11 PhD positions in the EU Horizon Europe Marie Skłodowska-Curie Doctoral Networks MSCA-DN Project SMILE (Multidi**S**ciplinary and **M**ult**I**scale approach for coup**L**ed processes induced by geo-**E**nergies, Grant Agreement No. 101073281)

Applications are invited for 11 PhD positions to be funded by the Marie-Sklodowska-Curie Actions Doctoral Network SMILE. SMILE is a consortium of high-profile universities, research institutions and companies located in Spain, France, Norway, Italy, Czech Republic, UK, Switzerland, the Netherlands and Germany.

Exceptional opportunities for promising young students on the following cutting-edge topics:

Geo-energy applications; Hydrogeology; Earth observations from space/remote sensing; Geomechanics; Geochemistry; Geophysics.

Keywords
Fluid injection, pressure buildup, cooling, deformation, geochemical reactions, induced seismicity, remote sensing monitoring, geothermal energy, geologic CO_2 storage, subsurface energy storage

Career Stage
Doctoral Candidates (DCs): these are 3-year PhD position open for graduated students (Master or equivalent).

Abstract of SMILE

Geo-energies, such as geothermal energy, CO_2 storage and underground energy storage, have a great potential to contribute to meet the Paris Agreement targets on climate change. Yet, their deployment has been hindered by a lack of a full understanding of the processes that are induced in the subsurface by large-scale fluid injection/extraction. The various processes involved (e.g., fluid flow, geomechanical, geochemical and thermal effects) imply complex interactions that cannot be predicted without considering the dominant coupled processes, which is rarely done. As a result, **some early geo-energy projects have occasionally developed unpredicted consequences**, such as felt and damaging induced earthquakes, gas leakage and aquifer contamination, dampening public perception on geo-energies. **SMILE aims at overcoming these challenges in developing geo-energy solutions by training a new generation of young researchers that will become experts in understanding and predicting coupled processes. Thus, they will be capable of proposing innovative solutions for the successful deployment of subsurface low-carbon energy sources while protecting groundwater and related ecosystems**. To achieve this ambitious goal, the doctoral candidates will be exposed to an interdisciplinary training on experimental, mathematical and numerical modelling of coupled processes, upscaling techniques and ground deformation monitoring using field data from highly instrumented pilot tests and industrial sites. The training in SMILE has been designed by both academic and industrial partners to train competitive researchers with both technical-scientific and transferable skills to enhance their employability in academia, industry and public sector. The outputs of the project will be largely disseminated. Outreach to society will be achieved through a conspicuous series of initiatives. SMILE will make a significant contribution to the societal challenges of securing clean and low-carbon energy sources.

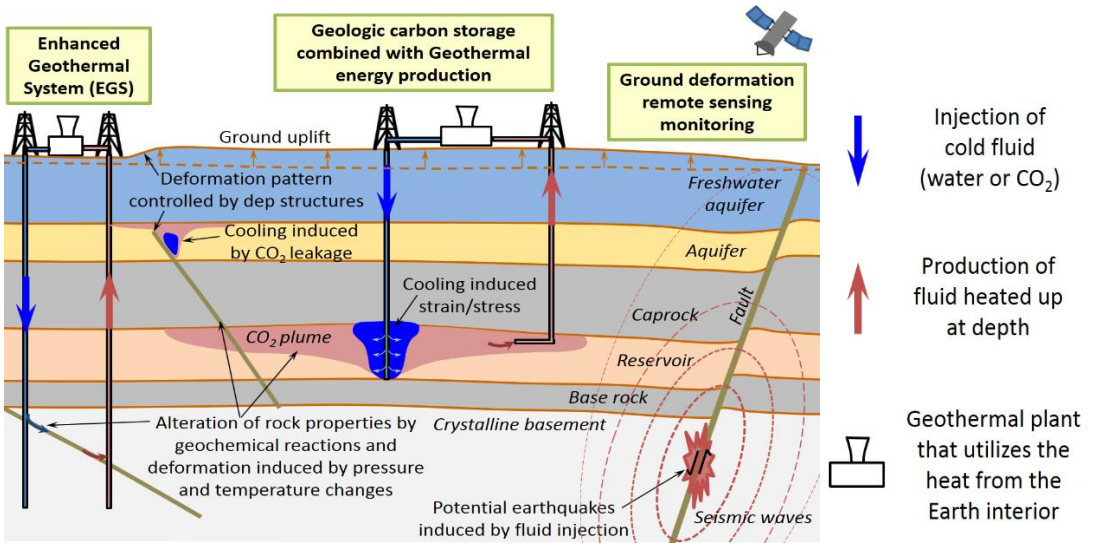

Figure 1: Schematic representation of some examples of coupled thermo-hydro-mechanical-chemical (THMC) processes induced by geo-energy applications as a result of fluid injection/extraction (Image designed by SMILE)

