Energy & Environmental Research Center (EERC)

SUBTASK 1.6 – BASIN ELECTRIC CARBON STORAGE RESEARCH PROJECT – NOVEL MONITORING TECHNIQUES DE-FE0024233

DOE Closeout Meeting
Date: 10/27/2025
EERC Subtask Manager: Trevor Richards
DOE Technical Monitor: Kyle Smith
Project Period of Performance: 05/01/2023–11/30/2025

Sponsors	Budget	Actual Expenses through 10/15/2025
DOE	$1,399,353	$1,399,353
DOE	$5,100,647	$4,839,426
Total	**$6,500,000**	**$6,238,779**

CURRENT AGREEMENT

EERC–DOE FE/NETL Joint Program on Research and Development for Fossil Energy-Related Resources Cooperative Agreement No. DE-FE0024233

Period of Performance

6/1/2015 – 11/30/2025

Management

- DOE: Isaac Andrew (Andy) Aurelio
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Five Topical Areas

(tasks)

19 Projects (subtasks) Approved to Date

17 Completed

15 Nonfederal Partners to Date

27% Cost Share
(20% contractually required)

PROGRAM TASK STRUCTURE
Current Agreement (24233)

- Task 1 – Carbon Storage R&D
- Task 2 – Carbon Capture R&D
- Task 3 – Oil and Gas R&D
- Task 4 – Strategic Studies
- Task 5 – Support of Office of Fossil Energy’s Evolving Mission

ACKNOWLEDGMENTS

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Great Plains Synfuels — DAKOTA GASIFICATION COMPANY — A BASIN ELECTRIC POWER COOPERATIVE SUBSIDIARY

BASIN ELECTRIC POWER COOPERATIVE — A Touchstone Energy® Cooperative

CARBON VAULT

North American COAL — FREEDOM MINE — THE COTEAU PROPERTIES COMPANY

EERC TEAM

Project Management Team


Trevor Richards


John Hunt


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Current Activity Leads


Kyle McBride


Amanda Livers-Douglas


Don Adams


John Hunt


Justin Kovacevich

Active Seismic

Passive Seismic

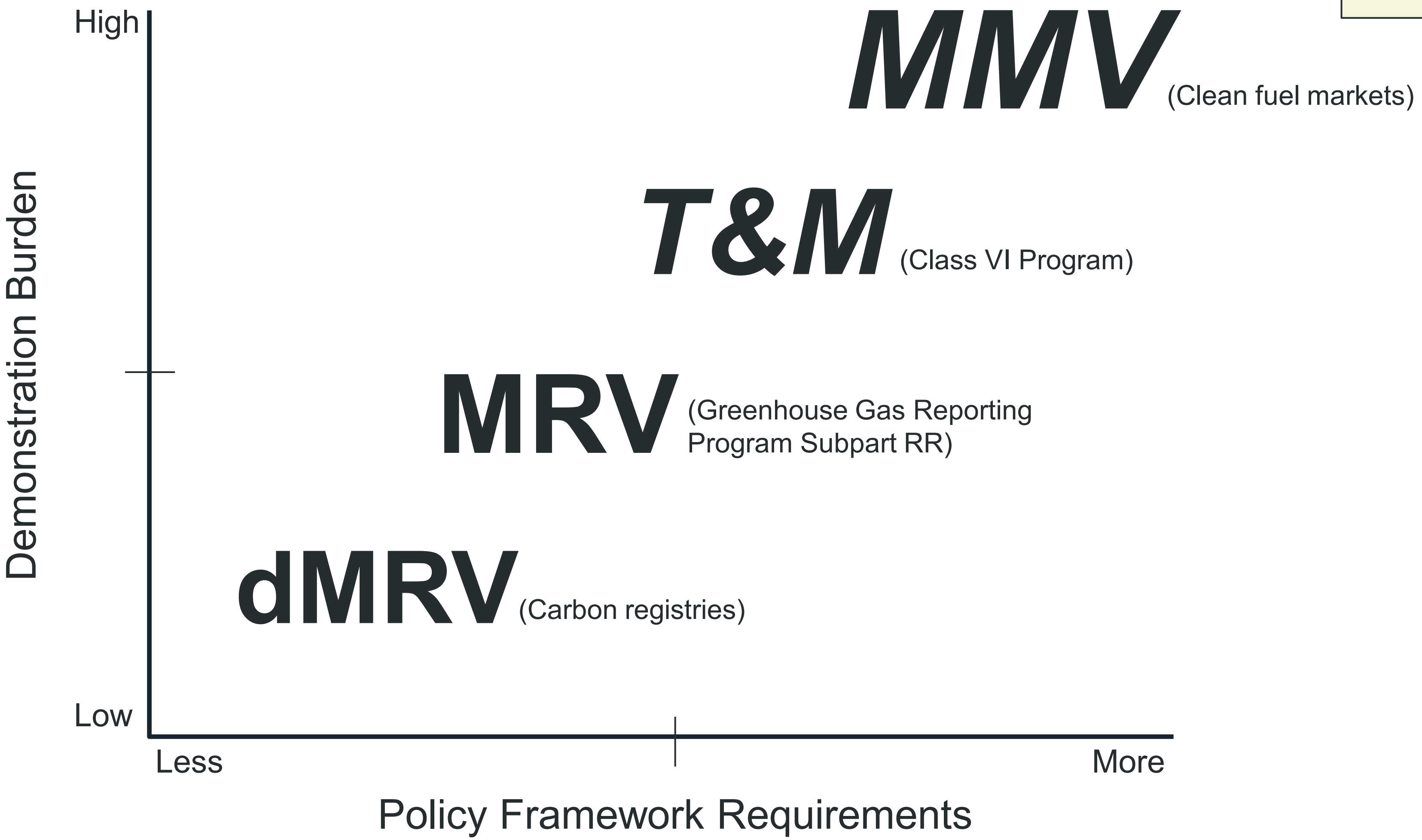
Controlled-Source Electromagnetics

Automated Soil Gas Sampling and Analysis

Drone-Based Surveillance Studies

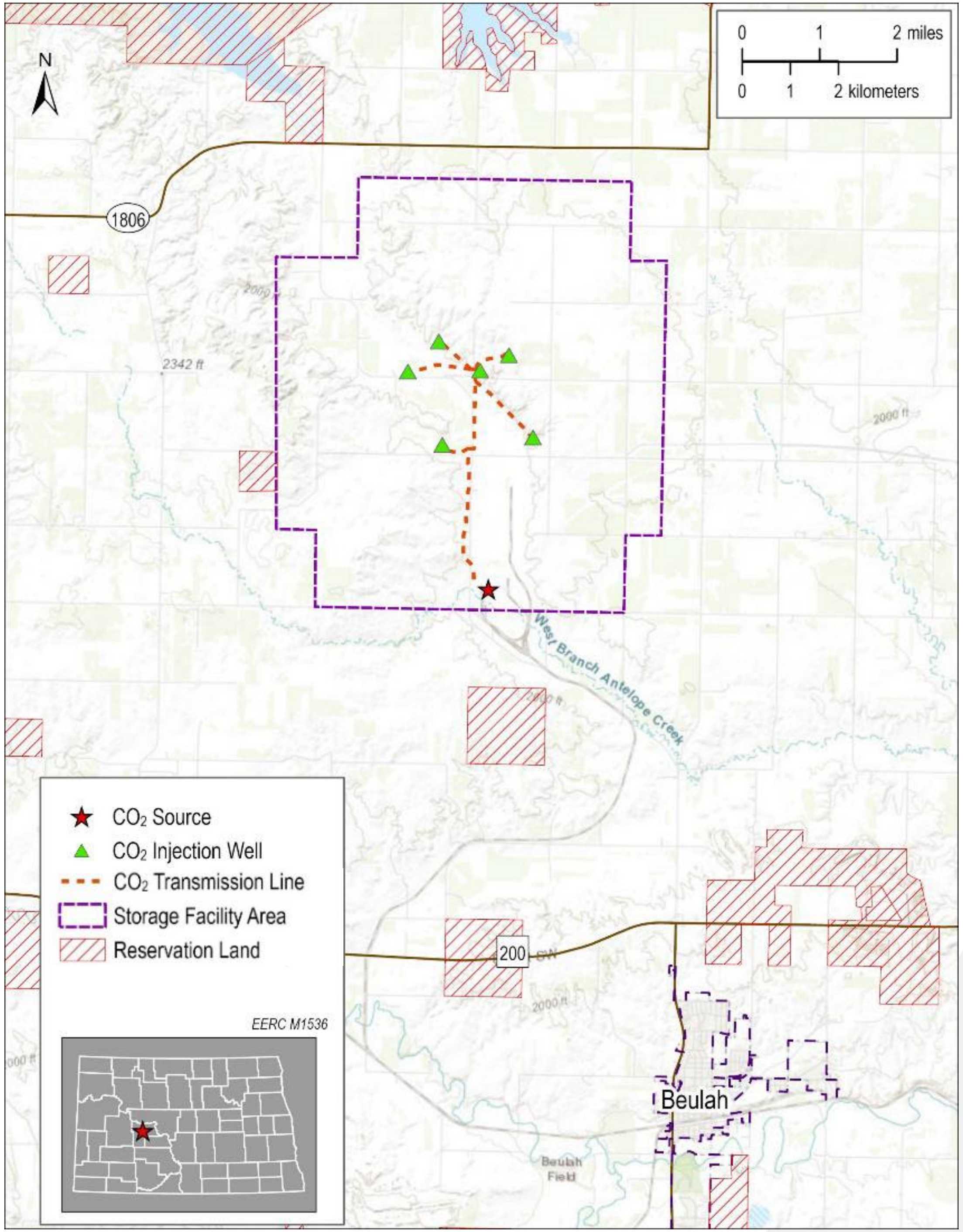
SUBJECT BACKGROUND

A = Accounting
d = Digital
M = Measurement or Monitoring
R = Reporting
T = Testing
V = Verification or Validation



PROJECT LOCATION

Carbon Dioxide (CO_2) Injection Operations in Beulah, North Dakota	
Project Operator	Dakota Gasification Company (DGC)
Project Overview	Largest coal-based carbon storage project operating in the world
Project Status	Operational as of February 9, 2024
Target Volume	~1 to 2.7 million tonnes (MMt) of CO_2 annually over a 12-year period
Volume Injected	>2.5 MMt of CO_2 (first 1.5 years)
Injection Wells	Six injectors
Target Reservoir	Deep saline aquifer ~5900 feet below ground surface
Target Incentives	Secured Subpart RR MRV plan for 45Q credits



EERC | UND UNIVERSITY OF NORTH DAKOTA

INJECTION RESERVOIR

- The Broom Creek Formation is a world-class reservoir.
  - Deep saline aquifer
  - Conventional reservoir properties

Property	Average Value
Lithology	Sandstone
Depth (ft)	5900
Net Thickness (ft)	150
Porosity (%)	25
Permeability (millidarcy)	250
Pressure gradient (psi/ft)	0.50
Temperature (°F)	150
Salinity (ppm)	43,000

GOAL AND OBJECTIVES

Goal:

- Validate novel monitoring techniques for CO_2 injection.

Objectives:

- Deploy technologies that either:
  - Track the injected plume in the reservoir.

  OR
  - Characterize the above-zone interval.

