
Supplmentary grants:	*not provided*
timetable	*Timetable is attached at the end of this document*
website	*https://www.uniroma1.it/it/offerta-formativa/master/2019/co2-geological-storage-internazionale*
language	*English*
Online teaching	*Not provided.*
Useful information	This course is provided within the EU project ENOS (Enabling Onshore CO_2 Storage in Europe) (*http://www.enos-project.eu/)* to prepare a new generation of young people who want to work on these topics. This training course will present an overview of the state-of-the-art of CCS operations and research; it will focus on the technical and scientific knowledge acquired in the European pilot sites (including the ones from ENOS project) for CO_2 injection and safety monitoring, the exploration of critical processes in laboratory studies, and numerical modelling.

Educational plan of Joint Postgraduate International Master in "**CO_2 Geological Storage**"

Module	**description**	**teacher**	**(SSD) (italian educational system classification)**	**CFU**	**hours**	**Type of teaching activity (lessons, exercises, etc.)**	**Type of exames) See below**
Module 1 - Introduction to CO2 geological storage - Social aspect	This is an introductory module about all the topic that will be considered in the master and deals with all the aspect of the CO_2 storage, the role of GCS and its potentiality to solve the climate change problems, the basic knowledge about the social impact of this technology.	Prof. S. Bigi Prof. E. Carminati	**Geo/03**	**3**	24 hours of lessons on a total of 75	Lectures	
Module 2 - CO2 Capture and transport. Present day industrial utilization of CO2	The module covers the other technologies that are linked to the geological storage of CO_2, ie transport and capture. The different industrial capture processes will be illustrated, assessing their advantages and disadvantages, as well as the best field of application (cements, hydrocarbons, etc.). Some examples of processes currently used in industry will be illustrated. The expected learning outcomes can be summarized as: • Define the different process to capture co2 from Industrial waste • Distinguish the advantages and disadvantages of each of these technologies • Know the present day distribution of these technologies at global level.	Dott. A. Pettinau (Sotacarbo) (Enos Project)	**ING-IND 24, 25**	**3**	20 hours of lessons on a total of 75	Lectures	

Module 3 - Introduction to exploration geophysics	The module introduces to the basis of seismic interpretation, focused on the site characterization and potential evaluation of reservoir suitable for CO2 storage. The module presents the main aspect of acquisition, elaboration and interpretation of seismic data, and, during the exercise, the interpretation of data using dedicated software for the reconstruction of the geological model in 2 and 3D. The expected learning outcomes can be summarized as: •Define different type of traps based on seismic interpretation •Provide basic knowledge about acquisition and processing of seismic reflection data, •Develop appropriate skills to support data interpretation; •Acquire methodologies for the development 3D geological models.	Prof. S. Bigi Prof. battaglia	**Geo/03 – Geo/11 Geo/10 Geo/12**	**3**	20 hours of lessons 8 hours of exercise on a total of 75	Lectures, Practical exercises	
Module 4 - CO_2 geological storage options - geology and geochemistry	The module will give an overview of the types of storage reservoirs from a geochemical-mineralogical point of view, the related trapping mechanisms and their potential CO_2 storage volumes. It will discuss the physical properties of CO2 under storage conditions which influence storage, and it will describe the geochemical processes that influence long-term isolation of CO2 in the reservoir. The expected learning outcomes can be summarized as follow:	Prof. S. E. Beaubien Prof. P. Ballirano	**Geo/03 Geo/08 Geo/06**	**3**	22 hours of lessons on a total of 75	Lectures	

	• Understanding of the basic concepts of CO_2 storage reservoir types, storage mechanisms, and CO_2 properties at storage depth. • Understanding of the geochemical processes that control gas-water-rock interaction, as related to mobility and isolation. • Develop appropriate skills to support data interpretation; • Acquire methodologies to understand geochemical models.						
Exams oral exam (presentation of the results from the practical exercises). Transfer to Zagreb University.							
Module 5 - Introduction to reservoir engineering	The module will give the students basic knowledge of multiphase flow mechanisms and parameters that can help in characterization of flow in porous rock. There will be explained the main principles of PVT description of fluids (brine, gas, oil), with emphasis on phase behaviour related to systems with large CO_2 content. Attention will be put on calculations related to injection (both miscible and immiscible) and on main principles of reservoir data surveillance. The expected learning outcomes are: • Choose the adequate equation to calculate flow permeability based on laboratory or well inflow data.	Prof. D. Vulin (Zagheb University)	**Geo/03 – ING-IND 30**	**3**	25 hours of lessons on a total of 75.	Lectures, computer exercises	

