

Workflow for Process Automation of Soil Gas Results from an Automated Soil Gas-Sampling System for Application in Carbon Storage Projects

*John E. Hunt, Trevor L. Richards, Xue Yu, and Nicholas A. Azzolina
University of North Dakota Energy & Environmental Research Center*

Summary

The Energy & Environmental Research Center (EERC) is conducting applied research at an active carbon storage project in North Dakota to assess and establish novel monitoring techniques as commercial methods. The program includes designing and deploying an automated, integrated, modular (AIM) monitoring network comprising multiple stations capable of collecting live data streams from multiple environments. Three AIM stations are currently associated with the network. Atmosphere, soil gas, groundwater, and deep subsurface conditions are measured at each station through the AIM approach, which complies with North Dakota underground injection control (UIC) Class VI requirements. The data streams, including soil gas measurements, are transmitted via a cellular network for cloud-based storage so that users can access on-demand and apply postprocessing workflows to disseminate results.

The EERC developed an automated workflow for processing soil gas measurements collected from the automated soil gas-sampling systems deployed across the project site. Raw soil gas measurements are collected from each station every 4 hours and automatically uploaded to a cloud database. The workflow begins by writing code to download the data to a workstation automatically, then the data are published to an online dashboard that visualizes the measurements in time-series plots and a process-based decision-making framework. This automated workflow accelerates the time from data acquisition to decision-making. It supports carbon storage project operators by preparing and delivering a live, standardized dataset for quick analysis and source attribution to provide assurance of containment and overall permit compliance.

AIM Soil Gas Station Overview

The EERC designed and installed soil gas-sampling profile stations at each AIM station. Engineering Design Group LLC (EDG) designed and fabricated the automation equipment, and the EERC installed the equipment. At each station, soil gas measurements are acquired from approximately 5, 10, and 15 feet below the ground surface (bgs). Each station includes a solar-powered automation box with sensors, pumps, and batteries installed aboveground near each profile station. The automation box and profile stations are connected via tubing (Figure 1).

Soil gas measurements are acquired every 4 hours (six times daily). Each measurement is assigned a unique identification number (ID), and the hardware timestamp (date and time) is recorded. The equipment measures carbon dioxide (CO₂) and oxygen (O₂) concentrations. Barometric pressure and air temperature are measured in the automation box and recorded with the CO₂ and O₂ measurements.

Tabular data recording the measurement ID, date and time, barometric pressure, air temperature, CO₂ and O₂ concentrations, and other identifying information are transmitted to a cloud database. These data are available for download through the EDG Client Portal cloud application every 4 hours.

Workflow

This proof-of-concept application includes downloading the data to a local drive at the EERC, preprocessing using the open-source statistical software R (R Core Team, 2024), and display in an online dashboard using FastAPI (FastAPI, 2024). The entire workflow is automated and can be deployed to work entirely in the cloud.

The CO₂ and O₂ sensors used in the soil gas-monitoring system are unaffected by barometric pressure or temperature effects. Therefore, no adjustments to the raw (as acquired) measurements are made.

Time-series plots at each station and depth (5, 10, and 15 ft bgs) of the CO₂ and O₂ measurements are plotted in the dashboard to visualize trends. The user can select a date range to limit the time series. In addition, crossplots of the corrected CO₂ and O₂ measurements are generated to place the concentrations into a decision-making framework based on the stoichiometric relationships between CO₂ and O₂ in biological respiration (Eq. 1) and methane oxidation (Eq. 2) (Romanak and others, 2012, 2014).

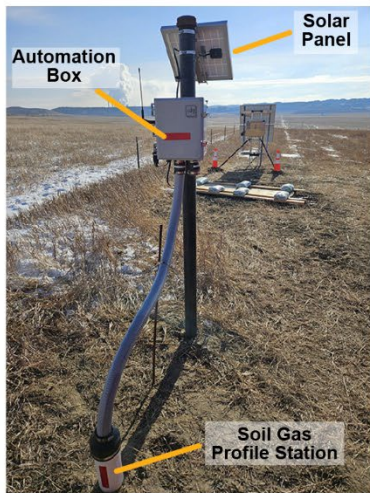


The plots based on stoichiometry aim to rapidly distinguish a CO₂ leakage signal from natural vadose zone CO₂. The ratio between O₂ and CO₂ is 1 for biological respiration (Eq. 1) and 2 for methane oxidation (Eq. 2). Therefore, soil gas measurements plotting along a slope of -1 reflect soil gas composition associated with biological respiration, while soil gas measurements plotting along a slope of -2 reflect soil gas composition associated with methane oxidation. Soil gas measurements plotting between these lines reflect mixtures of the two processes. Finally, soil gas measurements that plot above the slope of -1 (after measurement error is accounted for) may reflect an exogenous source of CO₂, which could indicate leakage from the storage complex (Figure 1).