- Realize efficiencies:
  - Cost-effective
  - Lower impact
  - More continuous
  - Faster feedback

Cost-effective

Lower impact

More continuous

Faster feedback

HIGH-LEVEL SUMMARY OF TECHNIQUES

CO_2 Plume-Tracking Techniques

Active Seismic

Passive Seismic

Controlled-Source Electromagnetics

Above-Zone (Assurance) Techniques

Shallow Electromagnetics

Automated Soil Gas Sampling and Analysis

Drone-Based Surveillance Studies

ACTIVE SEISMIC – SOURCE SELECTION

State-of-the-Art Method

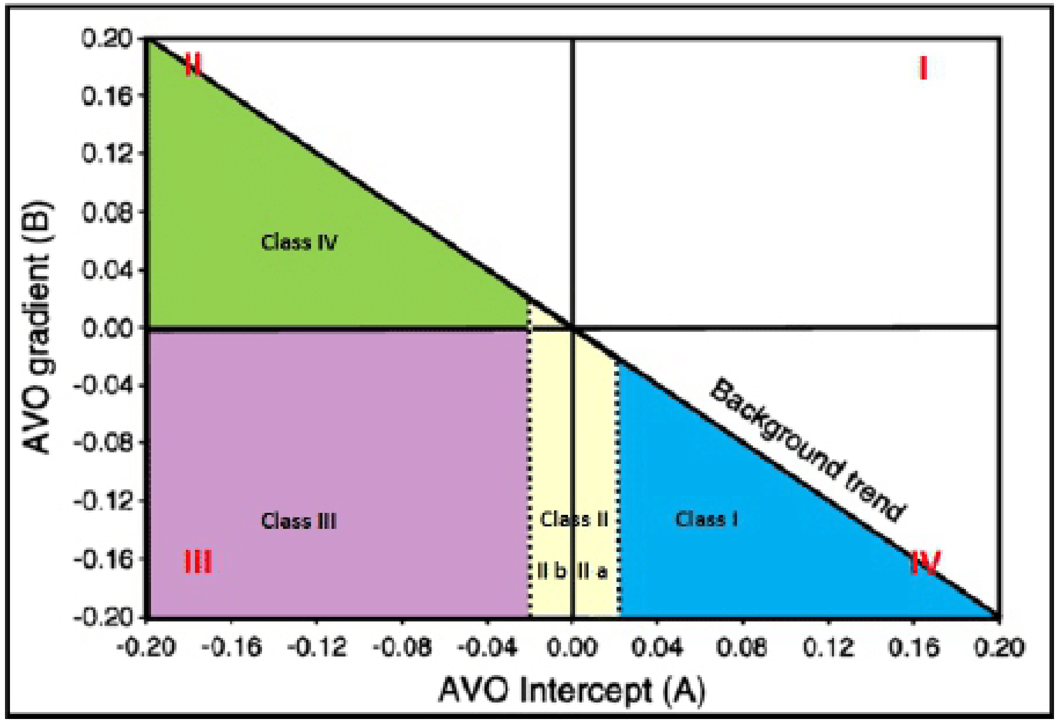
Vibroseis truck used to acquire DGC's commercial 2D survey.

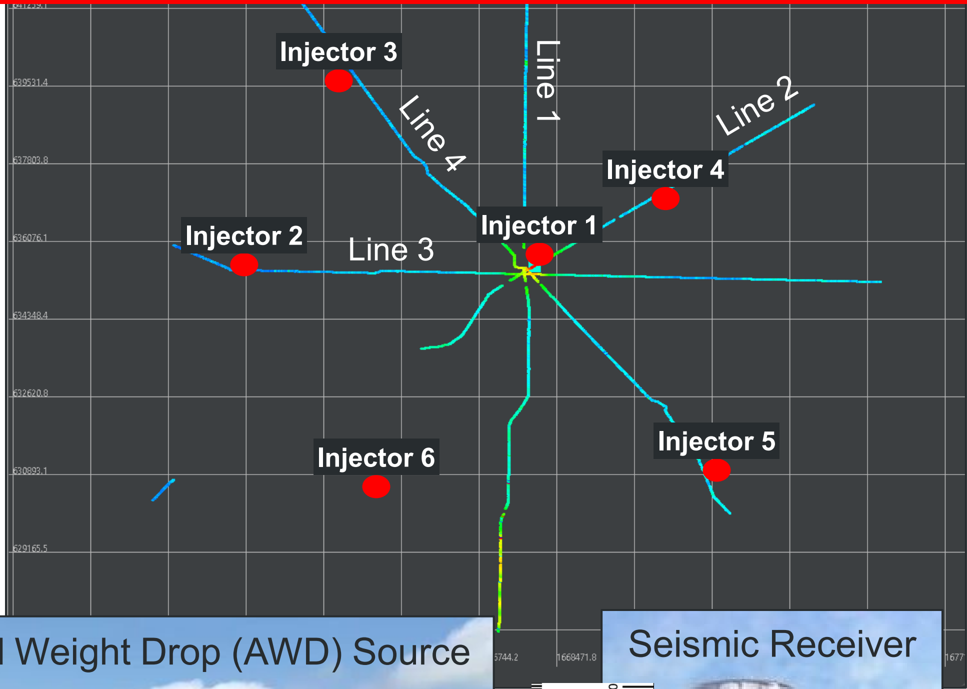
Novel Approach

Accelerated weight drop (AWD) used in this project.

ACTIVE SEISMIC – EXPERIMENT

- Objective: Observe time-lapse changes in the reservoir to track the injected CO_2.
- Used amplitude vs. offset (AVO) to observe time-lapse changes.

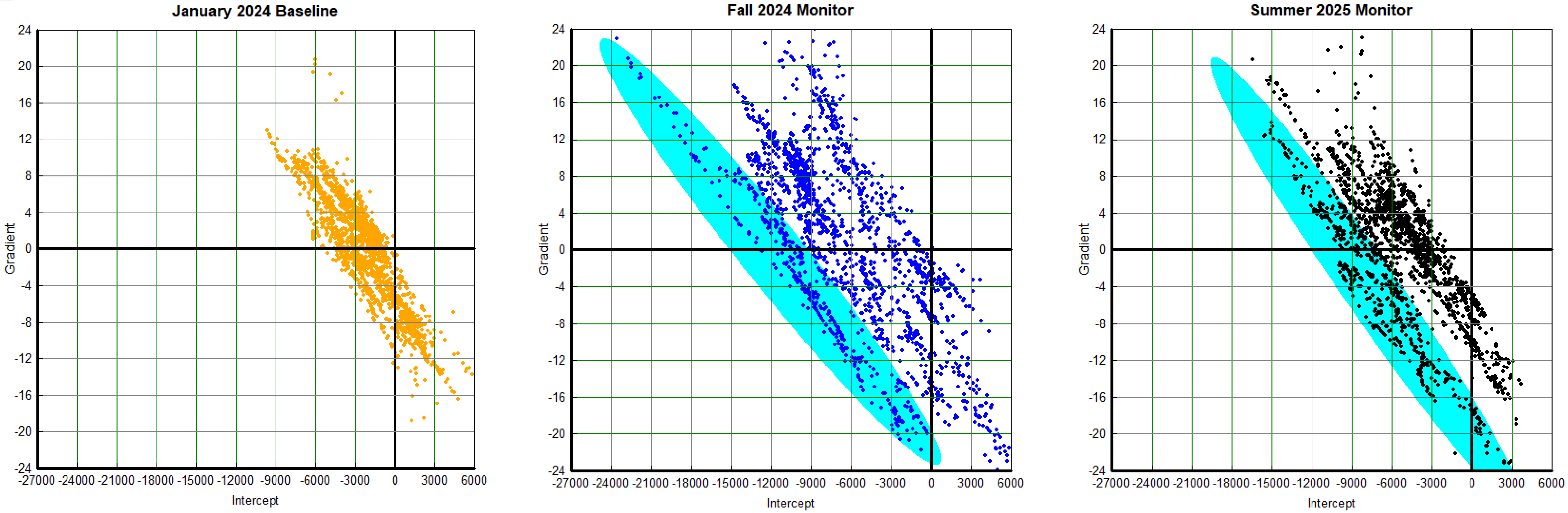




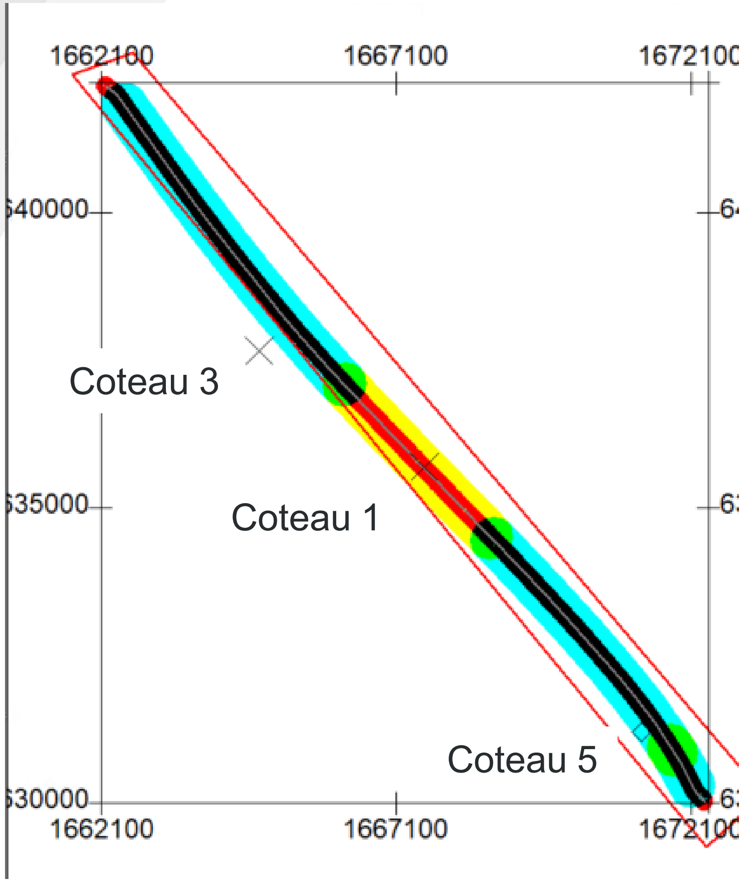
ACTIVE SEISMIC – RESULTS

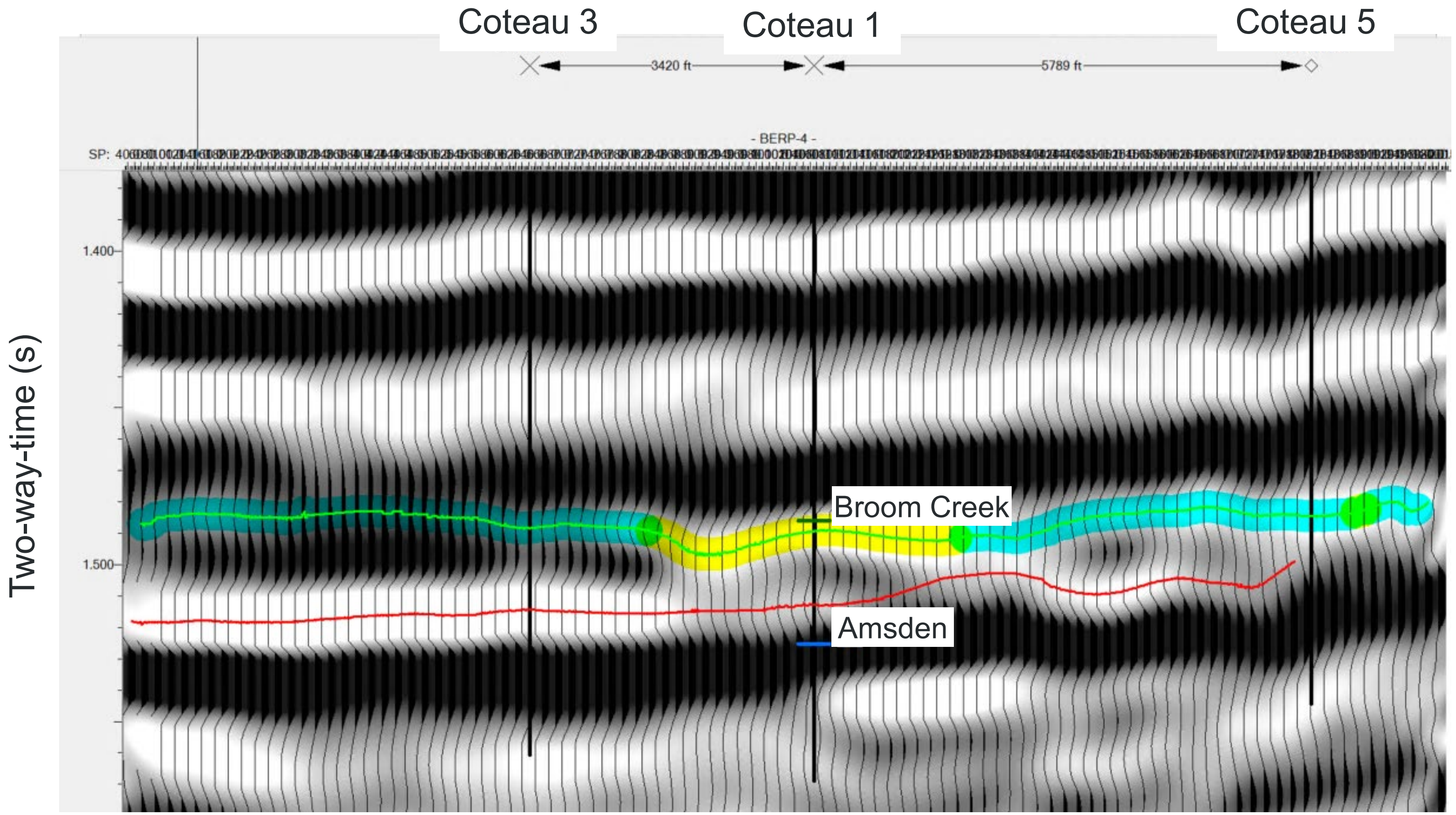
- AVO crossplots show a change in the reservoir's amplitude response that is characteristic of compressible gas after CO_2 injection.