	• Implement published correlations to put together all required parameters for volumetric calculations in the underground. • Predict pressure vs. recovery changes by material balance (MBE). • Prepare the dataset for fluid injection model. • Assess if there are issues regarding injectivity and fracturing pressure • Understand how Buckley-Leverett theory can be implemented to various cases of fluid injection. • Analyse production data and predict future recoveries. Implement the production decline curve analysis (DCA) and PVT data to predict CO2 emissions. • Demonstrate an integrated set of analyses for recovery, injection, and storage of fluids in a formation and justify interpreted measurement results.						
Module 6 - Storage site selection and capacity estimates	The module should introduce different approach when estimating CO_2 storage potential during basin assessment and CO_2 storage capacity of a certain storage object following site screening and based on site characterization. Course focuses on explanation of different issues arising when assessing potential for CO_2 storage or storage capacity of different types of storage objects (deep saline aquifers, depleted hydrocarbon reservoirs,	Bruno Saftic (Zagheb University)	**Geo/03**	**3**	25 hours of lectures on a total of 75.	lectures	

	coal seams, salt caverns). Also, procedures of detailed characterization of reservoir rocks and cap rocks are described. The expected learning outcomes can be summarized as follow: • Define different levels of assessment of CO_2 storage potential of a certain area • Define the deep saline aquifer and elaborate methods to estimate its properties important from the aspect of geological storage of CO_2 • Elaborate factors influencing possibility of geological storage in hydrocarbon reservoirs (type of trap, reservoir properties, pressure properties, seal efficiency, saturation) • Explain influence of coal structure and adsorption trapping on geological storage of CO_2 in coal seams • Explain the specificities of CO2 geological storage in salt caverns • Define criteria for assessing basin suitability for CO2 geological storage and to explain procedure of prospective storage site screening • Explain how different reservoir rock characteristics influence the rock's potential to store CO_2 and to describe how to assess them (lithology, heterogeneity, porosity, permeability) • Explain how different characteristics of cap-rocks influence the reservoir's potential to store CO_2 and to describe how to assess them (lithology and integrity of a cap-rocks).						

Module 7 - Numerical modelling of CO2 storage	This module introduces the students to numerical modelling, including an outline of how models are constructed followed by a focus on flow simulation. The course reinforces theory learnt in the module 5- Reservoir Engineering, which is essential to ensure that students can learn how to set up simulations and how to interpret results. The basic theory of flow simulation is presented, followed by a number of challenges (such as upscaling and dealing with uncertainty in reservoir properties). Finally, a review of more advanced processes, such as coupled modelling is presented. Expected learning outcomes are: • Explain how numerical modelling can be used to forecast CO2 storage capacity and outline the processes which can be simulated using numerical modelling of CO2 storage. • Describe the types of data required for building a static model, and outline the workflow for static modelling of a storage formation. • Review the factors which determine the behaviour of CO2 in a storage formation – density, viscosity, solubility, relative permeability and capillary pressure. • Outline steps required to set up a simulation of CO2 injection and storage.	Gillian Pickup Heriot Watt University Edinburgh, Scotland.	**Geo/03**	**3**	25 hours (12 lectures, 13 exercises) on a total of 75	lectures computer exercises	

	• Derive the equations for flow simulation in a 1D, single-phase compressible system and explain how the equations may be extended to two-phase flow. Describe methods of solving the flow equations. • Review the procedures of history-matching and quantification of uncertainty. • Discuss the issues involved in choosing a grid size (grid refinement) and in upscaling data for use in a grid cell. • Outline some more advanced modelling techniques – e.g. coupled flow simulation. • Set up and run simple simulations of CO2 injection to investigate migration, pressure build-up, dissolution and pore-scale trapping. • Perform simulations to study the effects of geological structure and heterogeneity on CO2 storage.						
Module 8 - EOR with CO2	The module will give the students insight to the mechanisms and evaluation methods for Enhanced Oil Recovery (EOR) and for enhancing the processes related to exploitation of underground resources in general. The emphasis will be put on processes that involve CO_2 injection or CO_2 emissions mitigation. Each student should come up with one project related to CO2 injection into underground.	D. VULIN (Zagheb University)	**Geo/03 – ING-IND 30**	**3**	25 hours on a total of a total of 75	lectures computer exercises	