Benefits and salary

The successful candidates will receive an attractive salary in accordance with the MSCA regulations for doctoral candidates. The exact salary will be confirmed upon appointment and is dependent on the country correction factor that applies to the living allowance (to allow for the difference in cost of living in different EU Member States). The salary includes a living allowance, a mobility allowance and a family allowance (if the recruited doctoral candidate has or acquires family obligations during the action duration, i.e., persons linked to him/her by (i) marriage, or (ii) a relationship with equivalent status to a marriage recognised by the legislation of the country or region where this relationship was formalised; or (iii) dependent children who are actually being maintained by the researcher). The guaranteed PhD funding is for 36 months. In addition to their individual scientific projects, all doctoral candidates will benefit from further continuing education, which includes internships and secondments, a variety of training modules as well as transferable skills courses and active participation in workshops and conferences.

Recruitment Procedure

Candidates should apply electronically (to the email indicated in the PhD position(s) of their interest and to msca.dn.smile@gmail.com) for one to maximum three positions and indicate their preference. Candidates should provide a detailed CV, a motivation letter, transcripts of bachelor and master degrees, and an English certificate. Applicants will need to prove that they are eligible, according to the DC definition, mobility criteria, and English language proficiency. The deadline for applications is the 31st of January of 2023.

The selected (short-listed) candidates will be interviewed by the supervisors. The final decision on who to recruit will be made by the selection committee. The selected DCs are to start their research at the beginning of the doctoral course 2023-24.

Applicants need to fully respect three eligibility criteria:

Supported researchers must be **Doctoral Candidates** (DC), i.e., not already in possession of a doctoral degree at the date of the recruitment. Researchers who have successfully defended their doctoral thesis but who have not yet formally been awarded the doctoral degree will not be considered eligible

Recruited researchers can be of any nationality and must comply with the following **mobility rule**: Researchers are required to undertake trans-national mobility (i.e., move from one country to another) when taking up the appointment. At the time of selection by the host organization, researchers must not have resided or carried out their main activity (work, studies, etc.) in the country of their host organization for more than 12 months in the 3 years immediately prior to their recruitment. Short stays, such as holidays, are not taken into account.

English language: Candidates must demonstrate that their ability to understand and express themselves in both written and spoken English is sufficiently high for them to derive the full benefit from the network training.

Description of the available 11 PhD positions:

DC1-PhD: Experimental investigation of the coupled THMC response of the caprock to CO_2 injection in a pilot test site

Objectives: Monitoring, analysing, and interpreting of interaction between injected CO_2 and the target facies in the Mont Terri Rock Laboratory, especially changes in temperature, pressure, and deformation based on experimental data. Together with partners listed below in the planned secondments, analysing potential correlation between hydrological, thermal, geomechanical, geochemical, including quantitative and qualitative uncertainty analysis

Expected Results: Identification and evaluation of relevant signals in time series obtained in the CL-Experiment at Mont Terri (CO_2LPIE, CO_2 long-term periodic injection experiment). Based on findings, evaluation of monitoring strategies and development of work flows including natural and anthropogenic signal analysis for scenarios of long-term experiments in underground rock laboratories

Host Institution: Armines (France)

Secondments: BGR, CSIC

Contact: Laura Blanco Martin (laura.blanco_martin@minesparis.psl.eu)

DC2-PhD: Quantitative ground deformation monitoring based on advanced DInSAR techniques

Objectives: Assessing the performance of current DInSAR techniques, making a full characterization of the different DInSAR error sources. Estimating the sensitivity of the DInSAR technique to deformation, and evaluating the precision level attainable by the DInSAR measurements using uncertainty analysis techniques. Optimizing the DInSAR data processing and analysis procedures to increase the precision and reliability of the DInSAR measurements

