ADVANCED CHARACTERIZATION OF UNCONVENTIONAL OIL AND GAS RESERVOIRS TO ENHANCE CO₂ STORAGE RESOURCE ESTIMATES

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U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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PROJECT TEAM

• DOE NETL
• Energy & Environmental Research Center (EERC) at the University of North Dakota
• Hitachi High Technologies America
PROJECT GOALS

• Development of advanced characterization methods and/or procedures to better identify the properties of organic-rich shales (and other unconventional reservoirs) that affect CO₂ transport and storage.

• Application of those methods to improve the existing equations used to volumetrically estimate CO₂ storage capacity.

NETL MASS STORAGE EQUATION

\[ G_{CO_2} = V_e \left[ \rho_{CO_2} \phi E_\phi + \rho_{sCO_2} (1 - \phi) E_s \right] \]

where:

\( G_{CO_2} \) = CO\(_2\) mass storage resource of organic-rich shale formation;

\( V_e \) = Volume of formation that can effectively be accessed for CO\(_2\) storage;

\( \rho_{CO_2} \) = Density of CO\(_2\) at reservoir conditions;

\( \phi \) = Total porosity due to pores and fractures;

\( E_\phi \) = Fraction of total porosity available for CO\(_2\) storage

\( \rho_{sCO_2} \) = Maximum mass of CO\(_2\) sorbed per unit volume of solid phase rock \((1 - \phi)\); and,

\( E_s \) = Fraction of solid phase available for CO\(_2\) sorption.

Levine et al., 2016; Goodman et al., 2014.
PROJECT OBJECTIVES

• Development of advanced field emission scanning electron microscopy (FESEM) and image analysis methods to better characterize the following within organic-rich shales and other tight formations:
  – Mineralogy and organic matter (OM)
  – Porosity and pore-size distributions
  – Fracture networks

• Collaboration with Hitachi to develop and/or improve data processing and image analysis routines to better characterize and quantify features of interest in unconventional formation samples.
PROJECT OBJECTIVES (continued)

• Collaboration with NETL’s CT Scanning Laboratory to investigate the effects of CO₂ exposure on organic-rich shales at the core scale.
• Development of image analysis-based methods to estimate the storage resource potential of unconventional formations in collaboration with NETL staff.

https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development
BAKKEN FORMATION LITHOLOGY

Upper Bakken Shale: Brown to black, organic-rich
- Bakken source rock

Middle Bakken: Variable lithology (up to nine lithofacies), ranging from silty sands to siltstones and tight carbonates
- Bakken tight reservoir rock (horizontal drilling target)

Lower Bakken Shale: Brown to black, organic-rich
- Bakken source rock
DATA ACQUISITION WITH AMICS

Field Parameters:
- Magnification – 1500x
- Image Resolution – 40 nm/pixel
- Field Size – 85 µm x 85 µm
- Total pixels per frame – 4.5 million
- Final mineral map frames – 40

LBS Example
- 66,000 Segments
- 47,000 X-Ray Points

Big Data Process!
IMAGE SEGMENTATION USING ILASTIC
OCCURRENCE OF KEY COMPONENTS (AREA %) IN EACH SCENE
The image analysis data also allow us to evaluate:

- Statistical parameters to assess key sample properties, such as compositional variability.
- Grain and pore size distribution.
- Fracture porosity.

Currently working on a method to approximate the volume of the various sample components based on 2-D extrapolation.
ESTIMATING EFFICIENCY FACTORS USING IMAGE ANALYSIS
## SHARED BORDER ANALYSIS

![Image of a map with different labels and areas highlighted]

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<th>Perimeter, µm</th>
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<td>OM AND Pores</td>
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SOLID BITUMEN STRUCTURE AND POROSITY
18829 – LOWER BAKKEN SHALE

OM Porosity: ~4.5%
OM Pore Sizes: 28–49 nm

OM Porosity ~6.5%
OM Pore Sizes: ~20–40 nm
NETL COLLABORATION

- Evaluation of CO₂ permeation/flow over time into fractured and unfractured Bakken core plugs.
- Multiple experiments have been completed:
  - Helium injection
  - Xenon injection
  - CO₂ injection
- All experiments accompanied by CT scanning and image analysis.
ACCOMPLISHMENTS TO DATE

• Development of advanced FESEM and image analysis methods to better characterize key components in organic-rich shales and other tight formations that could affect CO$_2$ storage.

• Collaboration with Hitachi to improve the data-processing and image analysis routines to better characterize and quantify features of interest in unconventional formation samples.