	Learning outcomes are: • Perform immiscible injection process analysis by implementing Buckley-Leverett equation, as the part of EOR process • List the most used EOR methods and warn about limitations and advantages of each method. • Understand the data upscaling process to prepare dataset for EOR evaluation • Perform feasibility analysis of a given EOR case. • Describe the PVT tests required for CO2-EOR. Describe the special PVT phase diagram for ternary system CO2-H2O-NaCl • Predict minimum miscibility pressure (CO2 and oil) and solubility (CO2 and brine) • Match the given laboratory data with PVT simulation software, and prepare (export) matched equation of state for further analysis (simulation) • Perform simulation test to determine dispersion model and performance of CO2 injection to the underground						
Exams: writing of term papers (seminars) to be submitted at the end for module 6, presentation required for module 5 and 8; written exams for module 7.							
Module 9 - Storage Risks	The module will introduce risk assessment for CO_2 geological storage to prevent any CO_2 leakage. The course focuses on risk assessment is an iterative process that must be made in each phase of a storage project, from selection,	Niels Poulsen GEUS,	**Geo/03**	**2**	20 h of lectures on a total of a total of 50	lectures	

	characterization and baseline study to site closure, post closure and final transfer of responsibility from operator to state. This assessment is the basis for designing a good monitoring plan and an effective plan for prevention and correction in case of leakage. The risk assessment and monitoring plan are updated when necessary, in particular in case of any abnormal behaviour or at closure and post closure phases. Attention will also be on the obligation to assess the risks and remediations associated with the CCS technology. The request learning outcomes are: • Define and introduction to risk research • Hazard identification and risk characterisation • Potential pathways for CO2 leakage • Environmental impacts • Risk assessment methodologies • Risk mitigation and remediation measures	Denmark					
Exams and transfer to Rome, Sapienza University - written exams							
Module 10 - Geophysical monitoring	The module introduces the principles of the main geophysical techniques applied to CO_2 storage. Course focuses on explanation of electrical, electromagnetic and seismic geophysical methods for assessing potential and limits of geological formations for CO_2 storage and their storage capacity, and for monitoring the CO_2 storage process. The expected learning outcomes can be summarized as follow:	Prof. M. Cercato	**Geo11**	**5**	40h of lectures, 2 days of fieldwork, on a total of a total of 125h	Lectures, exercise, fieldwork	

	•Explain the theoretical principles of geoelectrical and seismic methods applied to CO_2 storage; •Explain potential and limits of the geophysical reconstruction for CO_2 storage, in terms of resolution, depth of investigation and diagnostic capability; •Explain the inversion process and its application for characterization and monitoring of CO_2 geological storage; •Select the piecewise geophysical method to be applied for the particular case study related to CO_2 storage; •Design a geophysical campaign and define properly field acquisition parameters; •Process correctly geophysical data acquired in field by using specific software; •Link geophysical to petro-physical parameters of rocks and soils (lithology, heterogeneity, porosity, permeability); •Define criteria for monitoring the CO_2 storage process.						
Module 11 - Geochemical monitoring	This module will introduce a wide range of regional and detailed geochemical techniques used to monitor CCS sites to ensure carbon credit auditing, to find and quantify potential leaks, and to determine effectiveness of any remediation action taken. Lessons will describe the technical background and operation of each method, their advantages and disadvantages in terms of sensitivity, scale and resolution, and costs. Field exercises at the end of this module will give the	To define	**Geo/08**	**3**	26 h of lectures and 1 day of fieldwork on a total of 75 h	Lectures, exercise, fieldwork	

