Acoustic Emissions Sensing for Tracking CO_2 Movement in Caprock of CCUS System

Project Number DOE-FOA2401

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022

Paulsson, Inc. (PI)

OHIO GEOLOGICAL SURVEY
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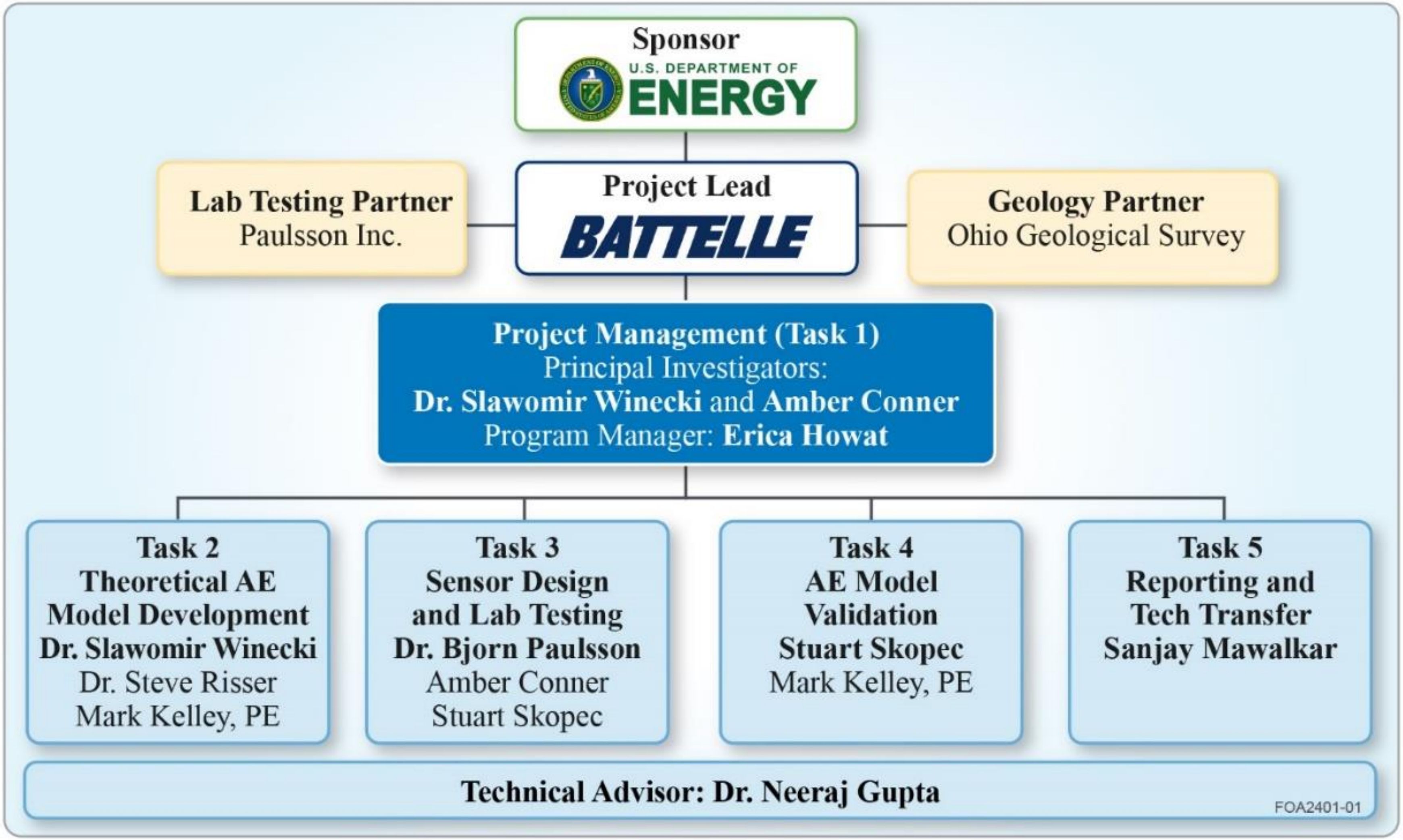
Project Participants



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Project Lead

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Lab Testing Partner
Paulsson Inc.

Geology Partner
Ohio Geological Survey

Project Management (Task 1)
Principal Investigators:
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Program Manager: **Erica Howat**

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Theoretical AE Model Development
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Task 5
Reporting and Tech Transfer
Sanjay Mawalkar

Technical Advisor: Dr. Neeraj Gupta

FOA2401-01

Deliverables / Milestones

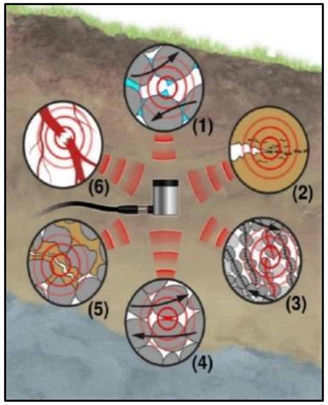
Task/ Subtask	Milestone Title & Description	Planned Completion Date	Budget Period	Verification Method
3.2	Identify suitable sensor components* and caprock samples**	April 2022	1	Technical Memo; Quarterly Report
2	Develop theoretical AE model for CO_2 flow in confining layers	August 2022	1	Technical Memo; Task-2 Technical Report
3	Complete CO_2 core flooding experiments and obtain AE data	January 2023	1	Technical Memo; Task-3 Technical Report
4.1	Complete lab-scale fluid flow simulation	August 2023	2	Technical Memo
4	Validate AE model	November 2023	2	Technical Memo; Task-4 Technical Report
5	Final Report	February 2024	2	Final Report

