Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation
Project Number DE-FE-00026517

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National Energy Technology Laboratory
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Presentation Outline

• Benefits to the DOE CCS Program
• Project Overview
• Methodology & Expected Outcomes
• Project Tasks Updates
• Project Milestones
• Project Timeline
Benefit to the Program

Carbon Storage Program Goal Support:

Goal (1) Develop and validate technologies to ensure 99 percent storage permanence by reducing leakage risk through early detection mitigation.

Goal (2) Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness by advancing monitoring systems to control and optimize CO$_2$ injection operations.

Goal (4) Contributing to the Best Practice Manuals for monitoring, verification, and accounting (MVA) with regard to IMS.
Benefit to the Program

IMS System Benefits:

• Reduce overall storage cost.
• Increase monitoring sensitivity.
• Increase monitoring reliability by using an integrated system.
• Optimize operation and maintenance activities.
• Reduce project risk during and after the injection of CO₂.
Project Overview:  
Goals and Objectives

• Develop an integrated IMS architecture that utilizes a permanent seismic monitoring network, combines the real-time geophysical and process data with reservoir flow and geomechanical models.

• Create a comprehensive monitoring, visualization, and control system that delivers critical information for process surveillance and optimization specific to the geologic storage site.

• Use real-time model calibration to provide reservoir condition forecasts allowing site optimization.
USGS Seismic Monitoring

IMS Area

- Surface station
- Borehole station
- Well geophone
- Well vertical DAS

1 km scale
Methodology

• The proposed ICCS IMS program is transformative. It integrates into a single real-time processing framework the following emergent technologies.
  – DAS seismic imaging (VSP & surface reflection)
  – Permanent surface orbital vibrator
  – Hybrid geophone/DAS microseismic array
  – DTS well integrity monitoring
Seismic surveys are considered the backbone technique for CO2 storage monitoring programs. Stringing thousands of cables and running thumper trucks every few years can test the limits of good neighbors. Costs are high.

Permanent reservoir monitoring offers a way to obtain higher quality information with minimal intrusion into surrounding lands –

• DAS provides high spatial and temporal resolution.
• Installation can be in horizontal directionally drilled boreholes beneath bodies of water, existing infrastructure.
• Excitation of DAS cables can be achieved through permanent fixed rotary sources for continuous monitoring.
Distributed Acoustic Sensing (DAS) Example from PTRC Aquistore DAS Baseline 3D-VSP

DAS VSP is becoming accepted technology.
Distributed Acoustic Sensing

- Standard optical fibre acts as the sensor array
  - Typical sampling at 10kHz on 10,000m fibre
  - Standard gauge length of 10m
  - Spatial sampling of 25cm
  - DAS measures change in average elongation per 10m gauge length per 0.1ms acoustic time sample, sampled every 0.25 m in distance

\[ u \left(z + \frac{dz}{2}, t + dt \right) - u \left(z - \frac{dz}{2}, t + dt \right) - \left[ u \left(z + \frac{dz}{2}, t \right) - u \left(z - \frac{dz}{2}, t \right) \right] \]

Parker et al., Distributed Acoustic Sensing – a new tool for seismic applications, first break (32), February 2014
Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained. Operate 2.5 hr/d

Force is adjustable

\[ F = m \omega^2 r \]
FAT Helical Wound Cable

Anderson and Shapiro – HWC on soft mandrel 1980 US Patent 4375313

Hornman et al. (2013 75th EAGE) introduced a helical wound FO cable

LBNL trialed multiple designs with varying physical properties

Line 5 installed one length of HWC for comparison to straight fiber

30° spiral wound on 58 Shore A rubber mandrel.

Lessons learned – acoustic impedance of cable and surrounding soil is important

Hornman et al. 75th EAGE 2013
Geophone Data

26,000 lb Vibe 70% force

SOV – 2 Single sweep
New Silixa Ltd. Carina Sensing System
100X Lower noise floor

Data collection courtesy Aquistore Project: PTRC/GSC/LBNL and JOGMEC
Fiber Optic Cable bored at approximately 20 feet.

