Environmental Monitoring Plan for Offshore CO_2 Injection in a Depleted Natural Gas Reservoir – Italy Experience

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The presentation at glance

1. Ispra activities in support of CCS
2. Italy experimental CO_2 injection project characteristics
3. Critical environmental monitoring aspects
4. General Monitoring Actions
5. Off-shore Environmental Monitoring Plan (EMP) Work Packages (WPs)

1- ISPRA activities in support of CCS

ISPRA is involved in the permitting process for the geological storage of CO_2 captured from the flue gas of a turbine serving a methane compressor station in Porto Corsini (RA) in technical and scientific-support of the National Secretariat for CCS.

ISPRA has been involved in the study of the CCS supply chain envisaged by Decree L.D. 181/2023 with regard to the issue of "clustering," i.e., identification of groups of emitters and areas potentially suitable for the storage of captured CO_2 for the identification of potential pipeline transport corridors.

ISPRA performs coordination functions of the Interest Group (IGCCS) within the European Network of environmental agencies (EPA network).

ISPRA is also involved at the United Nations Economic Commission for Europe-UNECE (TEIA) in the workstreams 2025/26 of the Convention on the Transboundary Effects of Industrial Accidents with reference to the "CO_2 Storage" workstream.

2- CCS Ravenna Phase 1: Project Overview

Objective:
Test geological storage of CO_2 in the depleted "PL2-C" reservoir of the "Porto Corsini Mare Ovest" (PCMW) field.

Scale:
Experimental injection of less than 100,000 tons of CO_2 to be scaled up to 4M t/a.

Location:
Offshore concession A.C26.EA, about 8 km from the Ravenna coast, on the platform PCW-C.

3- Geological and Technical Framework

Reservoir Characteristics:

- Depleted gas reservoir in the Adriatic Sea at 3000 meters depth under seabed.
- Suitable porosity and permeability for CO_2 storage (sandstones)
- Secure caprock to prevent CO_2 migration.

Static and Dynamic Models:

- 3D geological models to predict CO_2 behavior.
- Continuous model updates based on monitoring data.

4- Infrastructure and Injection Setup

CO_2 Capture:

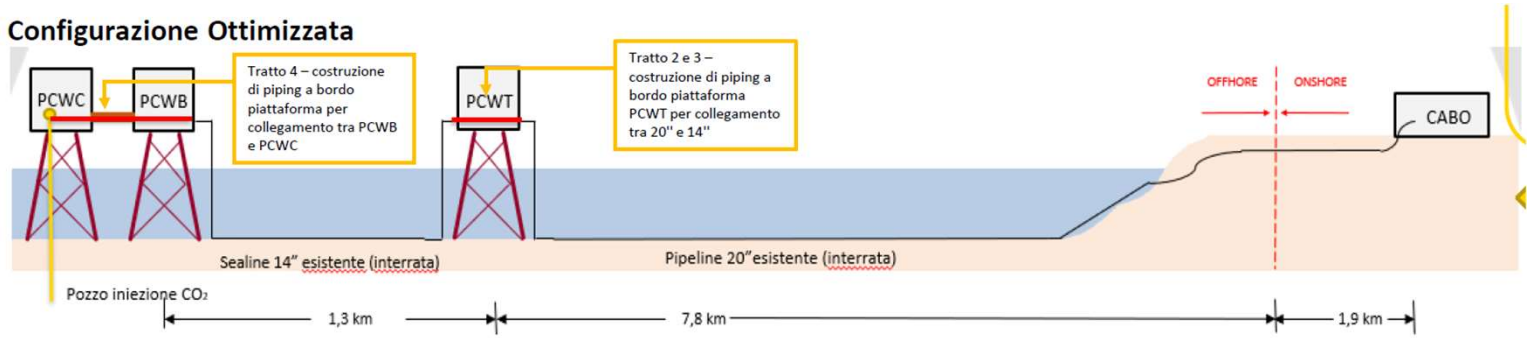
- Located at Casalborsetti Gas Plant, capturing up to 25,000 tons/year of CO_2.
- Uses amine-based absorption technology.

Transport System:

- Reuse of existing pipelines (20'' and 14'' pipelines) for offshore transport.
- CO_2 transported as a supercritical fluid to ensure stability.