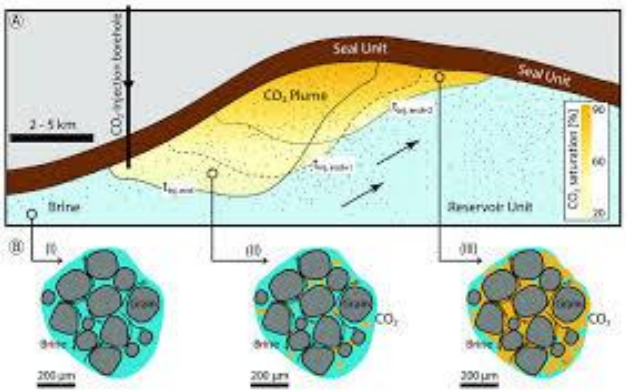
*Supply Chain issues led to a delay in procurement of experimental set up

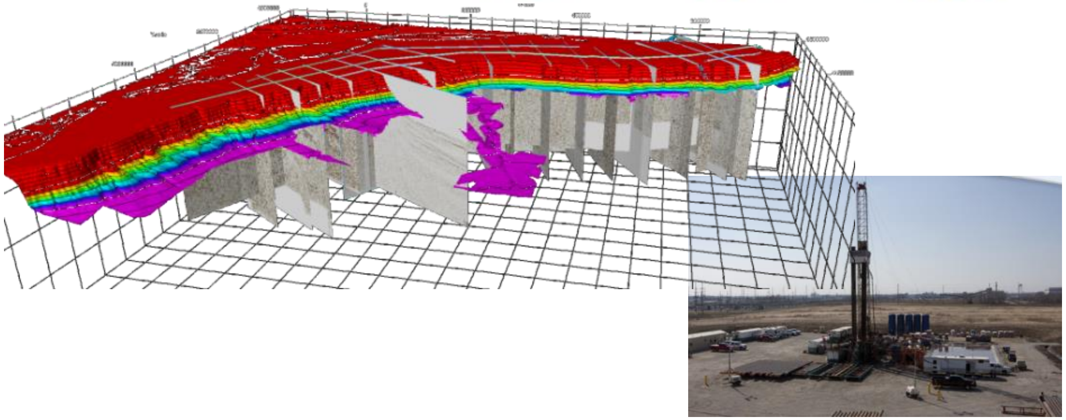
**Porosity/Permeability data received beginning of August

Project Overview: Overall Goal

Development of an acoustic emissions (AE)-based technique to predict the location and movement of CO_2 through a confining layer in carbon capture, utilization, and storage (CCUS) system.



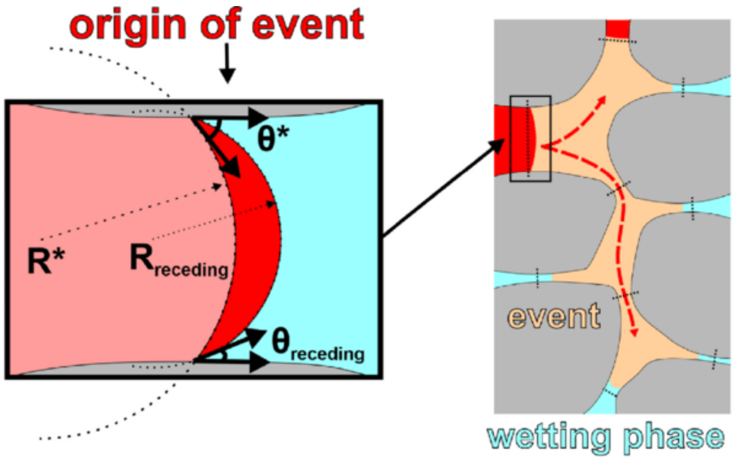


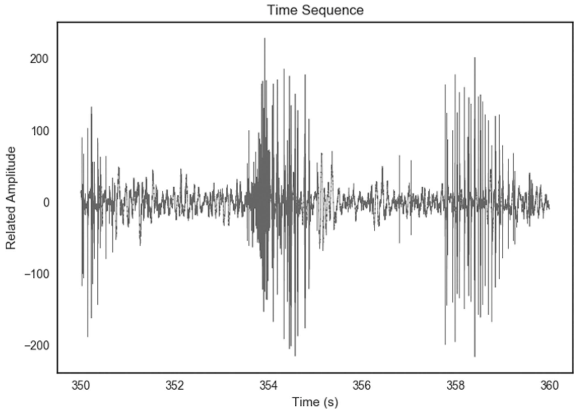


- Development of a **theoretical model** for CO_2-induced AEs in caprock layer
- Design of an **intrinsic sensor system** to detect and characterize AEs
- Design and completion of **laboratory experiments** to record AE data from CO_2 core flooding
- **Validation of the model** with experimental data and **lab-scale fluid flow simulations**