Preinjection (No CO_2) | 7 months of CO_2 Injection | 15 months of CO_2 Injection



ACTIVE SEISMIC RESULTS – SUMMER 2025



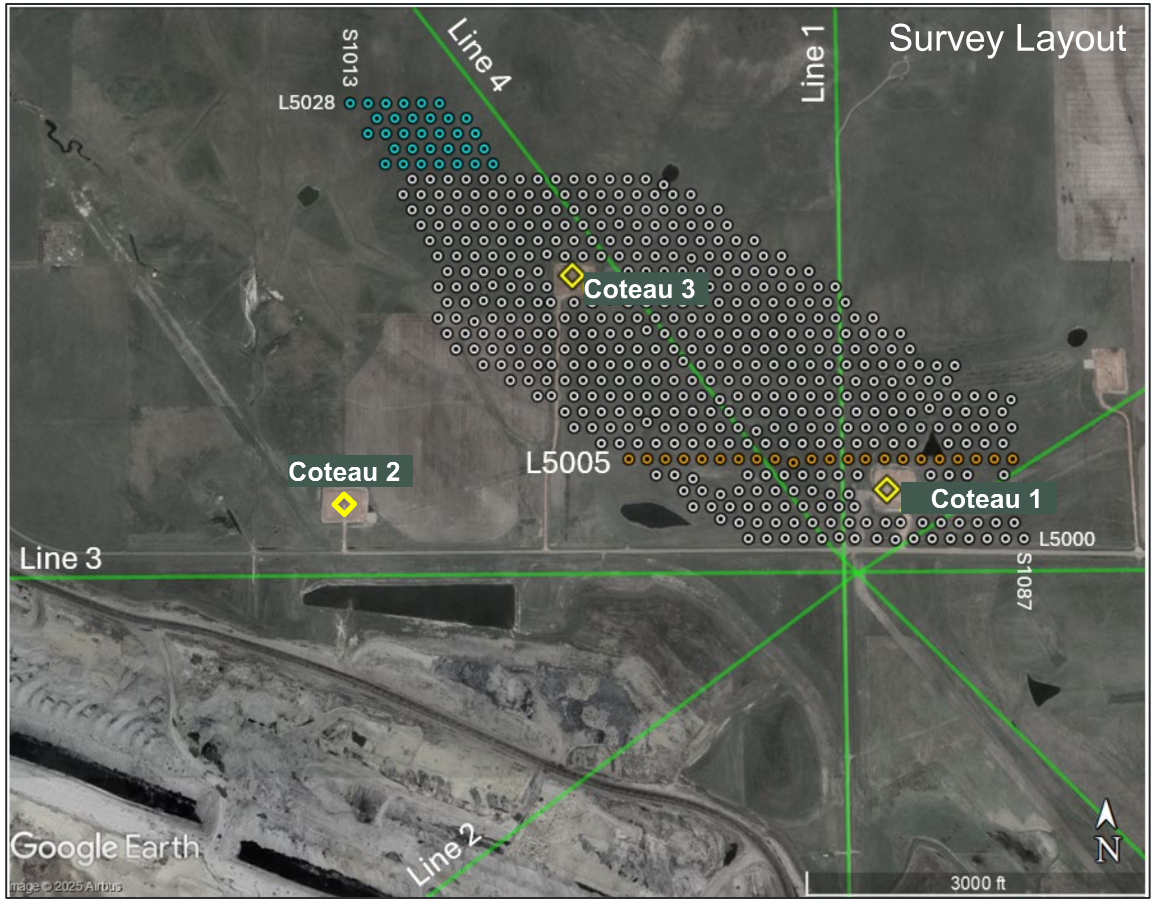


ACTIVE SEISMIC – ACCOMPLISHMENTS

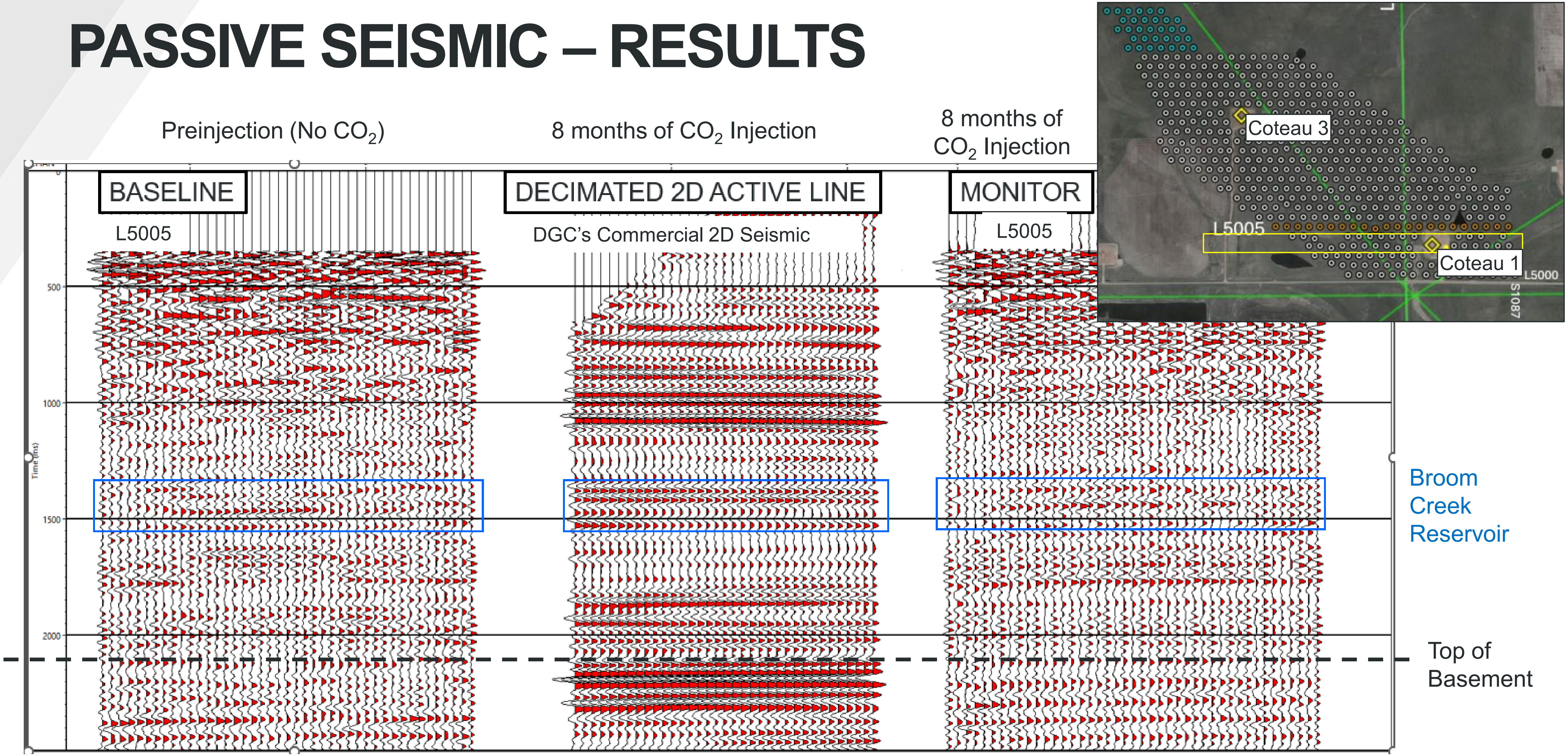
- Deployed a novel technique to track the injected CO_2 that resulted in:
  - High data quality for imaging the reservoir and identifying time-lapse changes that align with the commercial operator's findings from their vibroseis survey.
  - Lower-impact method of acquisition (i.e., lighter, smaller vehicle and source).
  - Reduced the size of the field crew (three to four individuals) involved.
  - Reduced setbacks (fewer data gaps) around infrastructure and small bodies of water.
  - Reduced overall acquisition costs by 1.5 to 2x compared with vibroseis 2D.
- The subcontractor who we worked with at this site has already applied learnings to other projects where the technology is being used to acquire 3D seismic data.
- The EERC recommends testing additional low-impact sources and using the weight drop to collect a 3D survey to determine the efficiency gained for acquiring 3D data compared with traditional vibroseis methods.

PASSIVE SEISMIC – DESIGN

- Objective: Observe time-lapse changes in the reservoir to track the injected CO_2.
- Novelty: **No seismic source**. Used ambient noise (e.g., nearby dam and trains) to generate seismic energy.



PASSIVE SEISMIC – RESULTS

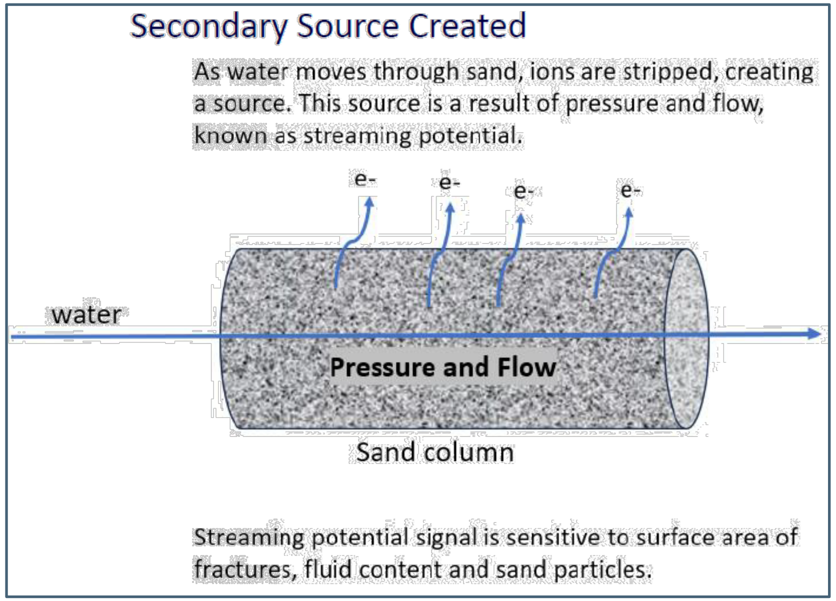


PASSIVE SEISMIC – ACCOMPLISHMENTS

- Deployed a novel technique to track the injected CO_2 that resulted in:
  - Seismic energy reaching the reservoir (and to basement); however, signal-to-noise was not high enough to detect time-lapse changes in the reservoir.
  - Lower-impact method of acquisition (i.e., no active source).
  - Reduced time in the field (four to five individuals over several days putting out and picking up equipment) overall.
  - Broad 3D characterization of the deep subsurface.
  - Similar overall acquisition costs compared with 2D AWD.
- The EERC recommends applying a novel approach to further remove ambient noise from the passive seismic data and potentially observe a time-lapse response, if present in the data. If successful, the EERC would also recommend acquiring a repeat passive survey optimized with more sensors and longer survey length.

