POLITECNICO MILANO 1863 | DIPARTIMENTO DI ENERGIA

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RESEARCH THESIS ON:

MACHINE LEARNING FOR CO_2 PLUME MONITORING BY PULSE CODE TESTING IN CARBON CAPTURE AND STORAGE PROJECTS

CONTEXT OF THE RESEARCH

Carbon capture and storage (CCS) will play a critical role in future decarbonization efforts to meet the Paris Agreement targets and mitigate the effects of climate change. The process typically involves CO_2 flow from a compression station to the injection wells through a network system and its safe storage into a depleted oil and gas reservoir or an aquifer. In this context, monitoring how the injected CO_2 spreads in the reservoir (CO_2 plume) is necessary to verify that the storage behaves as expected. However, tracking the front of the CO_2 plume from the measurements available at the wells is a challenging task. Pulse Code Testing (PCT) offers a promising solution: CO_2 is injected according to specific rhythmic patterns, and the induced pressure pulses travel through the reservoir and are recorded at monitoring wells. Given the known injection pattern, the recorded pressure signals can be decoded to estimate the inter-well connectivity, from which the CO_2 plume front can be tracked. Machine Learning (ML) methods can support this process by distinguishing the plume signature from background disturbances and by reducing the number of well tests required.

OBJECTIVES OF THE RESEARCH

In this context, the final objective of the thesis is to develop and validate ML-based methods for the estimation of inter-well connectivity and the tracking of the CO_2 plume front from PCT data. The thesis will be structured into the following phases:

- *Literature Review:* Analysis of PCT in the Oil & Gas industry, methods of inter-well connectivity estimation, techniques for CO_2 plume monitoring and the application of ML to these tasks;
- *Exploratory Data Analysis:* Analysis of simulated data reproducing the behavior of the wells before and after CO_2 breakthrough in aquifer and gas-depleted reservoir scenarios, including time-frequency analysis of the pressure signals (e.g., Fourier and wavelet transforms);
- *Method Development:* Development of methods with documented Python code for estimating inter-well connectivity and tracking the CO_2 plume front (e.g., physics-informed ML leveraging the diffusion equation, deep learning techniques for time series analysis);
- *Validation:* Final validation with the industrial partners on the simulated case studies, and benchmarking against the methodologies developed by the project partners.

The thesis work will be carried out within the collaboration between ENI and Politecnico di Milano (LASAR³) on CCS monitoring [1], with the support of Resermine for reservoir engineering. Simulated data will be provided along with operational constraints. Periodic technical meetings involving the industrial partners will be organized to review progress and validate results against real world challenges.

REQUIRED SKILLS

Coding skills in Python and good practices.
Technical communication skills in English.
Familiarity with machine learning and signal processing approaches will be appreciated. Knowledge on reservoir engineering and CCS processes is a plus.

RESEARCH TEAM

For further information and details about this thesis, please contact:

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- **Prof. Enrico Zio, enrico.zio@polimi.it**

References

[1] E. Vignati, F. Ursini, G. Floreale, P. Baraldi, I. Chouybat, E. Zio. Virtual Sensing for Real-Time Well Monitoring in CCS projects. *World CCUS Conference 2026*, European Association of Geoscientists & Engineers, 2026, pp. 1–5. doi: 10.3997/2214-4609.202622055.