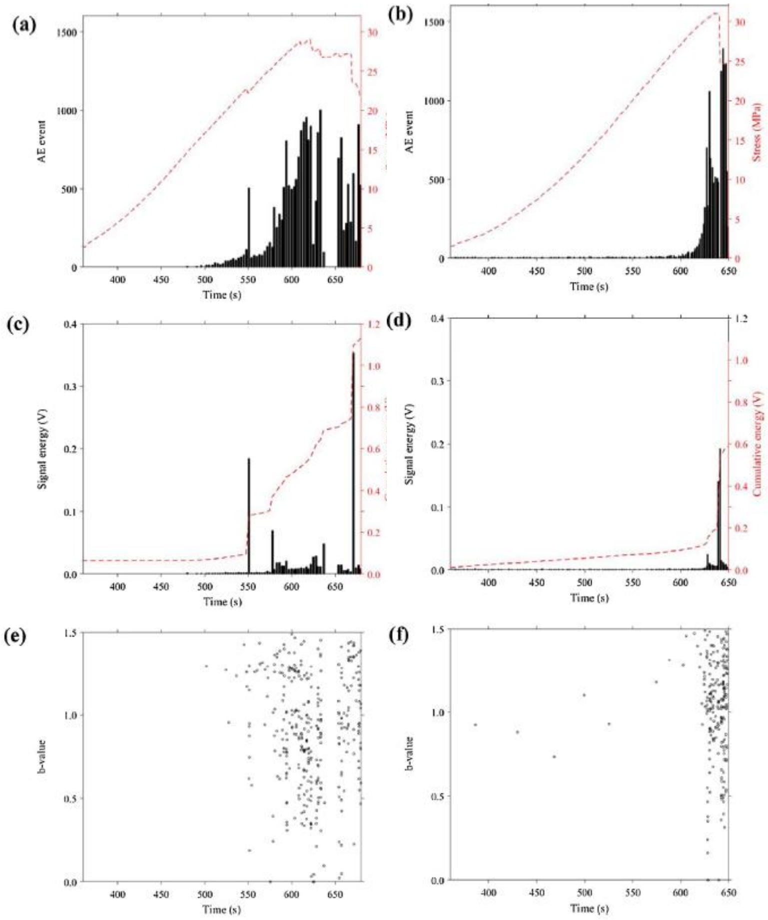
Theoretical Model Development

- Model Conceptualization
  - Identification of existing AE models
  - Development of physics-based model
- Theoretical Model Conception
  - Development of a model that captures key observable characteristics of CO_2 generated AE signals:
    - Amplitude, frequency of occurrences per unit volume of reservoir, acoustic frequency spectrum, and propagation and attenuation properties





Acoustic Emission Studies on Sandstones and Carbonates



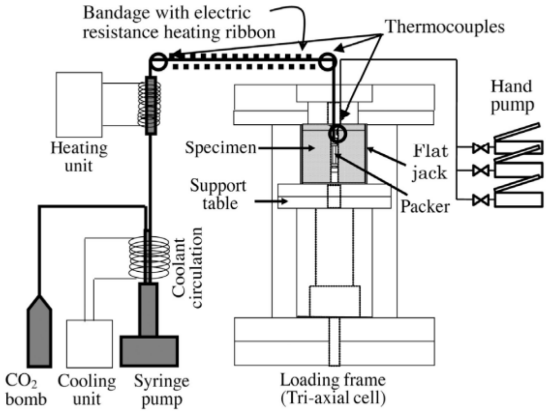
Modified from Tarokh et al. 2020 – Figure showing reloaded samples AE events (b,d,f) have fewer events

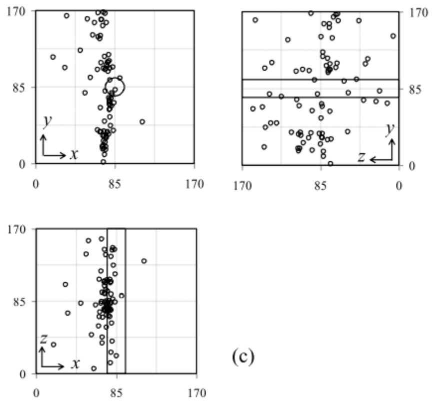
- Review acoustic emission CO_2 studies on reservoir carbonate and sandstone rocks. Studies indicated:
- Initial CO_2 injection shows the greatest AE generated events.
- Continued injection creates less AE events.
- Carbonates tend to be altered due to pressure, temperature, and interaction of CO_2 injection.

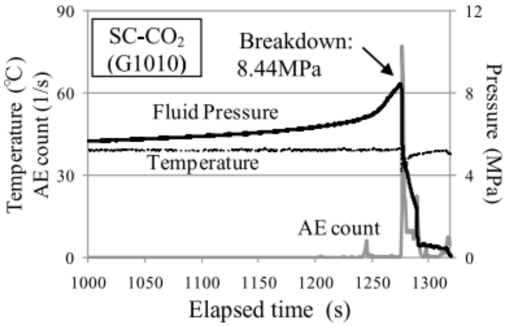
Acoustic Event Experiments

- Literature review grouped these studies into three categories:
  - Experiments where injection of fluid caused a fracture of rock sample and AEs
  - Laboratory-scale tests where injection fluid caused microseismic events and AEs
  - Laboratory experiments exploring the Haines jumps mechanism of AEs