CSEM – DESIGN

- Objective: Observe time-lapse changes in the reservoir to track the injected CO_2.
- Novelty: Used streaming potential (SP) to observe time-lapse changes.



CSEM RESULTS – SUMMER 2025

CSEM – ACCOMPLISHMENTS

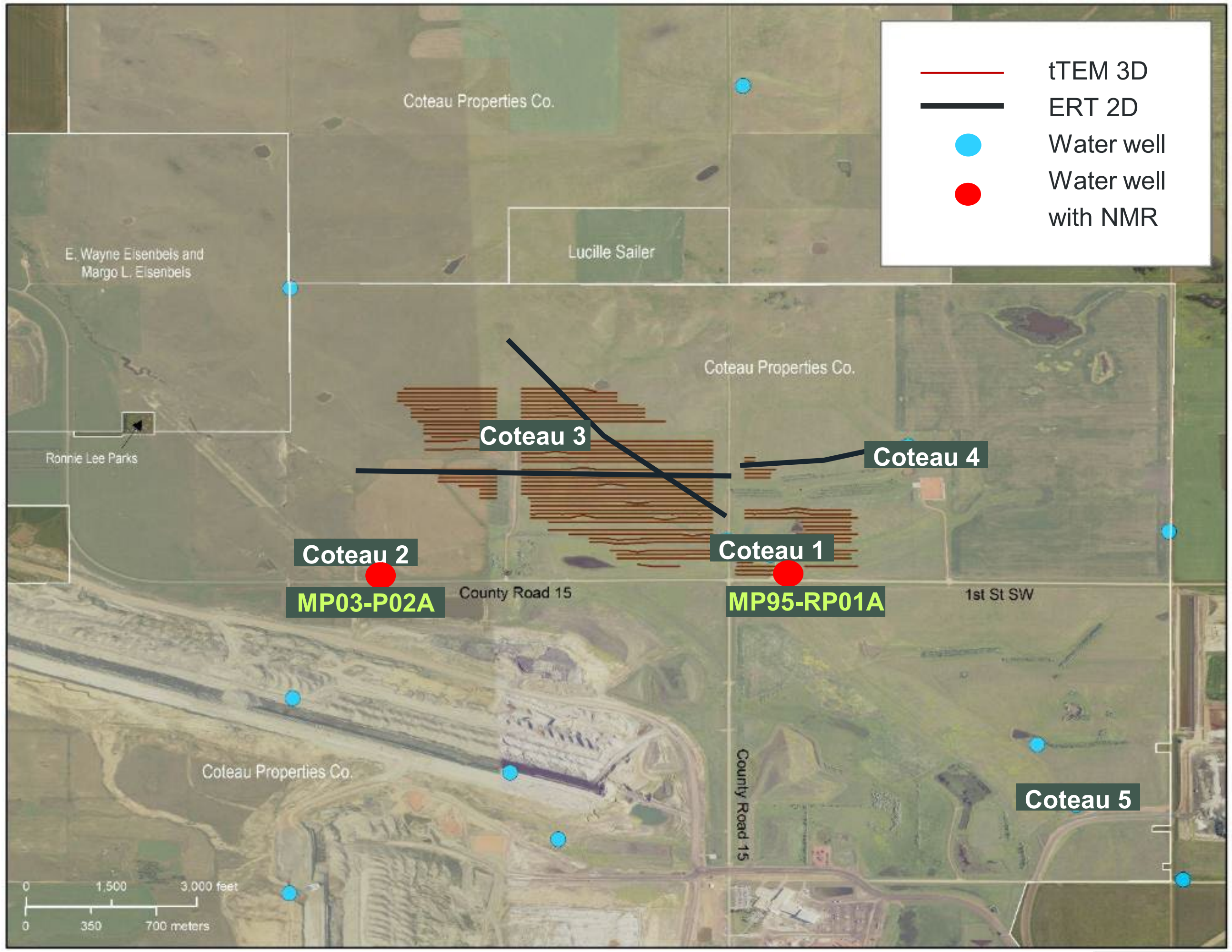
- Deployed a novel technique to track the injected CO_2 that resulted in:
  - High data quality for imaging the reservoir and uniquely shows the interplay of the reservoir's connectivity and response to injection.
  - Interpretations of plume extents that align with the commercial operator's findings from its vibroseis survey.
  - Lower-impact method of acquisition compared with 3D seismic.
  - Similar overall acquisition costs compared with a 3D vibroseis survey.
- Subcontractor who acquired and processed the data reported this is the first time the SP method was acquired by staggering or “toggling” injection between wells to dynamically detect well–well interactions.
- The EERC recommends expanding the survey extents to cover more injection wells for determining the potential far-field effects (preference of the plume to grow in one direction due to higher pressures near injectors).

SUMMARY OF PLUME-TRACKING METHODS

- Based on EERC experience with designing and contracting for seismic acquisition, using a minimal seismic crew with a single weight drop source offers a lower-cost option for acquiring monitoring surveys.
  - Conventional vibroseis acquisition ~1.5–2x more costly than AWD.
  - Weight drop source offers a low-impact alternative for monitoring programs.
- EM surveys are low impact relative to 3D seismic. CSEM survey is similar in cost/square mile to 3D seismic survey. This EM method delivers a map of the total electric field but can be inverted to a time-lapse response from the reservoir.
- Passive seismic survey comparable in cost to the active seismic survey and covers a similar extent. This seismic interferometry result is very low resolution compared with active 2D seismic.

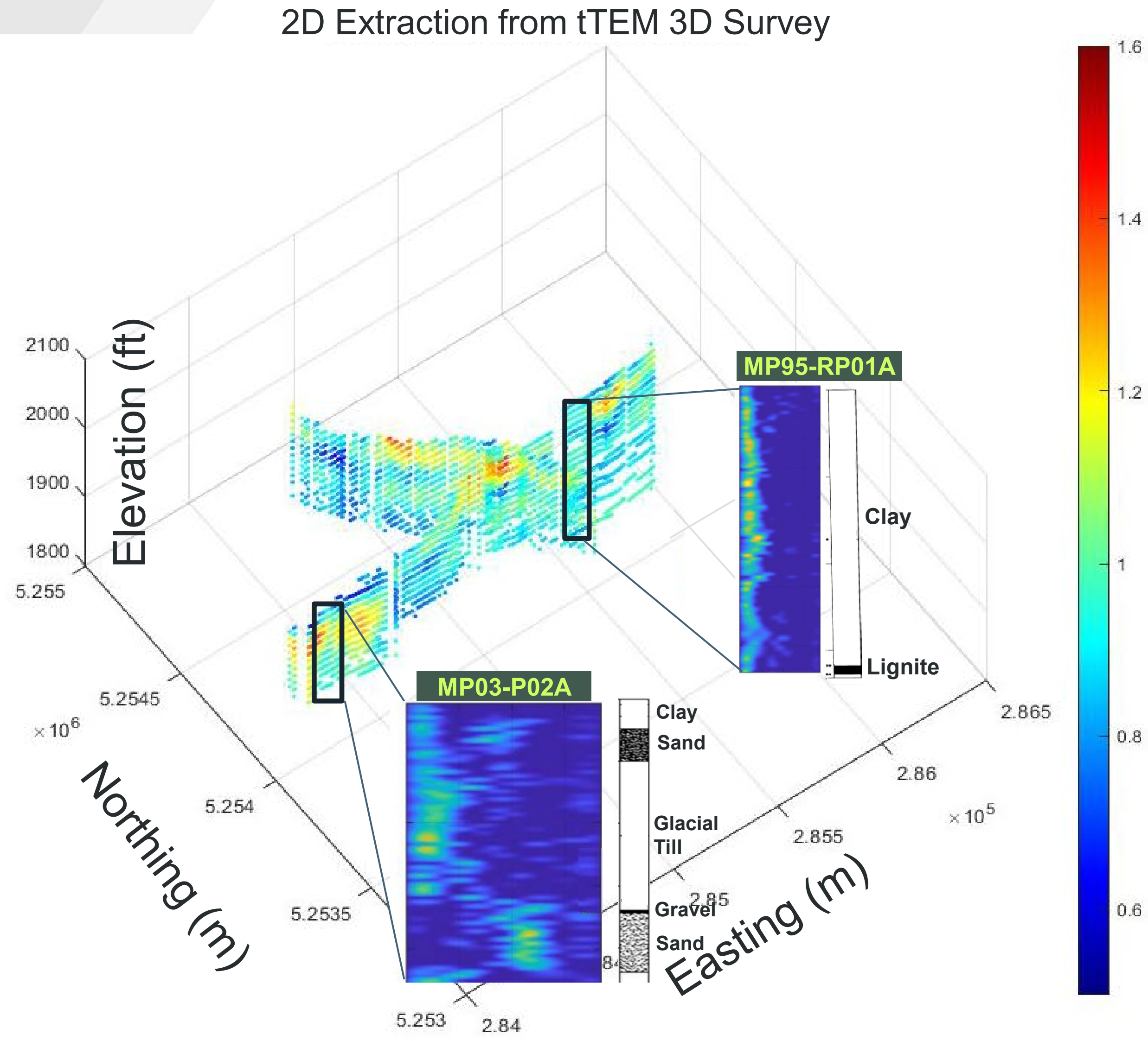
SHALLOW EM – DESIGN

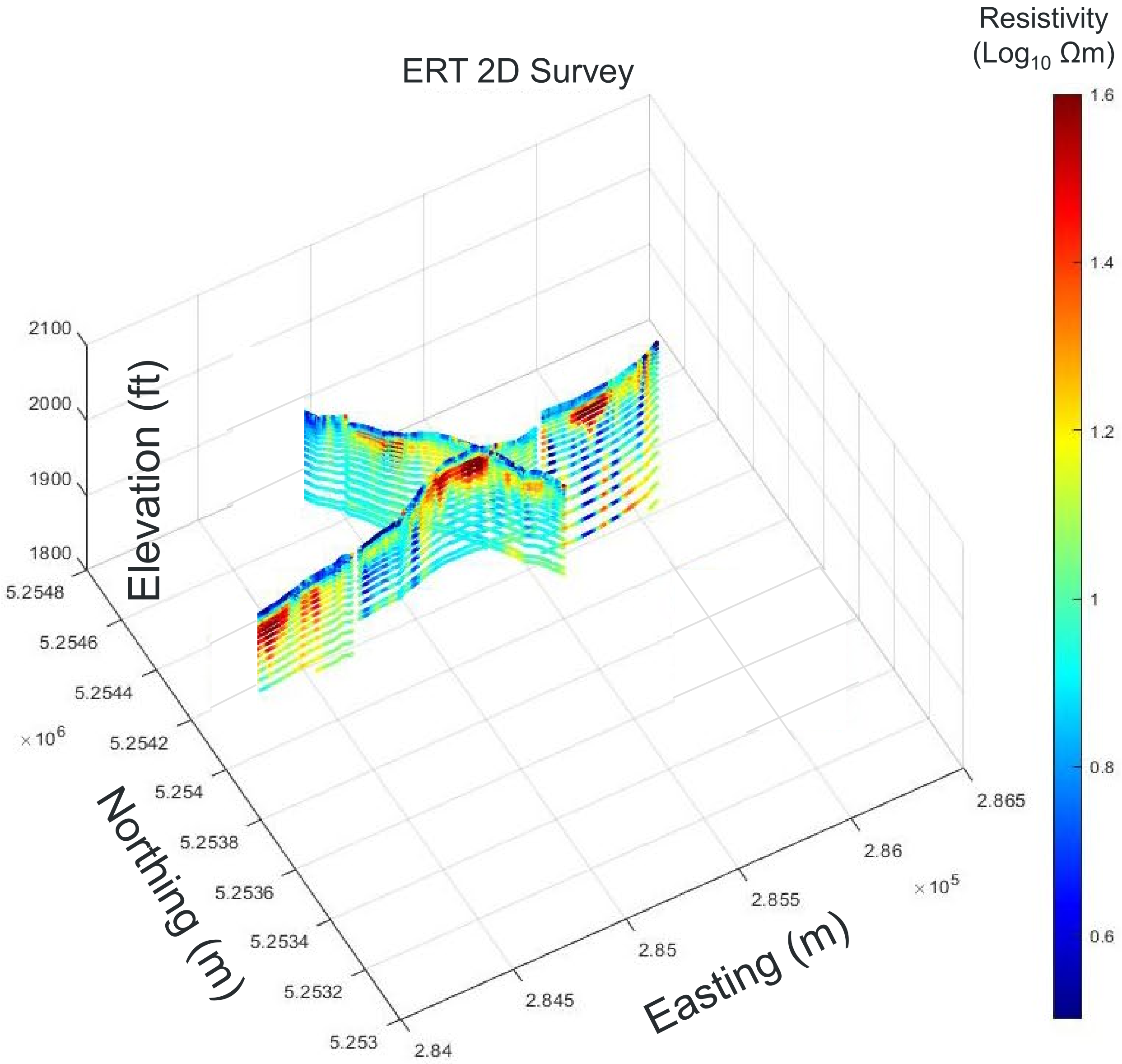
- Objectives:
  - Characterize near-surface lithology and saturation with multiple electromagnetic (EM)-based methods to help with CSEM processing and determine which is superior.
  - These methods are used to establish baselines for periodically monitoring subsurface conditions, such as saturation, which may change in the event of a leak.
- State-of-the-Art Methods:
  - Well-based nuclear magnetic resonance (NMR)
  - 2D electrical resistivity tomography (ERT)
- Novelty: 3D towed-transient electromagnetics (tTEM)