Expected Results: The entire research work will be focused on the quantitative aspects of DInSAR deformation measurement. A first important result will be a characterization of the different error sources that affect the main DInSAR outcomes, i.e., the deformation velocity maps and time series. A second part will be a comprehensive study of the sensitivity and the precision of the DInSAR observations. In SMILE, this aspect is important because the fluid injection or extraction is often associated with very small ground deformation. The third key result will be the optimization of DInSAR data analysis procedures, with the aim of improving the performance of current DInSAR techniques

Host Institution: CTTC (Spain)

Secondments: Gamma, GReD, BGR

Contact: Michele Crosetto (mcrosetto@cttc.cat)

DC3-PhD: New methodology of tracking underground injection from CO_2 storage, geothermal and other types of underground injection

Objectives: The main objectives are development and practical testing of seismic interferometry of alternative method for tracking injecting fluids in the underground. Currently we use passive seismic monitoring to detect induced seismicity and occasionally some projects use repeated active seismic (4D) surveys to track injected fluid in the underground reservoirs. Especially, CO_2 sequestration seems to

effectively show in 4D surveys the changes due to injected CO_2. However, such surveys are expensive and difficult to do. Recent rapid development of seismic interferometry allows to obtain surface (and sometimes even body waves) response between monitoring stations. The goal of this thesis would be to investigate the feasibility of the fluid placement detection from inversion of the Green's functions between receivers monitoring the reservoir and test this methodology on real data, establish its limitation and investigate optimal deployment including optimal deployment for shallow borehole receivers. Seismik has developed interferometric surface wave inversion software package which can be further enhanced for this project and has access to seismic monitoring dataset from Decatur project in Illinois (1Mt total over 3-year period). The investigation focus on both optimal network design (shallow borehole) and feasibility of interferometric monitoring.

Expected Results: Find optimal depth for shallow borehole receivers for microseismic monitoring. Find out strength of the S-wave velocity changes resulting from CO_2 sequestration on surface waves. Determine limits on accuracy of the surface wave inversion to detect these changes. Do the previous step for both reservoir and caprock. Test on real dataset from Decatur project. Propose and model ideal monitoring network design to determine underground placement

Host Institution: Seismik (Czech Republic)

Secondments: NTNU, CSIC

Contact: Leo Eisner (leo.eisner@seismik.cz)

DC4-PhD: Exploring coupled THMC processes occurring in the caprock in highly instrumented sites

Objectives: Identification and classification of the factors controlling injected/migrated CO_2 (e.g., using the case study results of the Mont Terri Rock Laboratory and using large-scale natural CO_2 analogues and caprocks), including the determination of relevant geochemical reactions, phase partitioning and geo-mechanical controls on migration. The focus will be on quantitative and qualitative uncertainty analysis and interpretations of results through simulations of the relevant coupled processes using state-of-the-art simulation codes and though calibration to monitoring datasets (temperature, pressure, strain, and flow rates)

Expected Results: THMC simulations of relevant interactions between injected CO_2 and caprock embedded in the CL-Experiment at Mont Terri (CO_2LPIE, CO_2 long-term periodic injection experiment) and application to mudrock sealing systems offshore Norway (e.g., Draupne shales of the Upper Jurassic Viking group). Based on findings, insights into consequences for caprock integrity will be drawn for different scenarios of gas and energy storage in the subsurface

Host Institution: NTNU (Norway)

Secondments: Craytive, UEDIN, ETHZ

Contact: Philip Ringrose (philip.ringrose@ntnu.no)

DC5-PhD: Reducing the uncertainty on subsurface heterogeneity from microseismic and geodetic data

Objectives: Develop a THMC characterization methodology to reduce the uncertainty on subsurface heterogeneity and identify faults that might induce seismicity based on induced microseismicity and ground deformation measurements