Rock Fracturing and AE Studies







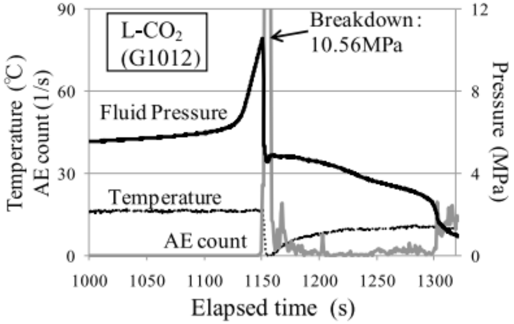
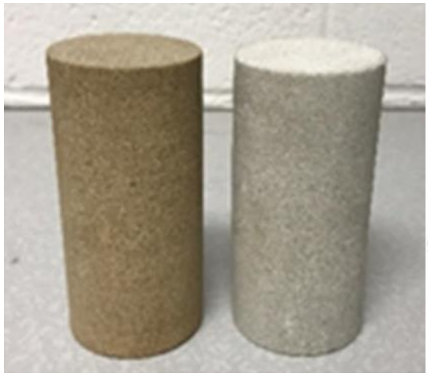
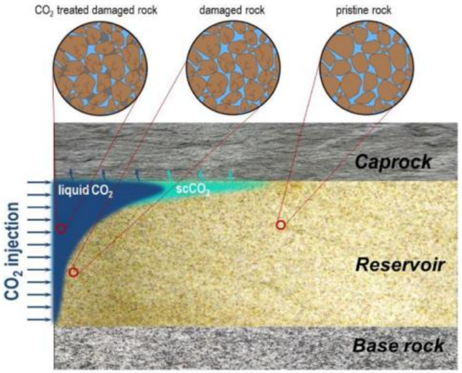


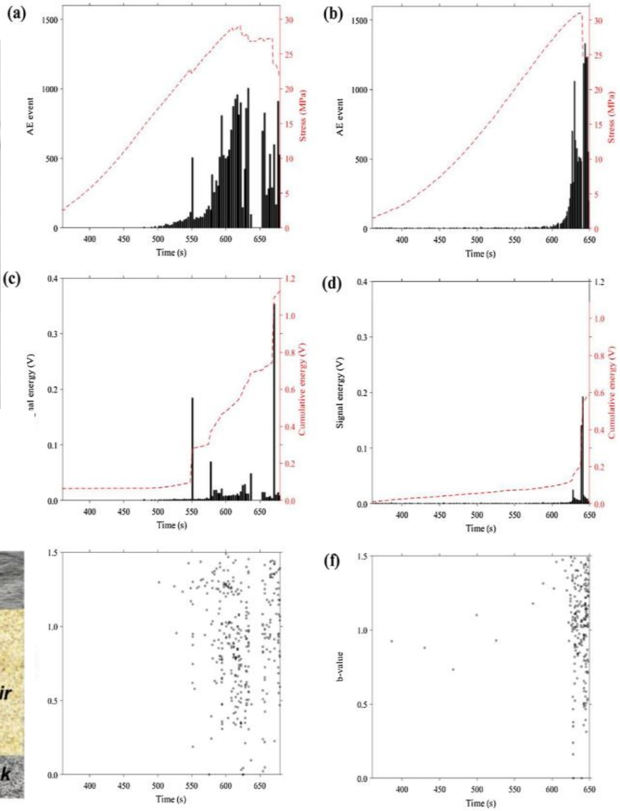
Figure adapted from Ishida et al. 2012

- Supercritical and liquid CO$_2$ injected into granite cubes until it fractures
- High pressures, up to ~1,500 psi, temperatures up to 55°C
- PZT elements with a resonance frequency of 300 kHz
- AE rate was measured as a function of CO$_2$ pressure until the granite rapture
- Location of AEs events was determined based on time delay information recorded by multiple sensors
- However, CO$_2$ injection does not traditionally cause fracturing