	students hands-on experience with a sub-set of the described methods. The expected learning outcomes can be summarized as follow: •Knowledge of what geochemical monitoring methods are available and how they work •Ability to choose the most appropriate methods based on a given site's characteristics and the specific monitoring goals of the project •Develop appropriate skills to support data interpretation.						
Module 12 - Drilling and wells	The module is an introductory course to drilling and wells. The topics covered will include drilling equipment, well control, well-testing, completions, and permeability enhancement. The module will be a mixture of descriptive material and also practical skills in conducting simple design calculations. The expected learning outcomes can be summarized as follow: •Describe basic drilling equipment, particularly drilling-rig components and mud circuit. •Explain use of various drilling mud additives. •Conduct basic design calculations to determine mud weights and casings needed for a given well based on simple models for defining fracture and formation pressure, swab and surge allowances, and circulation allowance. •Describe nature of kicks and basic principles of kick control.	Prof. Sean Rigby University of Nottingham Scoltland	**Geo/03 – ING-IND 30**	**2**	17 h lectures, 3h problems/exercises on a total of 50.	Lectures exercises	

	•Conduct basic calculations for determination of kill mud weight. •Explain the principles of core drilling. •Explain basic principles of directional drilling. •Describe some applications of horizontal wells. •Explain basic principles of well-testing. •Describe the process of completion and different completion types. •Describe methods of permeability enhancement.						
Module 13 - Economic and Regulatory aspects of CCS technology	The course provides an insight into the very basics of geological, regulatory, economic, and social aspects of the carbon capture and storage technology (CCS). CCS is considered as an important tool in decreasing global carbon dioxide emissions, thus capable of reducing the humankind's impact on the climate change. The success individual CCS projects is derived from suitable geological conditions, favourable regulatory framework that would contribute to their economic viability, and public support on the nation as well as local level.	Prof. Alla Shogenova Tallinn University, Estonia (Enos Project) Prof. Samuela Vercelli	**Geo/03 – ING-IND 35**	**1**	14h on a total of 25	Lectures	
Module 14 - CCUS and cross-cutting issues	The module will introduce different utilisation options of captured CO_2, including CO_2 use for enhanced recovery of resources (geothermal energy, coal-bed methane, shale gas, water), CO_2 mineral carbonation (using natural rocks and waste	Alla Shogenova, Tallinn University, Estonia	**Geo/03 – Geo/08 ING-IND24,25**	**3**	20h on a total of 50	Lectures	

	materials) and CO_2 use for hydrocarbon productions. The concept of Bio-CCS and negative emissions will be introduced, including direct and indirect GHG emissions, Bio-CCS technologies, their challenges and advantages and operating Bio-CCS projects. The module will also deal with: CO2 mineral carbonation; Comparison of CO2 Geological storage and mineral carbonation technologies; CO2 Storage in basalts; synergy of CGS with geothermal energy recovery; energy storage and water recovery; advantages of synergy of CGS with renewable energy recovery; the role of cement industry in producing CO2 emissions. Expected learning outcomes: • Awareness about different options of CO2 use • Explain bio-CCS technology, negative emissions, direct and indirect emissions, advantages and challenges • Explain mineral carbonation options routes • Explain chemical composition of rocks and determine the rock samples suitable for CO2 mineral carbonation, • Describe processes, parameters and advantages of in-situ mineral carbonation in basalts • Define technological options for CO2 use for enhanced recovery of geothermal energy.						

	• Explain the capture methods most of all suitable to capture CO_2 in the cement industry						
Exams, written (module 10) and oral (others modules)							
traineership 1	group work (5 groups of 2 students) This week will be organized with active student work, which will be divided into groups and will have to conduct a small research independently. The starting database will be the same for all groups. The result will be a geological interpretation and the evaluation of the storage potential of the proposed area.			5	125h	*Sapienza first edition;* *Zagreb second edition.*	
traineership 2	Total assessment and thesis work and side assignment for the project work. The students will be evaluated based on the scores obtained during the course and will be assigned the side for the internship according to the score, keeping in mind the interests of the student and the activities offered by the different institutions.		vari	15	375h	Project work, with final report and presentation to be discussed with the scientific commission / council.	
Final exams	The final exam consists of a presentation and defence of the result obtained from the activities done during traineeship 2.						
Other activities						Not provided	
TOTAL				**60**	**1500 h**		