Rotary Source Generator

INJECTION AND MONITORING WELLS (EXISTING)

DAS FIBER OPTIC LINE (BORED TO 20 FT)

NOTE 1: DISTANCES ARE MEASURED FROM CCS#2

VW#2 2,600 ft.
SS#2 2,150 ft.
SS#3 4,250 ft.
SS#4 2,705 ft.
SS#5 5,475 ft.

Plume Overlay

Fiber Optic Cable
Bored at approximately 20 feet.

North

ROTARY SEISMIC SOURCE GENERATOR (NOTE 1)
INJECTION AND MONITORING WELLS (EXISTING)
DAS FIBER OPTIC LINE (BORED TO 20 FT)

NOTE 1: DISTANCES ARE MEASURED FROM CCS#2
Expected Outcomes

• ICCS IMS project will provide a new approach towards comprehensive monitoring using automated workflows.
• Providing real-time support for operations.
• Maturing of DAS permanent reservoir monitoring for surface reflection seismic from a TRL of 6 to 8.
• Best practices report detailing IMS – CASSM technology.
PROJECT TASKS UPDATES
Task/Subtask Breakdown

Task 2.0 - IMS Design

• Design an IMS that utilizes seismic and process monitoring data to create a comprehensive monitoring, visualization, and control system that delivers real time information for process surveillance and optimization.

Subtask 2.1 - IMS Data Acquisition and Processing Equipment

• Identify the IMS’s required process and reservoir monitoring data feeds. Specify the IMS’s hardware requirements related to data acquisition, processing, and storage, which includes programmable logic controllers (PLC), device CPU, servers, and storage devices.
Subtask 2.2 - IMS DAS Surface Cable and Rotary Sources CASSM

• Design the layout and integration scheme for the surface DAS cable with the site’s existing well deployed DAS system. Design and specify rotary source equipment related to motor, bearings, coupling, oscillating source, instrumentation, and electrical.

Subtask 2.3 - IMS Software Design and Development

• Develop real-time data pre-processing, filtering, and stacking system for CASSM DAS data including automated reflection vertical seismic profile (VSP) analysis flow, horizon-based inversion code, integrated IMS graphical user interface, and inverse modeling to improve constraints on scCO₂ plume extent.
Subtask 2.3 – IMS Software Design and Development

- Main IMS software design challenge: Integrate heterogeneous data streams
- 3 major components: (1) Data input, (2) Core process, (3) Monitoring information output
- Core analysis processes
  - Monitor reservoir integrity in near-real time
  - Continuously update reservoir model through parameter estimation scheme
Geophysical and in-well data pre-processing layout

- In-well data input stream:
  - Pressure
  - Temperature (DTS)
  - Saturation
  - Flow rates
  - CO2 mass flow

- PLC and PI system:
  - Monitor data IO
  - Manage storage and data transfers

- Real-time CASS data input stream:
  - Raw DAS gathers
    - Surface seismic
    - VSP
  - SOV source sweeps
    - Pilot geophone records

- RAID data storage system

- File-formatting:
  - File format conversion
  - Data file concatenation

- IMS core process server:
  - Schedule daily data fetch
  - Data processing
  - Data filtering + erroneous-input check
  - Quantitative interpretation
  - Reservoir model calibration (joint inversion)
  - Operational-message creation
  - Access from off-site clients

- Long-term data storage

- Field management output:
  - Visualization
  - Operator information
  - Email alerts
Task 2.0 IMS Design
Subtask 2.3: IMS Software Design and Development

Time-lapse feasibility evaluation using synthetic seismic data
- Detectability of the time-lapse changes
- Interpretability of the time-lapse signals
- Repeatability requirements imposed on the CASSM system
Fold Analyses → Superb Spatial Sampling