• Evaluation of CO$_2$ permeation rates and changes over time in fractured and unfractured Bakken core plugs.
LESSONS LEARNED

• A shale is not a shale is not a shale…
• Uncertainties using FESEM to detect nano-scale porosity.
  – How do we account for CO₂ permeation and adsorption/absorption on or in nano-scale pore networks within OM?
  – Can we infer connectivity from CO₂ extraction data?
  – What relationships can be developed between measured sorption data and image analysis-derived parameters.
• Need additional adsorption data for kerogen and different clay types at reservoir pressure (4000–7000 psi).
SYNERGY OPPORTUNITIES

• This work helps us better characterize and quantify the physical and geochemical factors that affect CO₂ transport, migration, and sorption in unconventional (and conventional) reservoirs or other subsurface CO₂ storage targets.

• By better understanding the relationships between porosity, OM and clays in an undisturbed state, we are able to develop a method to estimate how much CO₂ might contact OM vs. clays (or reactive minerals).
  – This information allows us to expand NETL’s volumetric storage equation for organic-rich shales by providing a method to estimate the storage efficiency factors related to CO₂ adsorption on clays versus OM.
PROJECT SUMMARY

• Advanced classification of FESEM imagery is a great way to better understand the occurrence of and relationships between key factors that can affect CO₂ migration and storage in tight rocks.

• Bakken-specific observations:
  – The majority of pore space within the Bakken shales occurs within OM.
  – Most of the pore networks within the Middle Bakken are filled with illite.
  – OM porosity (as determined using FESEM) varies widely within individual samples and between samples from different wells and/or depths.

• Current work is focused on acquiring measured CO₂ adsorption data at reservoir conditions.

• Collaboration with NETL is ongoing to expand the volumetric storage equation for shales by accounting for the efficiency factors associated with CO₂ sorption onto clays and organic matter.
CONTACT INFORMATION

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THANK YOU!
BENEFIT TO THE PROGRAM

To improve understanding of the key geologic factors that influence CO\textsubscript{2} storage resource estimates in organic-rich shales and other unconventional reservoirs and to better define the efficiency factors associated with each key parameter, the Energy & Environmental Research Center (EERC) is developing advanced analytical techniques to better understand the distribution of clay minerals and organics, porosity type and volume, and natural fracture occurrence and characteristics in representative shale and tight rock samples. This effort supports NETL’s Carbon Storage Program goal of improving the ability to predict CO\textsubscript{2} storage capacity in geologic formations to within ±30% through improved characterization of key features that affect CO\textsubscript{2} storage in unconventional reservoirs.
PROJECT OVERVIEW
GOALS AND OBJECTIVES

The main goal of this project is to develop advanced characterization methods and/or procedures for studying the properties of organic-rich and other tight shale formations using advanced analytical techniques, with the aim of improving assessment methods for estimating the CO₂ storage capacity of such formations. The overall goal of the project will be accomplished through the following seven objectives:

- Develop advanced FESEM and image analysis methods to better characterize the mineralogy and kerogen content of organic-rich shales and other tight formations.
- Develop improved methods to better estimate porosity and pore-size distributions in organic-rich shales and other tight formations.
- Develop enhanced methods to improve the characterization of fracture networks within organic-rich shales and other unconventional rocks.
- Collaborate with Hitachi to develop and/or improve data processing and image analysis routines to better characterize and quantify features of interest in unconventional formation samples.
- Collaborate with NETL’s CT scanning laboratory in Morgantown to investigate the effects of CO₂ exposure on organic-rich shales at the core scale and evaluate CO₂ sorption within organic-rich shales.
- Develop improved methods to estimate the storage resource potential of unconventional formations in collaboration with NETL staff.
- Evaluate and quantify CO₂ sorption in Bakken shales.

The above tasks directly relate to NETL’s Carbon Storage Program goal of improving the ability to predict CO₂ storage capacity in geologic formations to within ±30%. How the project goals and objectives relate to the program goals and objectives. Eight milestones have been developed and are being tracked to ensure completion of the project goals and objectives.
ORGANIZATION CHART

- **DOE/NETL**
  - Funding Agency

- **EERC**
  - Project Administration
  - Project Management
  - Key Technical Lead

- **NETL**
  - Additional Laboratory Testing (CT Scanning Lab)
  - Support with Modification of Storage Resource Equation

- **Hitachi High Technologies**
  - Cost Share Provider
  - Shale Analysis Optimization Using FESEM
### Subtask Time Line

**Program Title:** BEEC-DOS Joint Program on Research and Development for Porel Energy-Related Resources  
**Cooperative Agreement No.:** DE-FC02-04ER63395  
**Subtask Title:** Subtask 1.1 - Advanced Characterization of Unconventional Oil and Gas Reservoirs to Enhance CO₂ Storage Resource Estimates  
**Subtask Manager:** Bethany Kosz  
**Period of Performance:** 9/1/16 - 4/30/19  
**Reporting Period:** 4/1/18 - 6/30/18

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<td>2 - Advanced Compositional Characterization of Organic-Rich Shale and Unconventional Reservoir Rocks</td>
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