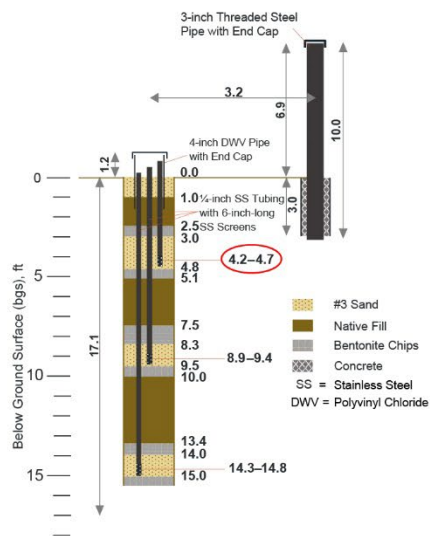
Conclusions

A critical consideration for carbon storage operators is providing assurance of storage permanence. Monitoring technologies are used to detect the injected CO₂ in the storage reservoir and ensure that CO₂ has not migrated above the primary confining zone and into the near-surface or surface environments. An ensemble of monitoring techniques is being tested at the project site. Three automated soil gas-sampling stations are part of this broad monitoring network. These stations operate successfully, providing near-real-time soil CO₂ and O₂ concentration measurements at 4-hour increments at approximately 5, 10, and 15 ft bgs. An automated workflow was developed to access the soil gas measurements through a cloud database, correct the raw measurements for field temperature and pressure measurements, and publish the data to an online dashboard. The early data show conformance with normal soil biological processes, with no indication of CO₂ leakage. As more data are collected, additional time-series functionalities will be incorporated into the dashboard to maximize the information value of the CO₂ and O₂ measurements. This presentation will describe the soil gas-monitoring stations, review the workflow from field measurements to the online dashboard, and show additional results from the recently acquired measurements.

(a) Station #2 Automation Box



(b) Station #2 Diagram



(c) Decision Framework

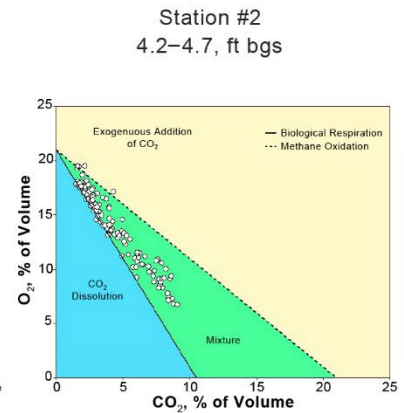


Figure 1. Illustrative figure showing a photo of the solar panel, automation box, and tubing above the ground surface (a), diagram for one of the soil gas-sampling profile stations (b), and an example CO₂ versus O₂ crossplot with the decision fields for biological respiration and methane oxidation for Station #2 acquired at 4.2 to 4.7 ft bgs (c). Additional time-series plots are available to the user through the dashboard. Measurement error is not accounted for in the illustration.

Acknowledgments

This material is based upon work supported by the U.S. Department of Energy under Award Number DE-FE0024233.

References

- FastAPI, 2024, <https://fastapi.tiangolo.com/> (accessed January 2025).
- R Core Team, 2024, R—a language and environment for statistical computing: R Foundation for Statistical Computing, Vienna, Austria, www.R-project.org/ (accessed January 2025).
- Romanak, K.D., Bennett, P.C., Yang, C., and Hovorka, S.D., 2012, Process-based approach to CO₂ leakage detection by vadose zone gas monitoring at geologic CO₂ storage sites: *Geophys. Res. Lett.*, v. 39, L15405, doi:10.1029/2012GL052426.
- Romanak, K.D., Wolaver, B., Yang, C., Sherk, G.W., Dale, J., Dobeck, L.M., and Spangler, L.H., 2014, Process-based soil gas leakage assessment at the Kerr Farm—comparison of results to leakage proxies at ZERT and Mt. Etna: *International Journal of Greenhouse Gas Control*, v. 30, p. 42–57, ISSN 1750-5836, <https://doi.org/10.1016/j.ijggc.2014.08.008>.