Critical Challenges. Practical Solutions.

SHALLOW EM – RESULTS





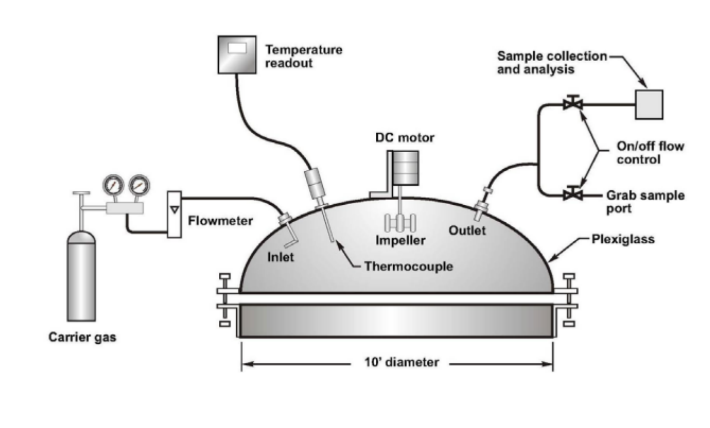
SHALLOW EM – ACCOMPLISHMENTS

- Deployed three EM-based techniques to assist in processing deep EM data:
  - The novel tTEM 3D dataset was fastest to acquire (single day compared to single day per well with NMR and ~1.5 weeks compared to ERT).
  - tTEM produced a 3D volume that looks nearly identical in terms of data quality and coverage when compared in 2D with the ERT survey. Furthermore, tTEM appears to represent geologic layering (horizontal bedding) more realistically.
  - tTEM survey was acquired at ~3x cost savings compared with a conventional 2D ERT survey and had lower impact during acquisition (ERT requires some minor digging of 1–2-ft-deep holes).
  - Faster acquisition means the tTEM results were available much sooner than ERT or NMR.
  - NMR is still useful for varifying whether initial resistivities are due to lithology or saturation effects and provides higher vertical resolution results and quantifies aquifer saturation, porosity, and permeability.
- The EERC recommends using tTEM surveys in the future to acquire this kind of data. In new areas, coupling the method with well drilling to obtain lithologic descriptions and well logs, such as NMR, is helpful for validating shallow EM interpretations.

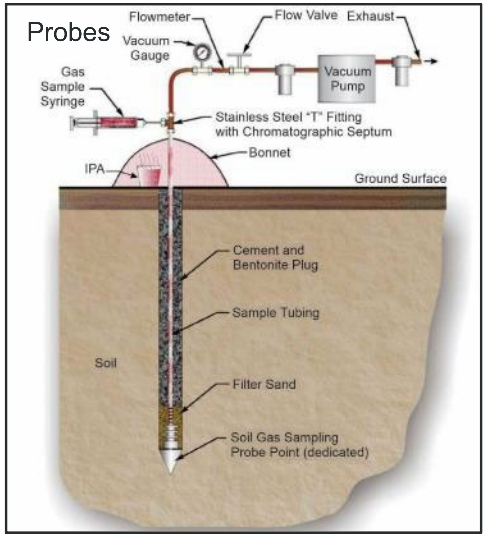
MONITORING WITH AIM

- Objective:
  - Monitor multiple (in- and above-zone) environments with collocated automation equipment, which could indicate signs of leakage.
- Novelty:
  - Develop and deploy a novel soil gas-sampling solution.
- State-of-the-art soil gas methods:

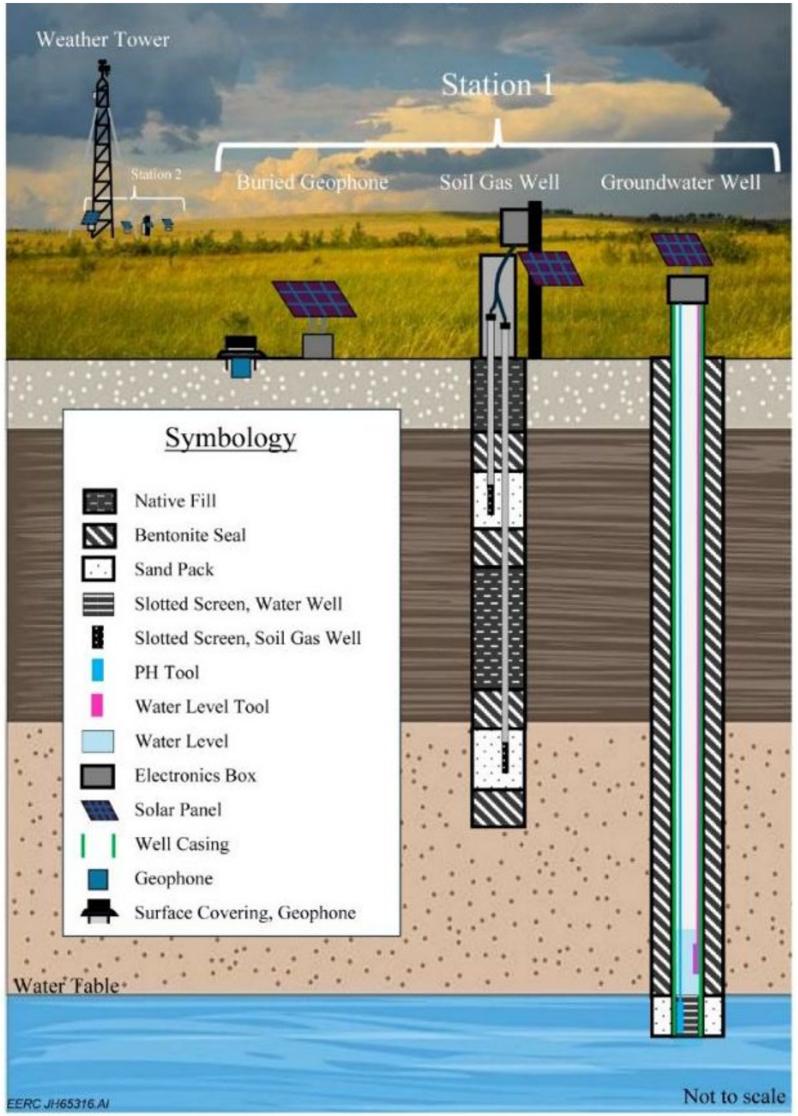
Flux chambers



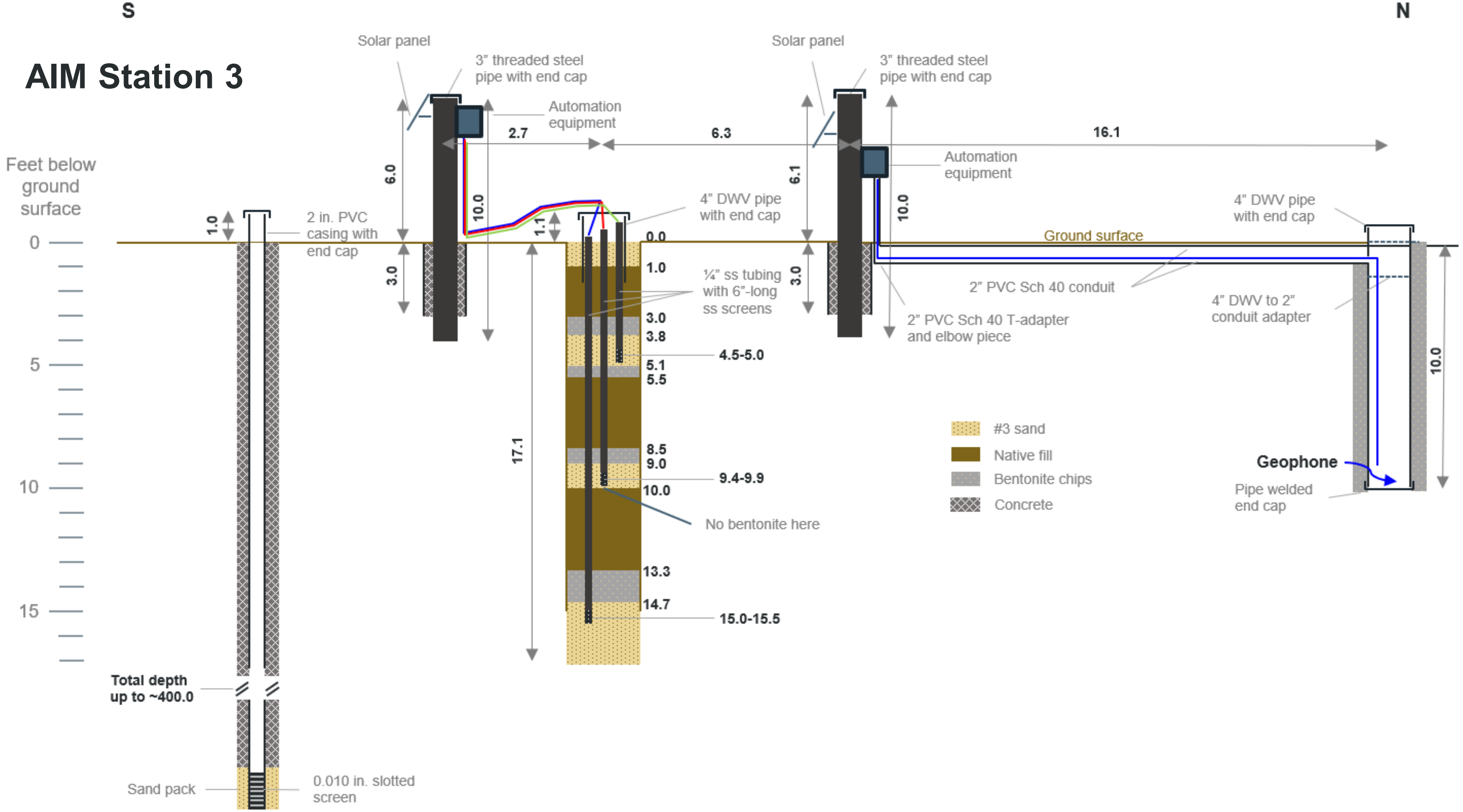
Probes



Automated, Integrated, Modular (AIM) Monitoring Concept



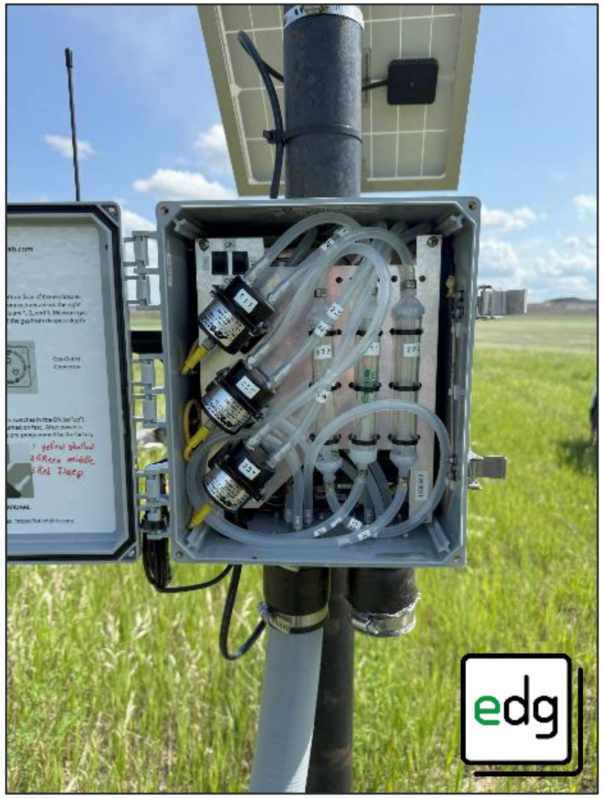
AIM – DESIGN

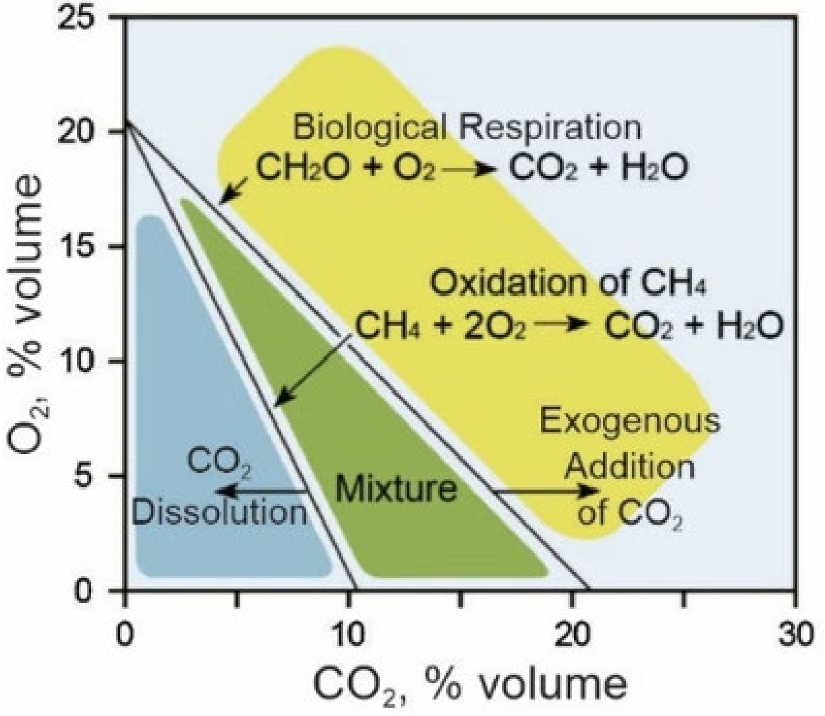

S
N
AIM Station 3
Feet below ground surface
0
5
10
15
Solar panel
3" threaded steel pipe with end cap
Automation equipment
2.7
6.3
16.1
6.0
6.1
10.0
1.0
1.1
3.0
2 in. PVC casing with end cap
4" DWV pipe with end cap
0.0
1.0
3.0
3.8
4.5-5.0
5.1
5.5
8.5
9.0
9.4-9.9
10.0
13.3
14.7
15.0-15.5
17.1
¼" ss tubing with 6"-long ss screens
No bentonite here
Ground surface
2" PVC Sch 40 conduit
2" PVC Sch 40 T-adapter and elbow piece
4" DWV to 2" conduit adapter
Geophone
Pipe welded end cap
#3 sand
Native fill
Bentonite chips
Concrete
Total depth up to ~400.0
Sand pack
0.010 in. slotted screen

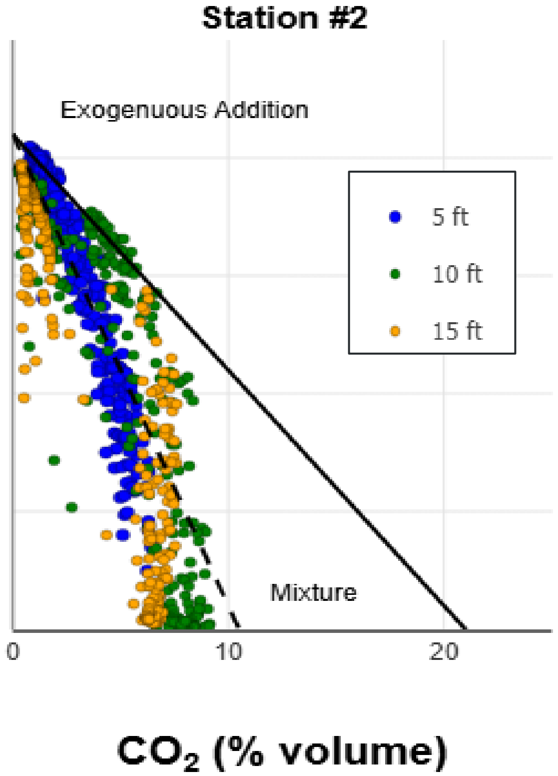

T146NR 88W
T145NR 88W
Station 1
Station 2
Station 3
CNTY RD 15
60TH
2ND

SOIL GAS RESULTS – SOURCE ATTRIBUTION

- Results indicate no leakage, and a mix of background processes are observed.







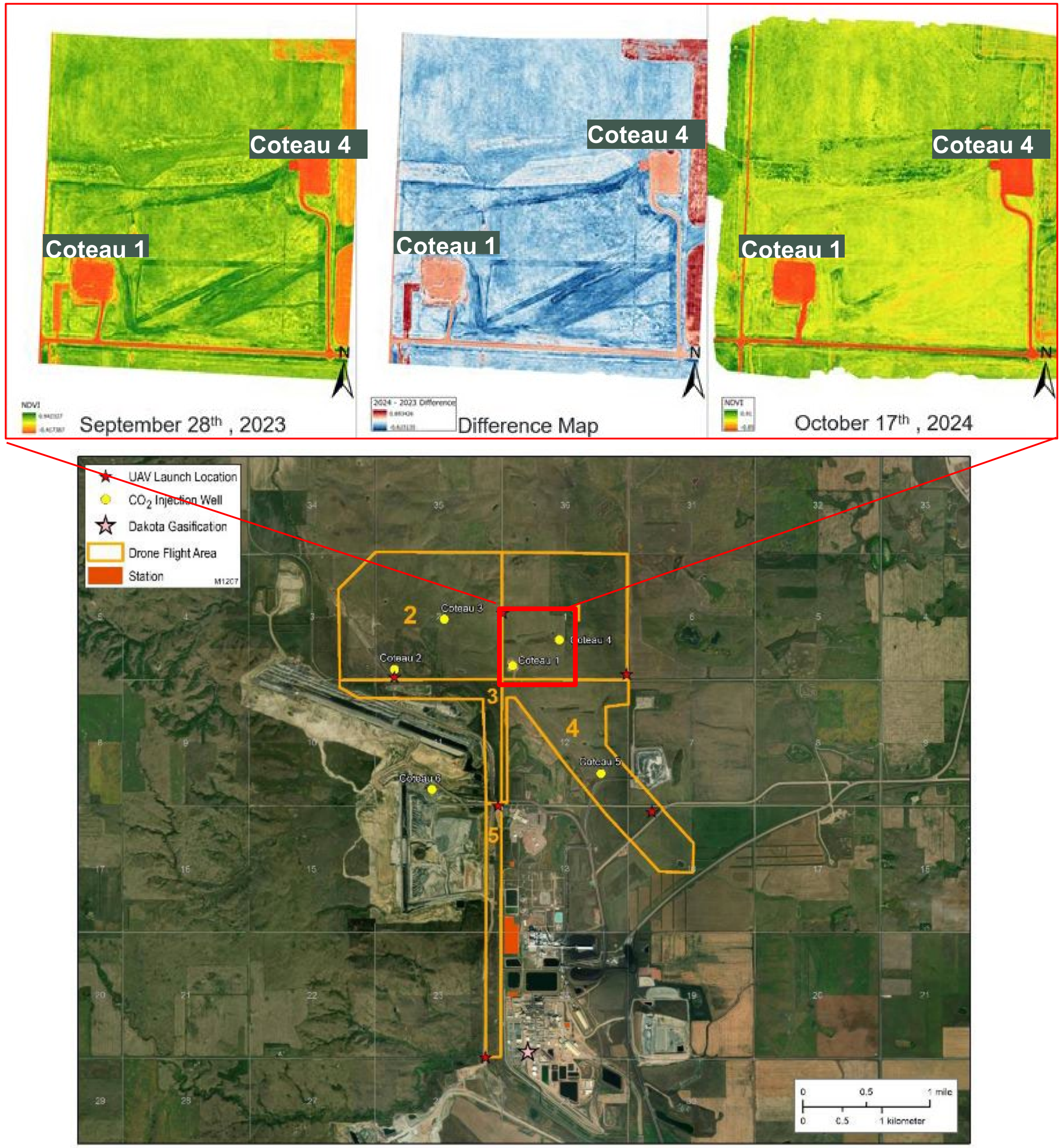
AIM – ACCOMPLISHMENTS

- Deployed three AIM stations to continuously monitor multiple environments:
  - Validated a system capable of monitoring both air and soil gas accurately in near-real time and maintained up-time above 99%.
  - The AIM concept supports placement of additional sensors (e.g., seismometers) for maintaining a low-impact monitoring plan.
  - Developed a dashboard tool that retrieves results from the field within 15 minutes of measurement and plots them for quick visualization and identification of potential anomalies.
  - Results were verified with commercial lab testing, which confirmed acceptable conformance (within 2% by volume) between methods.
  - Air/soil gas automation equipment estimated to generate a 2.5–3x cost savings per station deployed within the first 5 years of monitoring compared to traditional manual sampling probe methods.
- The equipment supplier reported that they have entered into multiple contract agreements with clients both in and outside of the United States to install this equipment at other sites for both research and commercial CO_2 injection operations.
- The EERC is very interested in installing more of these air/soil gas-monitoring stations at other sites and climates to further test the equipment and continue developing the dashboard tool to incorporate more novel ways to disseminate the data and generate decision frameworks.