Injection Well:

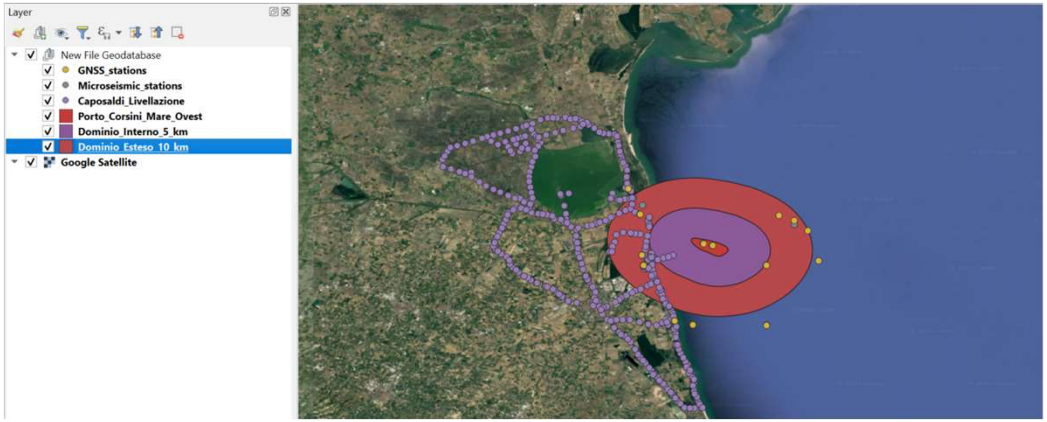
- PCMW 30 DIR B well used for injection.
- Well equipped with downhole sensors for real-time data.



5- Safety Measures and Environmental Impact

EMP and Environmental Impact Assessment (EIA) not mandatory in Italy for experimental project under 100.000 tons (at the time of project issuance)

- Voluntary Assessments conducted for onshore and offshore (marine and coastal ecosystems)
- Measures in place for emission control and noise management.



Risk Management:

- Plans for induced seismicity, soil deformation, and potential CO_2 leaks.
- Emergency response systems (Residual Risk Management) and mitigation protocols established.

6 - CO_2 Leakage Risks and Environmental Concerns

Potential Risks:

- Anomalous CO_2 migration through geological faults and fractures systems reactivated by injection.
- CO_2 accidental releases from pipeline (leakage scenarios).
- Impact on marine ecosystems and water quality in case of leaks.

Mitigation Strategies:

- Enhanced seismic monitoring for sensitivity to Low-Magnitude Events (DAS).
- Need for high-resolution sensors to detect small seismic activities.
- Managing background noise in the Adriatic Sea environment.
- QRA (Quantitative Risk Assessment).

Residual Risk Management:

- Emergency response protocols for rapid intervention.

8- Micro-seismic Monitoring

Purpose:
- Detect and analyze seismic activity related to CO_2 injection due to different behavior between injection and extraction.

Technology:
- Seismic sensors installed offshore and onshore.
- Distributed Acoustic Sensing (DAS) technology also used to integrate network microseismic data in an experimental way.

Data Use:
- Provides real-time insights into reservoir stability and injection impacts.

9- Ground Deformation Monitoring

Techniques Used:

- GNSS (+ SAR corner reflections) stations and leveling surveys onshore and offshore.
- Continuous monitoring of surface movements and subsidence risks.

Key Objectives:

- Detect micro-movements that may indicate reservoir stress.
- Prevent potential infrastructure damage.

10- Well Monitoring

In-Well Instrumentation:
- Flow Rate/Pressure and temperature sensors installed in the injection well.
- Fluid sampling and analysis tools to track CO_2 behavior.

CO_2 Plume Tracking into other 2 monitoring well
- Flow Rate/Pressure and temperature sensors
- Use of Pulsed Neutron technology for detection of CO_2 movement.

In-well measure will allow monitoring the movement and arrival of the CO_2 plume at the two selected monitoring wells with the aim of verifying the predictive accuracy of the developed 3D dynamic reservoir model

11 - Pipeline monitoring

CO_2 Transport Safety:

- Continuous pressure and flow monitoring along the pipeline in order prevent loss of containment
- Automatic shutdown systems in case of anomalies.
- Continuous removing H_2O from CO_2 streams in order to prevent corrosion

Standard Protocols:

- Regular pipeline integrity assessments.
- Defined standards for CO_2 transport in pipeline (in ratification).

12- Onshore Environmental Monitoring

Air Quality Monitoring:

- Continuous measurement of atmospheric emissions, including amine, VOC CO_2 and other pollutants.
- CO_2 Stream Continuous Monitoring
- PM10 monitoring during construction phase.

Water Monitoring:

- Monitoring for chemical pollutants in waste water

Those monitoring measures were added in the revision of the Integrated Environmental Authorization (IEA)

13- Off-shore Environmental Monitoring Plan: Requirements

Adaptability

- Multidisciplinary and dynamic Approach.
- The plan can be modified based on real-time data.
- Proactive adjustments to address emerging risks.