Microseismic and AE Studies



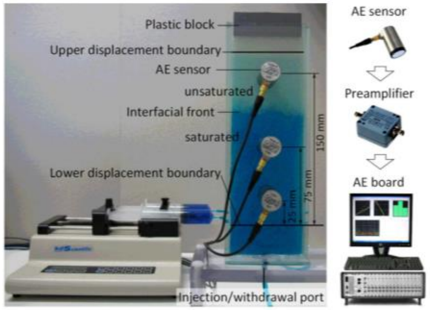


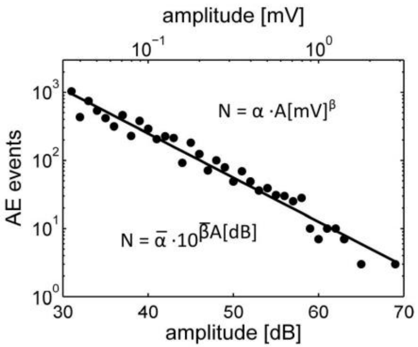


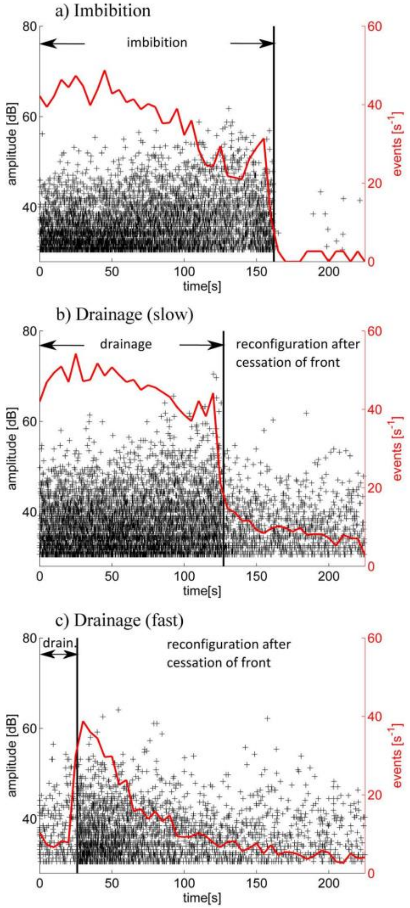
Figures modified from Tarokh et al. 2020

- Injection of $scCO_2$ into Berea sandstone
- Focus on changes of sandstone due to CO_2 injection and thermal treatment (at 300° C)
- AE sensors with 0.35 Hz to 25 kHz range, sampled at 400 kHz rate
- Most of the recorded AEs were in the 0.1 – 0.4 MHz range – see the next slide
- Significant changes of sandstone properties due to CO_2 injection were seen: 10-15% decrease of strength, 100% increase of permeability, 10% increase of porosity, 2x increase of creep rate

Haines Jumps





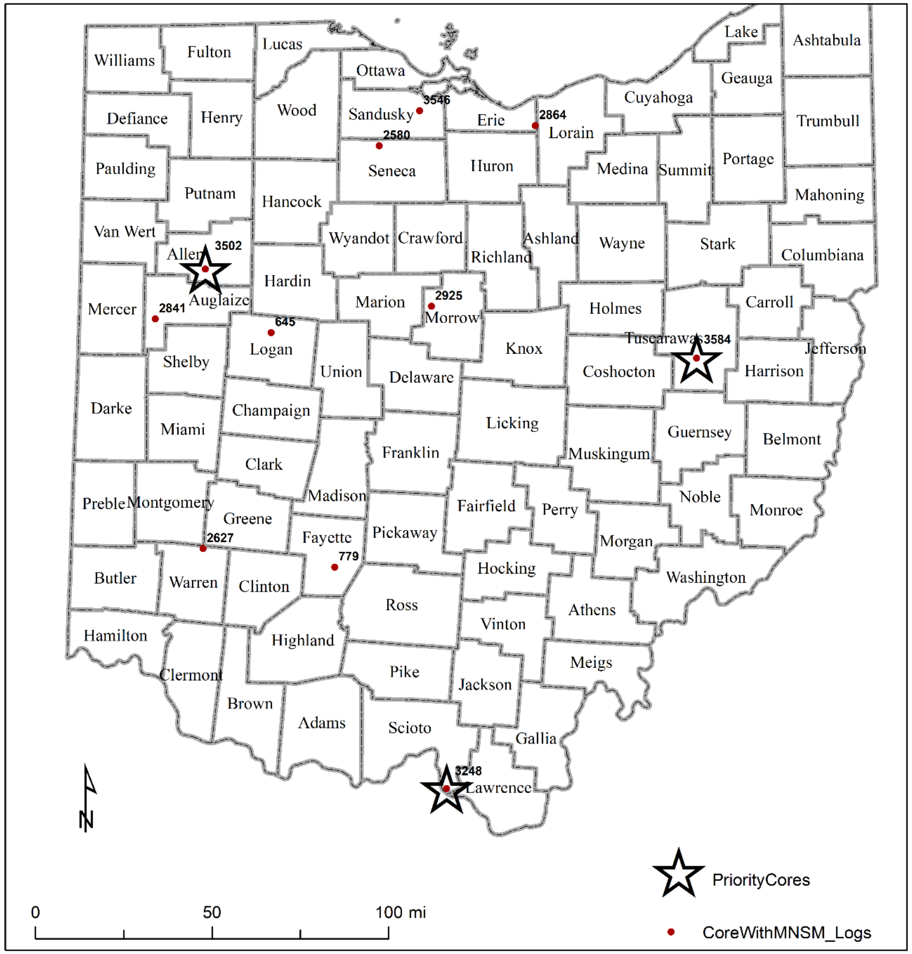


- Published literature reports Haines Jumps AE for water-replacing air at ambient conditions
- These studies showed a number of low-amplitude, high frequency AEs
- It is expected that Haines jumps will have small amplitude and their frequency may be large which restricts the distance of measurement capability