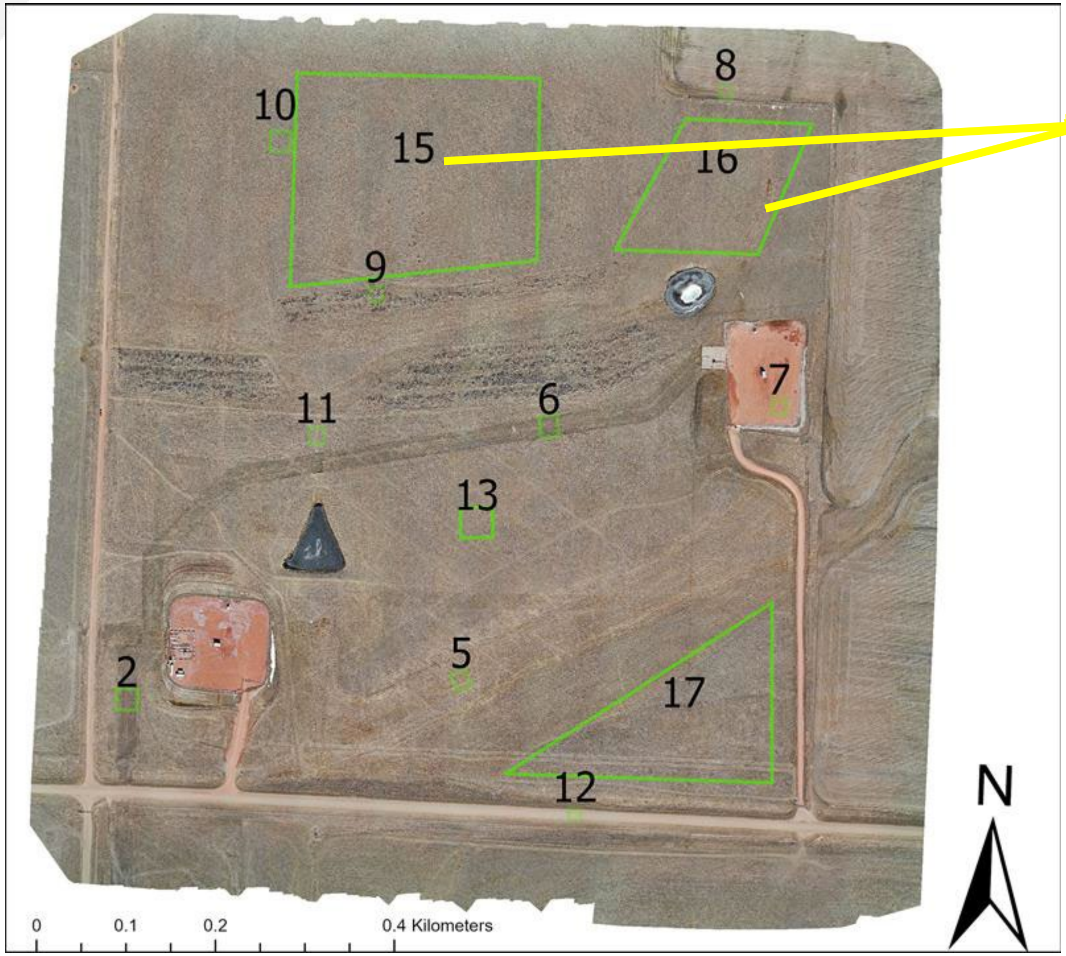
DRONE – DESIGN

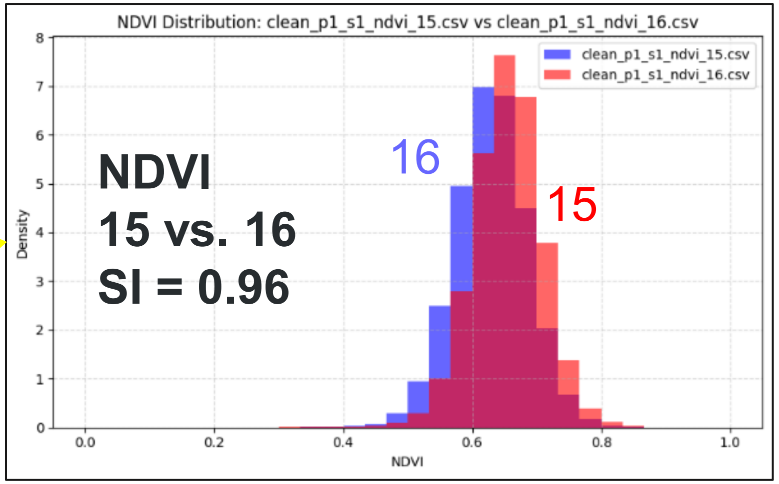
- Key objective:
  - Monitor surface conditions for potential signs of leakage using multispectral imaging.
- State-of-the-art method:
  - Satellite-based imagery coupled with subarea definition and statistical prediction limits.
- Novelty:
  - Determine a novel workflow to help investigate any anomalies detected.

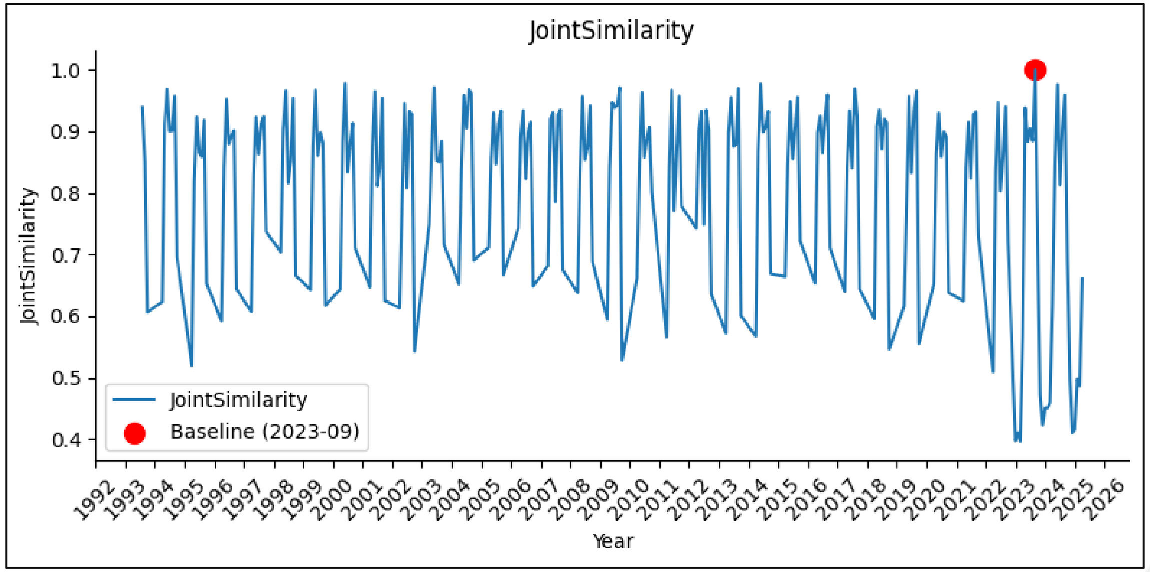
Drone equipment



DRONE – RESULTS

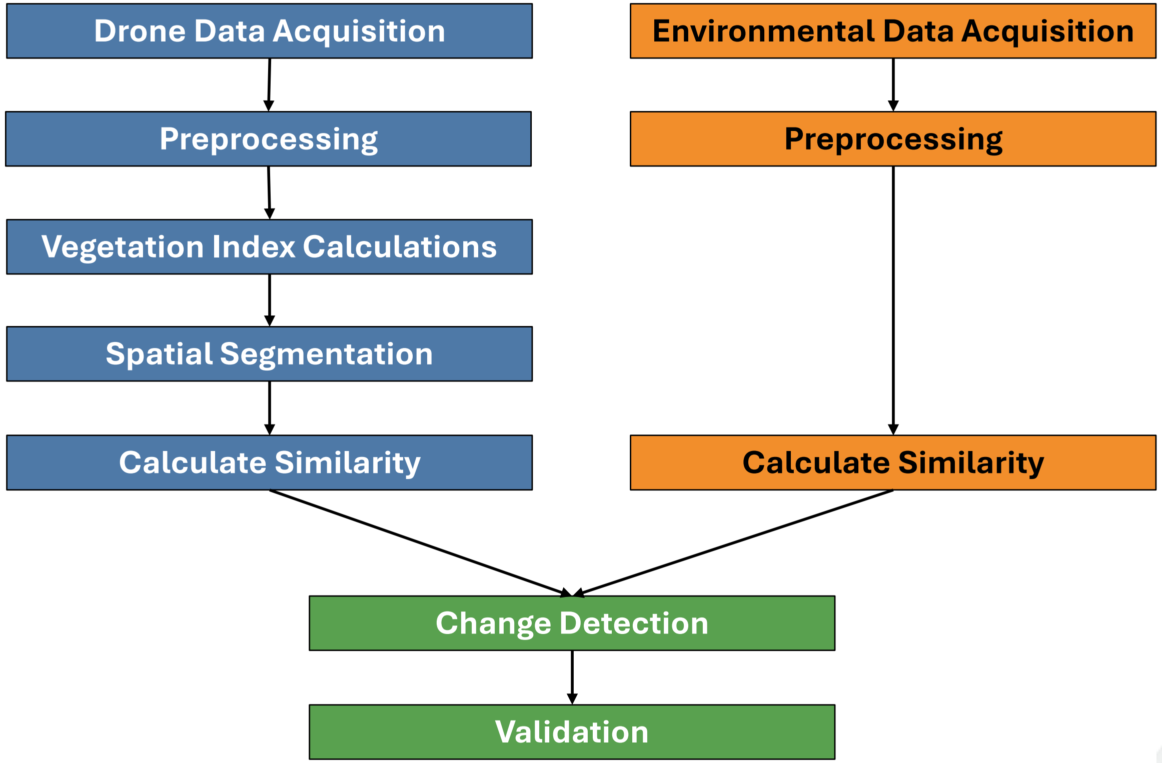






DRONE – ACCOMPLISHMENTS

- Completed three drone missions to gather multispectral information over the project site across multiple seasons. No leakage detected.
- Applied a novel similarity index (SI) workflow to quantify similarity of imagery data between various vegetative indices and weather patterns.
  - Determined that the best repeatability (correlation of 0.8 or greater) occurs in June and July at the site.
- The EERC developed this workflow and tested it at this site. EERC would like to automate the workflow and test it at other sites, including potential controlled leakage tests, to see how it performs.



SUMMARY OF RESEARCH CONCLUSIONS

CO_2 Plume Tracking

- The accelerated weight drop seismic source was demonstrated as a cost-effective and low impact method for reservoir monitoring when compared to traditional seismic sourcing methods, such as vibroseis and explosives.
  – Learnings from this method have already directly benefited other seismic projects using this same source.
- Passive seismic results demonstrated the ability to take advantage of a "seismically noisy" site and validate field data acquisition and a processing method for imaging deep subsurface geology.
- Electromagnetic (EM) streaming potential technology provided a unique dynamic time-lapse illustration of reservoir connectivity due to CO_2 injection.
  – This method is being applied to multiple industries where injection or production flows through the subsurface enhanced by fluids with contrasting conductivities.

Above-Zone Monitoring

- Towed-transient EM data were the most cost-effective for near-surface characterization when compared to traditional electrical resistivity surveys. Additional shallow characterization data, such as lithology logs or NMR logs, can help increase confidence in establishing initial conditions of resistivity.
- Deployment of three AIM stations successfully demonstrated the low-impact concept and resulted in a cost-effective, novel soil gas-sampling and analytical technique compared to manual soil gas methods.
  – The equipment setup developed through this project is already being deployed for application in both research and commercial CO_2 injection projects.
- A vegetation SI workflow was developed to help investigate any anomalies detected to limit response to false positives during multispectral analysis.