Compliance with legislative and permit requirements

- Adherence to Legislative Decree 162/2011 and EU CCS Directive 2009/31/EC.
- Mandatory communication of monitoring results to Ministry of Environment and CCS Commitee.

Post-Closure Monitoring

Long-Term Monitoring:

Annual inspections for three years post-closure and at least once every five years after responsibility transfer.

Objectives:

- Ensure long-term stability of the storage site.
- Validate permanent CO_2 containment.

14- Offshore Environmental Monitoring: Structure

Objectives of the Off-shore Environmental Monitoring Plan

- Characterize baseline environmental conditions before CO_2 injection (ante-operam).
- Monitor potential leakage and detect anomalies in sediment, water column, and marine biota (*ante operam, in-operam and post-operam*).
- Assess short and long-term ecological impacts.
- Develop models for CO_2 dispersion and ecosystem responses.

The EMP is structured into **n. 8 Work Packages** (WPs) subdivided in **tasks**:

WP1: Seafloor and Water Column Geophysics

WP2: Leakage Quantification

WP3: Physical, Chemical, and Biogeochemical Water Column Analyses

WP4: Physical, Chemical, and Ecotoxicological Sediment Investigations

WP5: Continuous Monitoring Stations

WP6: Modeling

WP7: Biota Investigations

WP8: Environmental Risk Assessment

15 - WP1: Seafloor and Water Column Geophysics

Conducts high-resolution surveys using Multibeam Echosounder (MBES), Side Scan Sonar (SSS), and Sub-Bottom Profiler (SBP) to detect morphological and acoustic anomalies in the seabed and water column useful detect the presence of gas in the seafloor and water column, as well as in the identification of bottom forms related to hydrocarbon fluid/gas spills.

Task 1.1 - Seafloor Geophysics

- *Sub-task 1.1.1* - High-resolution bathymetric surveys using MultiBeam Echosounder (MBES) to identify morphological anomalies linked to CO2 seepage.
- *Sub-task 1.1.2* - Seafloor imaging using Side Scan Sonar (SSS) to map sediment composition and morphology.
- *Sub-task 1.1.3a* - Detection of sub-seafloor anomalies using Sub Bottom Profiler (SBP).
- *Sub-task 1.1.3b* - Deep sub-seafloor surveys with Sparker technology to reconstruct geological structures.

Surveys: 1 pre-operam (2023), 2 in-operam (2024/2025), 1 post-operam (2025)

Task 1.2 - Water Column Geophysics

- CO2 leakage mapping through MBES surveys.

Surveys: 1 pre-operam (2023), 2 in-operam (2024/2025), 1 post-operam (2025)

16 – WP2: Leakage quantification

Implements acoustic surveys (bubble acoustic surveys) with echosounders and hydrophones to identify and quantify, by means CO_2 seepage detection test with controlled flow rate, potential CO_2 seepage from the seabed into the water column.

Task 2.1 - Acoustic Surveys (SIMRAD EK80 Echo Sounder)
- Identification and quantification of natural and potential storage-induced CO_2 leaks.
Surveys: 1 pre-operam (2024), 1 in-operam (2024), 1 post-operam (2025)

Task 2.2 - Continuous Acoustic Monitoring
- Continuous broadband hydrophone surveys linked to WP5.
missions: 2 pre-operam (2023/2024), 2 in-operam (2024/2025), 2 post-operam (2025/2026)

17 – WP3: Physical, Chemical, and Biogeochemical Water Column Analyses

Monitors temperature, salinity, pH, dissolved oxygen, and carbonate system parameters to assess potential changes resulting from CO_2 leakage.

Task 3.1 - Physical and Chemical Properties (CTD Sensor)
- Multi-parametric CTD probe used to measure water column parameters.
Surveys: 3 pre-operam (2023/24), 3 in-operam (2024), 4 post-operam (2025/26) in 45 sample points

Task 3.2 - Biogeochemical Properties (Niskin Bottle Water Sampling)
- Analysis of carbonate system alterations due to CO_2 release.
Surveys: 3 pre-operam (2023/24), 3 in-operam (2024), 4 post-operam in 18/45 sample points x 2 different depths

Task 3.3 - Phytoplankton Community
Surveys: 3 pre-operam (2023/24), 3 in-operam (2024), 4 post-operam (2025/26) 18/45 sample points x 2 different depths

Task 3.4 - Zooplankton and Ichthyoplankton Community
Surveys: 3 pre-operam (2023/24), 3 in-operam (2024), 4 post-operam (2025/26) 18/45 sample points x 2 different depths

18 – WP4: Physical, Chemical, and Ecotoxicological Sediment Investigations

Evaluates the impact of CO_2 injection on sediment composition, toxicity, and associated benthic organisms.