Figures modified from Moebius et al. 2012

Core Selections

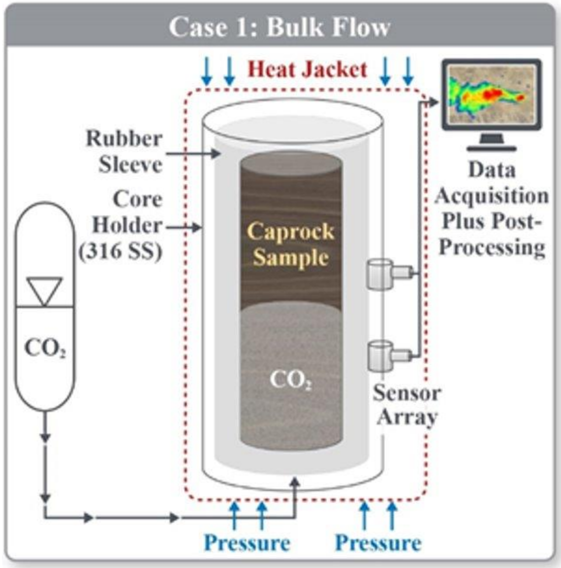
- 8 cores sample intervals
- Rock lithologies: Sandstone (reservoir), carbonate (reservoir), carbonate/shale (caprock)
- Reservoir Rocks
  - Porosity average = 8%
  - Permeability average = 16mD



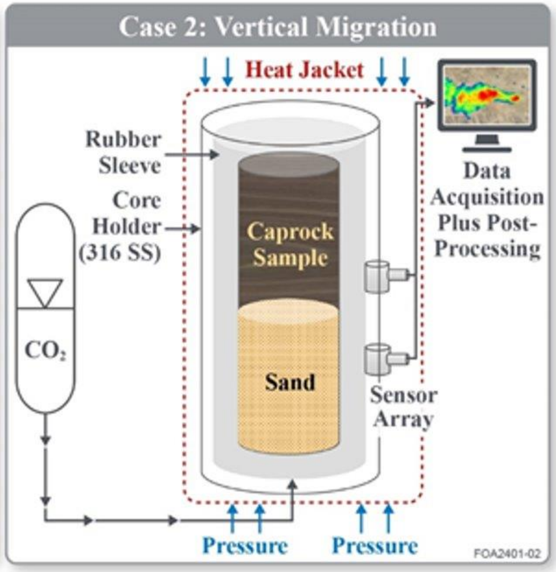
Sensor Design and Lab Testing

Design and build a system that can saturate a reservoir core sample with brine followed by injection of supercritical CO_2 (scCO_2) through the sample at various pressures and temperatures under the two injection schemes. This test will seek to:

- Establish sensor system validity in elevated pressure and temperature conditions
- Observe signal strength and attenuation, sensitivity of existing acoustic detection systems, and acoustic background from other processes
- Demonstrate, theoretically but quantitively, that the AE signals can be detected.



Advective Flow



Diffusive Buoyancy-Driven Flow

Experimental Set Up Procurement Timeline

- March 14: Initial experimental set up order placed by Paulsson, Inc. with Control Group for June 6 delivery

- May 5 – June 17: When it became likely that the initial order with Control Group would not be filled, Paulsson initiated a design review with DCI

- June 15: Paulsson cancels the Control Group Order due to vendor’s inability to complete the order

- June 21: Paulsson placed the second order with DCI Corporation in Utah.

- September 27 – October 11: Expected delivery window of the equipment, both purchased and borrowed components

- October 1 – October 20: Install the equipment

- October 20 – October 30: Test the equipment

- November 1: Begin acoustic emissions experiments

- November 30: End acoustic emissions experiments

Summary

- Literature search task was completed
- Cores have been selected and tested for petrophysical properties
- Theoretical Model is under development
- Experimental Set Up has been ordered from a second supplier and is awaiting delivery
- Next Steps:
    - Build experimental set up
    - Test generic core samples
    - Test selected seal and reservoir rock core samples

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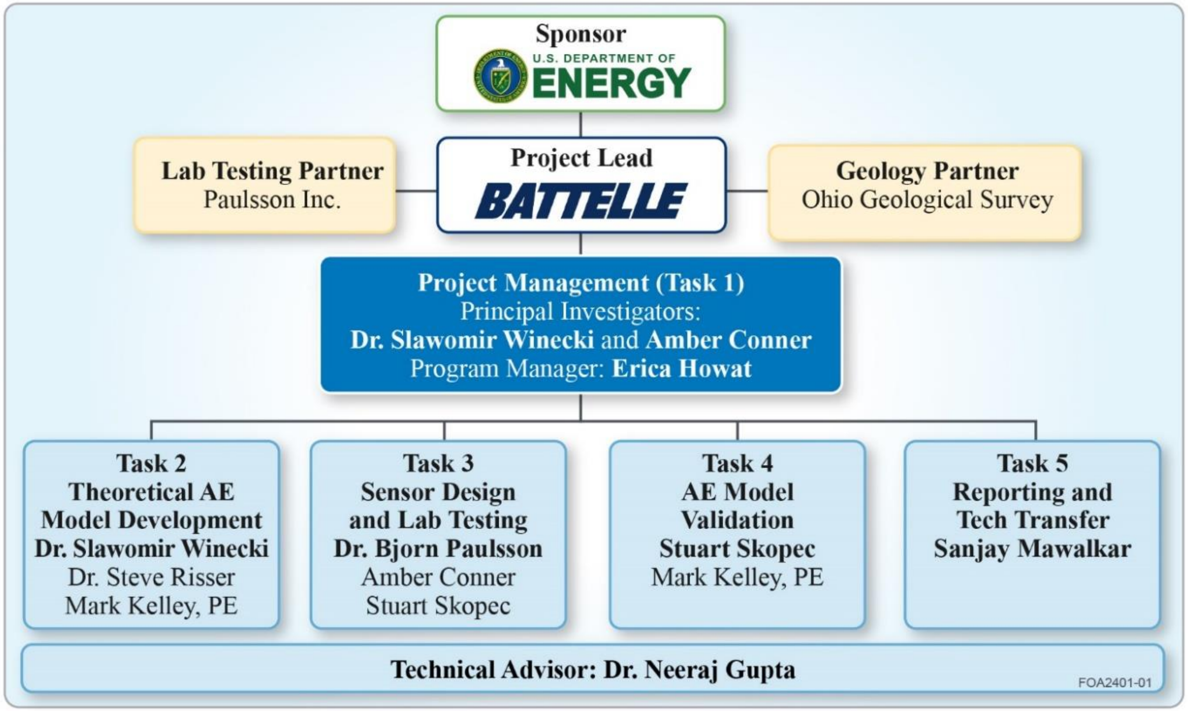
Organization Chart