TECHNOLOGY TRANSFER

Title	Author(s)	Format	Conference	Journal
PHASE 2				
Recent Collaborations and Innovations to Demonstrate Next-Generation Techniques for Monitoring Subsurface Carbon Storage	Hunt, J., Richards, T., Kurz, B., and Gorecki, C., Sorensen, J.	Oral Presentation	World Carbon Capture, Utilization, and Storage (CCUS) Conference, Bergen, Norway, September 1–4 2025	N/A
Time-lapse electromagnetic methods for monitoring plume development in a carbon storage reservoir	MacLennan, K., Richards, T., Pugh, T., and Kurz, B.	Oral Presentation	IMAGE, Houston, Texas, August 25–28 2025	N/A
Workflow for process automation of soil gas results from an automated soil gas-sampling system for application in carbon storage projects	Hunt, J., Richards, T., Yu, X., Azzolina, N.	Oral Presentation	Geoconvention, Calgary, Alberta, Canada, May 12–14 2025	N/A
Role of Geophysics in CCUS	Richards, T.	Oral Presentation	Geophysical Society of Houston Workshop, May 6, 2025	N/A
Novel CCUS Monitoring of Approved Class VI Sorage in North Dakota	Richards, T.	Oral Presentation	Dallas Geophysical Society Meeting April 24, 2025	N/A
Novel Carbon Storage Monitoring Methods	Richards, T., Hunt, J., Barajas-Olalde, C., Kovacevich, J., McBride, K., and Kurz, B.	Oral Presentation	American Institute of Chemical Engineers (AIChE) Annual Meeting, San Diego, California, October 27-31 2024	N/A
Utilizing 3D mechanical earth models for calibration and validation in a large-scale carbon capture and storage project in North Dakota	Jo, T., Djezzar, S., Barajas-Olalde, C., and Richards, T.	Oral Presentation and Paper	17th International Conference on Greenhouse Gas Control Technologies (GHGT-17), Calgary, Canada, October 20–24	GHGT-17
Basin Electric Carbon Storage Research Project - Novel Monitoring Techniques	Richards, T.	Oral Presentation	FECM/NETL Carbon Management Research Project Review Meeting in Pittsburgh, PA August 5-9 2025	N/A
PHASE 1				
Design of an AIM network	Hunt, J., Botnen, B., and Richards, T.	Poster Presentation	CCUS Conference, Houston, Texas, March 11–13	N/A
Enhancing CO_2 Storage Complex Characterization in the Williston Basin: An Integrated Approach of Petrophysical Evaluation and Core Analysis	Sofiane Djezzar, Aldjia Boualam, César Barajas-Olalde, Trevor L. Richards, and Bethany A. Kurz	Oral Presentation	CCUS Conference, Houston, Texas, March 11–13	N/A

This subtask produced the following:
- One journal article
- Nine oral presentations
- One poster presentation

RECOMMENDED FUTURE WORK

CO_2 Plume Tracking

- Collect sparse 3D seismic survey with low-impact weight-drop source to demonstrate cost/benefit compared to 2D approach.
- Apply novel approach to remove additional noise from 3D passive survey. If successful, collect repeat survey to assess its effectiveness to track injected CO_2.
- Expand survey extents of controlled-source EM streaming potential survey to cover more injection wells for determining how adjacent injection and associated pressure affects of the CO_2 plume movement and reservoir connectivity.

Above-Zone Monitoring

- Continue testing soil gas-monitoring equipment over the next 3–5 years to demonstrate long-term performance, including other locations/climates.
- Automate novel similarity index approach and test workflow in controlled leakage tests.

POTENTIAL OPPORTUNITIES

- The EERC is in preliminary discussion with oil and gas industry and research entities interested in continuing the evaluation of cutting-edge geophysical CO_2-monitoring technologies with the potential to reduce cost, increase efficiencies, and reduce surface impacts.
  - The commercial CO_2 injection sites in North Dakota provide a unique opportunity to test emerging technologies because of the depth of the target reservoir(s) and the volume of CO_2 being injected.
  - Additional federal and/or state dollars may be critical to the continuation of these initiatives, plus industry involvement has the potential to provide substantial commercial cost share.
  - These technologies are also applicable for monitoring CO_2 migration associated with EOR applications as well as for monitoring fluid movement associated with geothermal projects.

THANK YOU – QUESTIONS?

CO_2 Plume-Tracking Techniques

Active Seismic

Passive Seismic

Controlled-Source Electromagnetics

Above-Zone (Assurance) Techniques

Shallow Electromagnetics

Automated Soil Gas Sampling and Analysis

Drone-Based Surveillance Studies

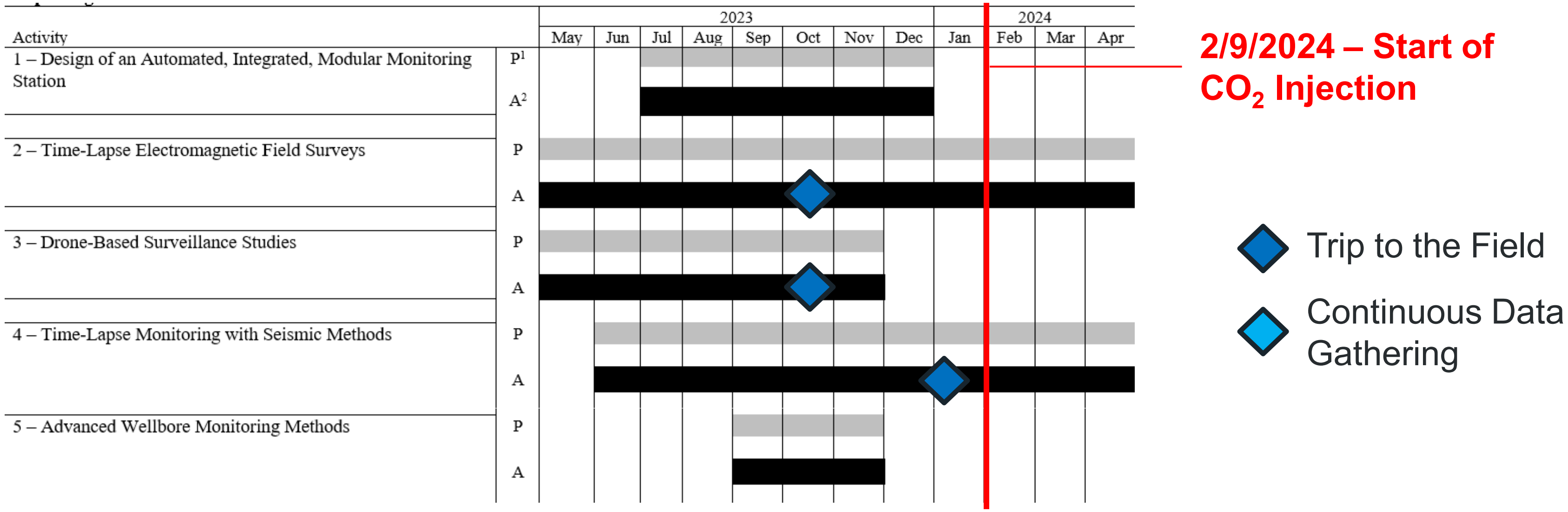
DISCLAIMER

DOE Acknowledgment

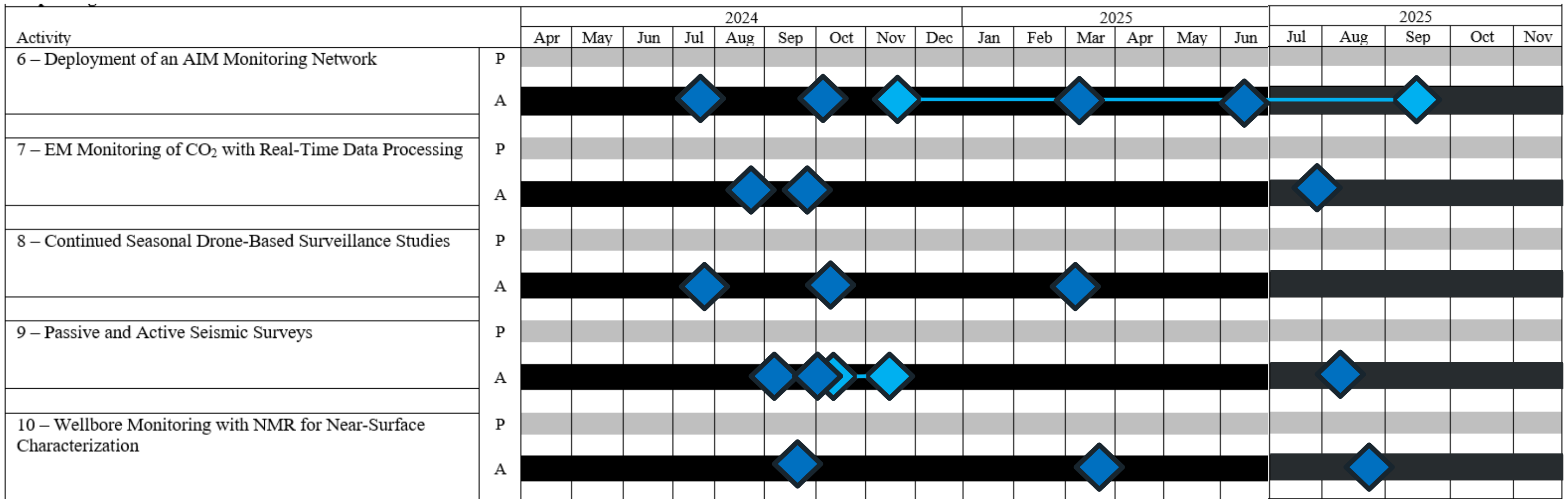
This material is based upon work supported by the Department of Energy under Award Number DE-FE0024233.

PROJECT TIMELINE

Phase 1



Phase 2



MILESTONE LOG (from May 22, 2025)

Phase 1 Milestone Description	Planned Completion Date	Actual Completion Date
M1 – Baseline Geophysical Data Collected	10/31/2023	10/31/2023
M2 – Baseline Logging and Analysis Completed	NA*	NA
M3 – Drone Survey Products Created	10/31/2023	10/31/2023
M4 – Conceptual Design and Draft Schematic of AIM Station Completed	12/15/2023	12/15/2023
M5 – Passive Seismic and Geomechanics Completed	1/7/2024	1/7/2024
M6 – Cloud-Based Data Analysis Tools Developed and Tested	3/31/2024	3/31/2024
M7 – Active Seismic Processing Completed	3/31/2024	3/31/2024

Phase 2 Milestone Description	Planned Completion Date	Actual Completion Date
M8 – CWC EM Monitor 1 Survey Permitting and Procurement Completed	9/6/2024	9/6/2024
M9 – Drone Monitor 1 Survey Permitting Completed	6/24/2024	6/24/2024
M10 – Seismic Monitor 1 Surveys Permitting and Procurement Completed	8/27/2024	8/27/2024
M11 – AIM Stations Fabricated and Installed	12/31/2024	11/22/2024
M12 – CWC EM Monitor 1 Survey Field Data Collected	9/30/2024	9/30/2024
M13 – Drone Monitor 1 Survey Collected	8/2/2024	8/2/2024
M14a – Passive Seismic Monitor Surveys Collected	11/29/2024	11/21/2024
M14b – Active Seismic Monitor Surveys Collected	10/6/2024	10/6/2024
M15 – NMR Logging Run 1	9/20/2024	9/20/2024
M16 – Presentation of Initial Results as White Papers, Conference Papers, Journal Articles, or Technical Briefings	11/30/2024	10/29/2024
M17 – Drone Monitor 2 Survey Collected	3/15/2025	3/7/2025
M18 – NMR Logging 2 Data Acquired	3/31/2025	3/15/2025
M19 – Soil Gas Live Data Streaming and Processing Dashboard Created	6/30/2025	5/19/2025
M20 – All Monitor Data Collected	9/15/2025	8/29/2025
M21 – Time-Lapse Inversions Complete	10/15/2025	10/15/2025

DELIVERABLES

ID	Title/Description	Planned Completion Date	Actual Completion Date
D1	Quarterly report	7/30/2023	7/28/2023
D2	Quarterly report	10/30/2023	10/30/2023
D3	Quarterly report	1/30/2023	1/29/2024
D4	Draft topical report	2/29/2024	2/29/2024
D5	Final topical report	4/30/2024	4/30/2024
D6*	Project data to EDX	4/30/2024	4/30/2024
D7	Quarterly report	4/30/2024	4/30/2024
D8	Quarterly report	7/30/2024	7/30/2024
D9	Quarterly report	10/30/2024	10/30/2024
D10	Quarterly report	1/30/2025	1/30/2025
D11	Comprehensive draft topical report	3/30/2025	3/30/2025
D12	Quarterly report	4/30/2025	4/30/2025
D13	Quarterly report	7/30/2025	7/30/2025
D14	Quarterly report	10/30/2025	
D15	Comprehensive final topical report	11/30/2025	
D16*	Project data to EDX	11/30/2025	
D17	Quarterly report	1/30/2026	