PRESENTATION OUTLINE

• Project Overview
  – Study area
  – SASSA concept
• Reservoir Simulations and 2-D Line
• Array Design and Acquisition
• Data Processing and Interpretation
• Accomplishments
• Lessons Learned
• Synergy Opportunities
• Summary

Before Reclamation

Active Receiver Location

After Reclamation
STUDY AREAS AND TARGET

Muddy Fm
~4500 ft deep
~30 ft thick

Stratigraphic Column for the Bell Creek Area with Lithology

SASSA Study Area

Bell Creek Oil Field
SASSA CONCEPT

• Applying the seismic method to track CO₂ movement in the reservoir.
  – Sparse array and one stationary source.
  – Monitor discrete locations in the reservoir (weekly).
  – Changes to the reservoir reflection character may indicate the passing of CO₂.
  – Validation with dynamic reservoir simulations and 2-D time-lapse seismic.

• Why: Incremental results, actionable information, low impact, possibly cheaper cost, relocate and reuse.
SEISMIC SOURCE

• Gisco ESS 850
  – 850-lb (385-kg) weight accelerated with a slingshot.
  – Powerful, flexible, electrically powered.
  – Safe remote operation within a locked structure.
RECORDING SYSTEM

• Fairfield Zland system
  – 96 autonomous nodes – three-component 5-Hz geophones.
  – Programed to wake and receive data on weekends.
  – Handheld units for node deployment, GPS location, and mapping.
  – Data Management server.
  – Charger and data download racks.
DATA QUALITY

- 2-D data have reflection characteristics similar to the conventional 3-D survey in the same area.
- Reflections from the reservoir are weak or intermittent in this area.
Monitoring focuses on four injector–producer patterns covering about 1 square mile.

Orange dots represent monitored points.
• Monitoring focuses on four injector–producer patterns covering about 1 square mile.
• Orange dots represent monitored points.
• Blue triangles represent receiver locations.
DETERMINING RECEIVER LOCATIONS

• Because of dip and structure, locating receivers required...
• 3-D velocity modeling:
  – Layered velocity model based on 3-D seismic depth volume
  – Lidar elevation data
• Iterative ray-tracing to locate geophone positions that illuminate the desired reflection point locations.
ARRAY DATA ACQUISITION

• 41 data sets harvested.
• Some data collections missed because of:
  – Internet outage.
  – Equipment repair.
  – Abstention due to weather.
• Source fired remotely ~50 to 100 times.
  – Increased signal-to-noise through vertical stacking.
  – Receiver domain processing prior to stacking.
SOURCE REPEATABILITY

Near-Field Source Signature over Time

NRMS < 0.3

Spring Rains
MULTIDOMAIN APPROACH

Common Azimuth Gather

Pseudo Inline and Crossline

Common Receiver Gather

Inline A

Crossline D
RECEIVER DOMAIN PROCESSING
Channel 92

Simple Processing Flow:
• Spherical divergence
• Trace editing
• Bandpass (4-8-56-64-Hz)
• 30-Hz notch
TIME-LAPSE DIFFERENCING
Channel 32

Difference Display
Week Number

Monitor Point

Reservoir

Time (ms)

Gas Per Unit Area Total (feet)

0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.8
0.8 - 0.9
0.9 - 1.0

Active Producer
Active CO2 Injection
Water Injection
Injection-Disposal
Planned Injector
Planned Producer
Shut In
Plugged and Abandoned
TIME-LAPSE DIFFERENCING

Channel 92

Difference Display

Week Number → 05/07/16

Monitor Point

Reservoir

Time (ms)
TIME-LAPSE DIFFERENCING

Channel 24

Difference Display

Monitor Point

Week Number

Time (ms)

Reservoir
COMPLEMENTARY TIME-LAPSE ANALYSIS

• Levin 4-D quick look method
  – Calculation and comparison of shaping filters


LEVIN METHOD TEST

• To test the Levin method and refine parameters, it was applied to a 4-D time-lapse crossline known to encounter areas with and without CO₂.

Crossline 179 Difference Display

Time-lapse difference map of the reservoir displaying RMS amplitude changes.
LEVIN METHOD RESULT ON 3-D CROSSLINE

Crossline 179 Difference Display

Shaping Filter

Shaping Filter Center Sample Amplitude
APPLICATION OF LEVIN METHOD

2-D Baseline

2-D Monitor

Shaping Filter
DYNAMIC RESERVOIR SIMULATIONS

• Predictive simulations of CO₂ saturation using Computer Modelling Group (CMG) software to corroborate and help evaluate SASSA results.

• 2-D line for validation appears to skirt the saturation fronts.
TIME-LAPSE DIFFERENCING

Channel 85

Difference Display

Week Number → 04/03/16

Monitor Point

Reservoir

Time (ms)
APPLICATION OF LEVIN METHOD

Channel 92

Difference Display

Week Number → 05/07/16

Time (ms)

Reservoir

Shaping Filter

Week Number →

Time (ms)
KEY CONSIDERATIONS

• Main factors contributing to the success of the SASSA method
  – Source repeatability
  – Noise attenuation
  – Identification of time-lapse changes not associated with changes in CO₂ saturation
ACCOMPLISHMENTS TO DATE

• System implementation and data acquisition complete
  – Equipment was procured – seismic source, recording system, remote control system, source structure and footing hardware. Geophysical modeling software and data processing software were purchased.
  – Source location was selected – geophysical modeling was completed, monitor locations (midpoints) chosen, and receiver locations determined.
  – Physical system was implemented in the field. Source structure and footing built, 2-D baseline acquired, semipermanent main array installed.
  – Baseline data acquired prior to CO₂ injection. Monitor data acquired on a weekly schedule for 1 year and periodically harvested.
  – Final monitor 2-D line acquired. System retrieved and stored for next use.
ACCOMPLISHMENTS TO DATE