- Focus: southeast-northwest branch of the “L-shaped” ADM acquisition layout
- Sources: 3 surface orbital vibrators (SOV)
- Receivers:
  - 2 downhole DAS array at CCS2 (1919 m) and VW2 (1493 m)
  - 1 buried surface DAS array (CCS2→SOV3; offset range = 791 m)

- High fold count (>= 100) within 850-meter radius of the injection well CCS2
- Fold count as high as 750 in the 50-meter vicinity of CCS2
Time-Lapse Analyses → Promising Detectability and Interpretability

Both time-lapse metrics (NRMS and time shift) show good sensitivities to the migration of the scCO2 plume front ($NRMS_{\text{max}}$: 30%-110%; $\Delta t_{\text{max}}$: 1 ms to 5 ms)

- Majority of NRMS > 10%–30% detectability thresholds (literature values for surveys of ”good” repeatability)
Noise Analyses (AWGN) → Time-Lapse Signals Require More Stacks

- SNR improvements of stand-alone monitor survey with increasing stack counts
- SNR improvements of time-lapse signals with increasing stack counts

- Small plume thickness → Time-lapse signal intensity lower than primary reflections of stand-alone survey → Require 3-4 times more stacks than conventional surveys
- Achievable with SOV
Subtask 2.4 – Design of Passive Microseismicity Monitoring System

- Develop near real-time extraction of DAS derived data into detection and location processing system. Develop processing, filtering, stacking, cross-correlation tools to automatically pick phase arrival on DAS channels. Test detection and location weighting for improved event location uncertainties.
Subtask 2.4 – Design of Passive Microseismicity Monitoring System

- Automated detection of seismic signals of interest
- Grouping in families and subfamilies of similar characteristics
- Template matching on stacked subfamilies to arrive at group of similar waveforms (used to extract travel times, etc.)
- Likely detection threshold lowering by an order of magnitude
Deliverables / Milestones / Decision Points

Task 1.0 - Project Management and Planning
- Updated project management plan.
- Complete NEPA documentation.

Task 2.0 – IMS Design
- Final design documentation including but not limited to: process instrument diagrams, equipment specifications, and IT network diagram.
- Algorithm description and testing results for the data pre-processing, filtering, stacking, and VSP analysis tools for CASSM DAS data and horizon-based inversion tools for the IMS.
Task 3.0 – IMS Construction
• Topical report detailing the final constructed design including as-built design documentation such as process instrument diagrams, equipment specifications, and IT network diagram. The report will include a section on the integration of all components of the IMS.

Task 4.0 – IMS Operation
• Topical report detailing the commissioning and operation of the IMS. The report will include sections on plume tracking and best practices for utilization of the IMS CASSM system.
• Passive Seismic Monitoring – Quarterly Seismic Event Catalog.

Briefings & Technical Presentations
• DOE annual briefings to review and explain the plans, progress, and results of the technical effort.
## Milestone Status – Q3 2016

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### Project Timeline

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**Design**

- Task 4: IMS Data Acquisition and Processing Equipment
- Task 5: Design CASSM
- Task 6: IMS Software Design and Development
- Task 7: Design Passive Microseismicity Monitoring system
- Task 8: IMS Final Design Review
- Task 9: IMS Equipment Procurement
- Task 10: Construction and Environmental Permits

**Installation**

- Task 12: IMS Data Acquisition and Processing Equipment Installation
- Task 13: IMS DAS Surface Cable and Rotary Sources CASSM Installation
- Task 14: IMS Control, Monitoring, and Data Acquisition, Software Installation
- IMS Installation Complete

**Operation**

- Task 18: IMS Operation
Updated Project Timeline

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IMS Project Summary

Supports Carbon Storage Program Goals.

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• Increase monitoring sensitivity.
• Increase monitoring reliability by using an integrated system.
• Optimize operation and maintenance activities.
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