Expected Results: An information and computing framework that integrates geodetic, pressure, temperature and geochemical measurements with coupled THMC simulations will be developed to continuously characterize the subsurface during operation of geo-energy projects. Anomalous surface deformation

patterns will serve to identify the presence and characteristics of geologic structures, like conductive and low-permeable faults. By developing a precise workflow that permits a continuous characterization in quasi-real-time, the knowledge on the subsurface can be updated, providing valuable information to the decision makers of geo-energy projects in order to operate the sites minimizing the risk of inducing felt seismic events. The developed characterization methodology will be tested using microseismic and ground deformation data of the CO_2 injection at Decatur, Illinois and the CL-Experiment at Mont Terri. The DC will collaborate with DCs 2 and 10 on the ground deformation measurements, with DC 11 on evaluation of rock properties, with DC 7 on subsurface deformation induced by fault reactivation and with DC 3 on designing passive microseismic monitoring networks to assess changes in caprock sealing capacity

Host Institution: CSIC (Spain)

Secondments: ETHZ, GReD, Seismik

Contact: Víctor Vilarrasa (victor.vilarrasa@csic.es)

DC6-PhD: Use of Invasion Percolation methods to model gravity segregation in CO_2/HC/brine systems

Objectives: Advance in the understanding of gravity segregation of CO_2, hydrocarbon (HC) and brine systems by enhancing modelling capabilities of mixing HC and CO_2 phase in highly heterogeneous brine-saturated rock, coupling Invasion Percolation approach with geomechanics

Expected Results: Project will mainly use the Permedia® modelling tool which has been widely applied to CO_2 migration problems, as well as various open source research codes to develop enhancements for handling fluid mixing between HC and CO_2 phases in brine-saturated media. The Invasion Percolation modelling approach has the advantage of being able to solve CO_2 migration phenomena in very high-resolution rock models, but generally neglects fluid exchange and mixing phenomena. Simplified fluid mixing functions (e.g., flash calculations with gravity segregation) would be applied to a range of scenarios in order to better understand gravity segregation in CO_2/HC/brine systems as well as application to hydrogen storage. The Invasion Percolation solutions will be tested against multiphase-flow models of the same system in order to improve the Invasion Percolation formulation for CO_2 migration problems. Methods for improved handling of the fluid pressure field, which is normally neglected in conventional Invasion Percolation models, will also be developed. The calculation of the fluid pressure field will be used to incorporate, in collaboration with DC 5, the geomechanical response of the rock to CO_2 injection. The concept of separately solving the brine-phase pressure field and then modifying the threshold pressures which control the percolating CO_2 clusters will be developed and tested using the database of CO_2 storage sites provided by Equinor. The approach could lead to much improved methods for handling CO_2 migration problems within saline-aquifer CO_2 storage systems, both at the reservoir and basin scales

Host Institution: NTNU (Norway)

Secondments: ETHZ, CSIC

Contact: Philip Ringrose (philip.ringrose@ntnu.no)

DC7-PhD: Dynamic fracturing in a THM framework: Upscaling applications to geo-energy production and induced seismicity

Objectives: This work includes the development of a fully coupled THM framework based on pre-existing finite element codes. A dynamic fracturing model, which accounts for released kinetic energy, is to be integrated in the THM framework. Once the dynamic THM fracturing platform is developed, it will be applied to different project configurations. Given the inherent uncertainties in the knowledge of geothermal systems,

a statistical analysis will be carried out to estimate the impact of the variation of model input parameters on the risk of rupture and fault reactivation and thus, optimize the production while reducing the risk of felt seismic events. Induced seismicity will be utilized in an inverse analysis approach to plot the hydraulic fracture envelope. It will be also used in calculating the kinetic energy spread in the medium, and henceforth controlling/predicting the magnitude of induced seismic events

Expected Results: We would aspire to develop an upscaling approach where our THM dynamic fracturing platform can be applied to large geological scales while taking into account natural anisotropies. Such anisotropies self-demonstrate in terms of elastic, dynamic, and transport properties. Once this upscaling approach is developed, we will consider models with large faults that can be assigned different dynamic and fluid transport properties from the surrounding rock formation. We expect that assigning to faults weaker elastic and dynamic properties would affect the directional homogeneity of far-field geological stresses, which would consequently, have direct impacts on the shape and orientation of the created fluid driven fractures. The fluid-heat interaction with geological faults and pre-existing natural defects/joints is expected to trigger slip and to induce seismicity. Inverse analysis techniques will be utilized to locate seismic events, specifically during shut-in and flow back to better understand and evaluate post-peak induced seismicity. We will also investigate the influence of different injection scenarios/multi-stage fracturing, fault orientation with respect to the injection well, and the amount of the injected fluid on the efficiency of the reservoir development prior to further exploitation