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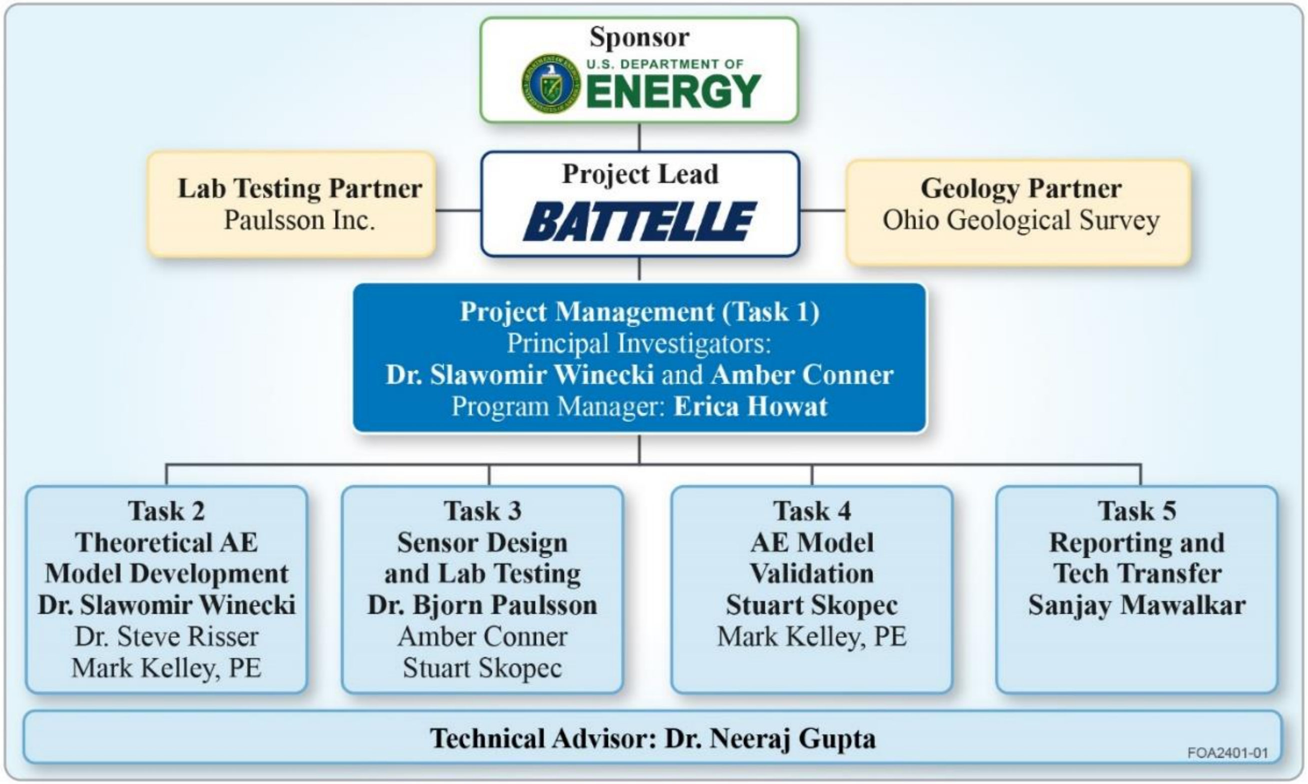