- Data collection, processing, interpretation, and validation
  - Data collection is complete – 41 weeks of data collected.
  - 2-D baseline and monitor seismic data acquired, processed, and interpreted.
  - Wells in the study are history-matched and predictive simulations computed, providing an indication of where CO₂ saturations exist in the study area.
  - Processing workflow developed, refined, and applied. Several innovations have been devised to working with this unique data set, including...
    - Common receiver gather processing
    - Azimuth gathers
    - Pseudo inlines and crosslines
    - The Levin 4-D quick look method to computationally assist in identifying gas-affected locations
  - In-depth analysis and validation of the results are in progress.
ACQUISITION LESSONS LEARNED

- Ground roll presented a data-processing challenge.
  - Interferes with reflections on nodes offset <2200 feet from the source.
- General noise levels varied from week to week and required counteraction.
  - Wind is a big variable – burying the nodes and shooting earlier in the day may help.
  - Gauging current weather conditions before shooting would be an advantage. Rain is noticeable.
  - More cultural noise occurred than expected. Power line noise, pipeline noise, and pump motor noise near producing wells have presented challenges.
  - Individual nodes require individual attention based on noise proximity.
- The source shed was protected with a lightening rod, but not from a voltage surge.
  - An overvoltage surge entered on the power wires, traveled along the battery charger cables, and damaged ALL electronics connected to the source batteries, and more through an Ethernet port.
  - Note: Fuses protect against CURRENT surges, not overvoltage conditions.
  - If the chargers were plugged into the UPS, damage would have been limited to the UPS.
  - The source signature recorder memory was corrupted by the surge. Best practice would be to harvest shot data after each weekly salvo to eliminate data lost to SSR damage.
SYNERGY OPPORTUNITIES

• Several international CO₂ storage projects are experimenting with fixed sources and permanent or semipermanent receiver arrays.
  – Aquistore (Canada)
  – Otway (Australia)
  – Tomakomai (Japan)
  Lessons learned from each may be applicable.

• Complementary monitoring method used in combination with the CO₂ EOR monitoring using the Krauklis wave presented later today.
SUMMARY

• Key findings
  – Results are not black and white, but confidence is high that the data show changes due to CO₂.
  – Reservoir simulations show where effort should be concentrated.
  – Ambiguity in identifying changes due to CO₂ exists because of noise levels.
  – Solutions involving data-processing techniques and interpretation methods are being explored to remove ambiguity.

• Future plans
  – Finalize analysis, and validate if possible. Prepare the final report.
  – Submit for publication findings from the study to a scientific journal.
ACKNOWLEDGMENTS

• Thank you to…
  – Denbury Onshore LLC: for field access and assistance in the Bell Creek Field.
  – CGG GeoSoftware: for the donation of HRS-10 software that was used in generating some of the results for this project and presentation.
  – DOE Project Management: Andrea McNemar
  – Staff at the EERC including senior management, project management, technical staff, field teams and field support, project support, legal and contracts, procurement, travel, administration, IT, graphics, editing, and more.

• This material is based on work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. DE-FE0012665.
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CONTACT INFORMATION

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

www.undeerc.org
701.777.5344 (phone)
701.777.5181 (fax)

Amanda J. Livers
Research Geophysicist
alivers@undeerc.org
APPENDIX

• Benefit to the Program
• Project Overviews, Goals, and Objectives
• Organization Chart
• Gantt Chart
• Bibliography
BENEFIT TO THE PROGRAM

• Program goals addressed:
  – Develop and validate technologies to ensure 99% storage performance.
  – Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
  – Develop best practice manuals for monitoring, verification, accounting, and assessment.

• The SASSA method is a novel application of existing technology with the potential to track the location of a CO₂ saturation front in the subsurface in a timely and cost-effective manner:
  – To improve measurement and accounting of storage performance.
  – Provide a means of remotely detecting out-of-zone migration of CO₂ (ensuring containment effectiveness).
  – Contribute to best practices for monitoring, verification, and accounting (MVA).

BENEFITS STATEMENT

The project will address Area of Interest 1, “Tools and technologies that provide accurate, high-resolution measurement of CO₂ saturations, plumes, and pressure fronts in the subsurface,” by using commercially available technology to create an innovative, scalable, automated monitoring system for the purpose of detecting the movement of a CO₂ plume and pressure front resulting from the injection of CO₂ into the subsurface. The project goals will be accomplished by deploying the proposed technology at an existing commercial CO₂ enhanced oil recovery and storage project. The results of this effort will validate the use of existing technology to effectively monitor the migration of CO₂ in the subsurface in a cost-effective, noninvasive (both to the environment and the operator) way. These results will contribute to the Carbon Storage Program’s goal of developing and validating technologies to measure and account for 99% of injected CO₂ in the injection zones.
PROJECT OVERVIEW
GOALS AND OBJECTIVES

• Demonstrate and evaluate a novel seismic deployment method that can be operated remotely (and potentially automated) to show where and when a carbon dioxide (CO₂) miscible front passes a particular subsurface location.

• Goals
  1. Install a semipermanent seismic system in the field that includes a safe and remotely operated seismic source.
  2. Collect and process data records to identify time-lapse changes that can be verified as being due to the presence of CO₂.
Figure 1. Project organization chart.


THANK YOU!