Host Institution: Armines (France)

Secondments: ETHZ, CSIC, CTTC

Contact: Laura Blanco Martin (laura.blanco_martin@minesparis.psl.eu)

DC8-PhD: Simulation of thermal, hydraulic and mechanical stress distribution in heterogeneous layered reservoirs

Objectives: To identify the key processes operating which impact the surface deformation signal during fluid injection as a function of the THM changes in the system. To identify the key geological facies related controls on the transfer of deep seated reservoir strain to the surface. To train the student in the use of FEM and FVM codes for coupled THM problems, introduce them to state-of-the-art numerical code architecture necessary to simulate flexibly THM problems. To upscale from THM lab scale experimental measurements to field measurements

Expected Results: A literature review on methodologies used to upscale THM coupled processes at sub cm scale to reservoir injection scale. Numerical simulation of surface deformation of laboratory scale samples in the GREAT cell. Numerical prediction of surface deformation as a consequence of fluid injection of geothermal sites. Application of multiple upscaling approaches, including the geomechanical facies approach

Host Institution: UEDIN (UK)

Secondments: Armines, Quintessa

Contact: Christopher McDermott (christopher.mcdermott@ed.ac.uk)

DC9-PhD: Advanced Persistent Scattered Interferometry (PSI) techniques for ground motion monitoring

Objectives: To develop advanced PSI techniques adapted to the ground motion monitoring needs of SMILE. This will involve new procedure to select the measurement points (amplitude-based, coherence-based, new approaches to be developed and tested), the use of different types of SAR polarizations to increase the

measurement point density, and an in-depth study of the effects of soil moisture on the PSI estimates, especially using short temporal baselines

Expected Results: Contribution to a literature review focused on the most relevant PSI algorithms. Full characterization of the various error sources that affect the PSI estimates. Development of advanced PSI techniques tailored to the needs of SMILE: new procedures to select the PSI measurement points; a feasibility study on the use of complementary SAR polarizations; and an in-depth study of the (negative) effects of soil moisture on the PSI estimates

Host Institution: CTTC (Spain)

Secondments: Gamma, GReD

Contact: Michele Crosetto (mcrosetto@cttc.cat)

DC10-PhD: Automated analysis of ground deformation time series

Objectives: To develop an automated software tool to analyse the ground deformation time series obtained from Galileo-enabled low-cost GNSS receivers, also in conjunction with area-wise DInSAR monitoring (in collaboration with CTTC) and with a-priori information from ground modelling (in collaboration with Armines)

Expected Results: The ground deformation time series obtained from Galileo-enabled low-cost GNSS receivers need to be properly analysed in order to determine the characteristics of the movements. The activities of this project will include the development of a software tool to automatically read the time series data, detect and remove outliers, characterize trends and discontinuities, also based on a-priori information about the expected ground features

Host Institution: GReD (Italy – the PhD will be activated at Politecnico di Milano University, and carried out in co-tutelage with GReD)

Secondments: CTTC, Armines

Contact: Eugenio Realini (eugenio.realini@g-red.eu)

DC11-PhD: The aid of laboratory in the characterization of caprock/reservoir CO_2 storage geological formations

Objectives: To develop an experimentally based study of the complex interaction between reactive pore fluids and rock matrix, in typical caprocks and reservoir rocks. Data will be collected both at laboratory scale and at in situ at ongoing pilot projects (e.g., at the Mont Terri and Bedretto Underground Labs, as well as at the islandic CO_2 storage facility). The aim is to provide a link between relevant mechanical/hydraulic parameters and fluid-rock interaction. Experiments will be also tailed to link the characteristics of the rocks to seismic/aseismic slip, addressing the induced seismicity issue

Expected Results: To provide a complete dataset on geomechanical parameters linked to fluid-rock interaction in caprock/reservoir rocks. The data will be input in numerical simulations

Host Institution: ETHZ (Switzerland)

Secondments: CSIC, Seismik, BGR

Contact: Alba Zappone (alba.zappone@sed.ethz.ch)