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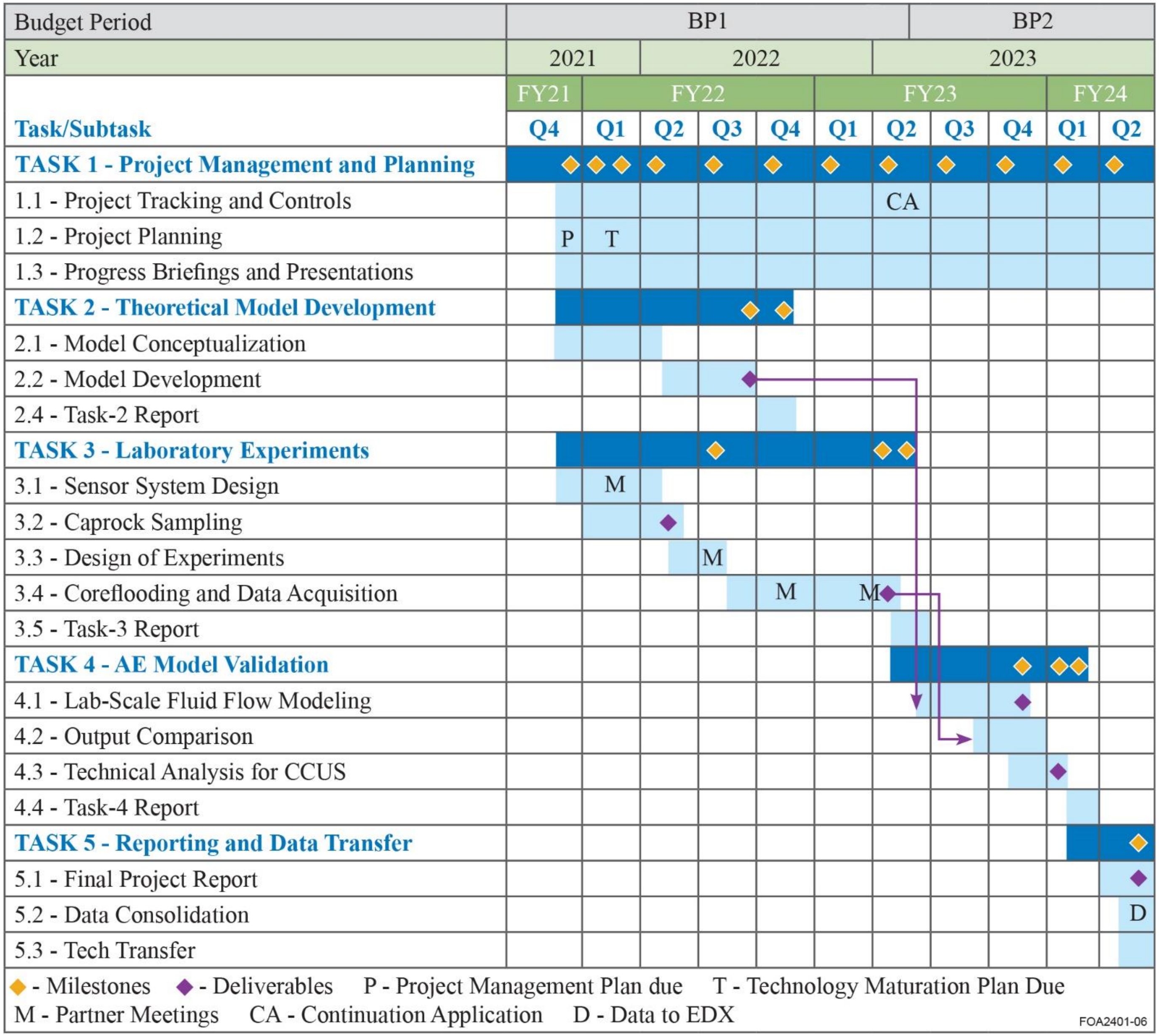
Funding (DOE + Cost Share)

	Budget Period 1	Project Total
Federal Share	$640,075	$799,354
Cost Share Total	$184,612	$204,612
Project Total	$824,687	$1,003,966

Gantt Chart



Budget Period	BP1							BP2			
Year	2021		2022				2023				
	FY21	FY22				FY23				FY24	
Task/Subtask	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**
TASK 1 - Project Management and Planning	■ 🔶	■ 🔶🔶	■ 🔶	■ 🔶	■ 🔶	■ 🔶	■ 🔶	■ 🔶	■ 🔶	■ 🔶	■ 🔶
1.1 - Project Tracking and Controls	▨	▨	▨	▨	▨	▨	▨ CA	▨	▨	▨	▨
1.2 - Project Planning	▨ P	▨ T	▨	▨	▨	▨	▨	▨	▨	▨	▨
1.3 - Progress Briefings and Presentations	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
TASK 2 - Theoretical Model Development	■	■	■	■ 🔶	■ 🔶						
2.1 - Model Conceptualization	▨	▨	▨								
2.2 - Model Development			▨	▨ ◆							
2.4 - Task-2 Report					▨						
TASK 3 - Laboratory Experiments	■	■	■	■ 🔶	■	■	■ 🔶🔶				
3.1 - Sensor System Design	▨	▨ M	▨								
3.2 - Caprock Sampling		▨	▨ ◆								
3.3 - Design of Experiments			▨	▨ M							
3.4 - Coreflooding and Data Acquisition				▨	▨ M	▨ M	▨ ◆				
3.5 - Task-3 Report							▨				
TASK 4 - AE Model Validation							■	■	■ 🔶	■ 🔶🔶	
4.1 - Lab-Scale Fluid Flow Modeling							▨	▨	▨ ◆		
4.2 - Output Comparison								▨	▨		
4.3 - Technical Analysis for CCUS									▨	▨ ◆	
4.4 - Task-4 Report										▨	
TASK 5 - Reporting and Data Transfer										■	■ 🔶
5.1 - Final Project Report											▨ ◆
5.2 - Data Consolidation											▨ D
5.3 - Tech Transfer											▨

🔶 - Milestones ◆ - Deliverables P - Project Management Plan due T - Technology Maturation Plan Due
M - Partner Meetings CA - Continuation Application D - Data to EDX

FOA2401-06