Task 4.1 - Sediment Physical and Chemical Analysis
- Characterization of sediment properties.

Surveys: 2 pre-operam (2023/24), 2 in-operam (2024), 2 post-operam (2025/26) in 19/51 sample points (0-10 cm)

Task 4.2 - Benthic Chamber and Water-Sediment Interface
- Measurement of dissolved carbon fluxes and early diagenesis processes.

Surveys: 2 pre-operam (2023/24), 2 in-operam (2024), 2 post-operamn (2025/26) 3 station points x 24h

Task 4.3 - Sediment Ecotoxicology
- Multi-species and multi-endpoint toxicity tests following regulatory standards.

Surveys: 2 pre-operam (2023/24), 2 in-operam (2024), 2 post-operam (2025/26) in 19/51 sample points (0-10cm)

Task 4.4 - Biological Responses in Marine Organisms
- Benthic foraminifera analysis for Ecological Quality Status (EcoQS).
- Surveys: 2 pre-operam (2023/24), 2 in-operam (2024), 2 post-operam (2025/26) in 19/51 sample points (0-1 cm)

19 – WP5: Continuous Monitoring Stations

Deploys fixed monitoring platforms (Benthic Lander) equipped with sensors to collect real-time environmental data over extended periods for comparing and tuning with other data collected

This Work Package (WP) aims to collect useful data for monitoring through current measurements in the water column, acoustic measurements (hydrophones – Task 2.2), and the continuous collection of chemical data at the seabed level, at multiple points within the storage site characterized by potential significant CO_2 leakages. The monitoring results will support the interpretation of the data acquired in Task 2.2 and WP 3.

The activities will focus on the management, quality control, and analysis of the data stored by the instrumentation housed in the lander.

Data collection on currents, hydrophone measurements, and chemical parameters:

- Depth/Pressure
- Temperature
- Conductivity
- Dissolved Oxygen
- Fluorescence
- Turbidity
- pH/Redox
- CO_2 (dissolved gas sensors)
- Marine current measurements (using an acoustic Doppler current profiler – ADCP)

Missions: 2 pre-operam (2023/2024), 2 in-operam (2024/2025), 2 post-operam (2025/26)

4-5 month x mission

20 – WP6: Modeling

Develops numerical models to simulate CO_2 dispersion, migration patterns, and potential ecological effects within the marine environment.

The purpose of this Work Package (WP) is to develop a model through the simulation of CO_2 emissions into the sea from natural or induced leakages and to assess CO_2 dispersion and the chemical kinetics of related phenomena.

Using data collected during the pre-operational, operational, and post-operational phases of WPs 1, 2, 3, and 4, an ecological model will be developed to quantify and evaluate the alterations resulting from CO_2 release, including its interaction with the surface marine sediments above the storage area.

In particular, the data obtained during the operational and post-operational phases will be used to validate and optimize the model to achieve more accurate predictive scenarios.

21 – WP7: Biota Investigations

Examines microbial, meiofaunal, macrofaunal, and fish communities to detect biological responses to CO_2 exposure.

Task 7.1 - Benthic Community Studies in sediments
- Analysis of microbial, meiofauna, and macrofauna communities.
Surveys: 2 pre-operam (2023/24), 2 in-operam (2024), 2 post-operam 2025/26 in 19/25 sample points (0-2 cm x 1/3 samples)

Task 7.2 - Fish Population Studies
- Characterization of fish populations to assess potential CO2 leak impacts.
Surveys: 6 pre-operam (2024), 8 in-operam (2024), 12 post-operam (2025/26)

22 – WP8: Ecological Risk Assessments

The purpose of this WP is to conduct a risk analysis on water matrices. The analysis will be based on possible release scenarios and, for the water matrix, on the modeling results from WP6. Comparison matrices will be applied to outline various critical CO_2 release scenarios.

- Impact assessment: Identification of potential negative and positive, direct, indirect, and cumulative impacts, along with related mitigation measures.
- Risk assessment: Identification of potential environmental impacts on the ecosystem linked to events with uncertain or unlikely probabilities.
- Recommendations and conclusions: Summary of the evaluations conducted and any necessary recommendations to minimize the project's potential impact on marine environmental components.

Thanks for your attention

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