A Nonconventional CO$_2$-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

Project Number DE-FE0024431

Nathan Webb, Scott Frailey, and Hannes Leetaru
Illinois State Geological Survey

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration
August 18-20, 2015
Presentation Outline

• Benefit to DOE Program
• Program and Project Overview
• Methodology
• Outcomes
• Accomplishments to Date
• Summary
• Bibliography
Benefit to DOE Program: Goal and Area of Interest

• Goal: Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness

• FOA Area of Interest: 1A - Opportunities, Knowledge Advancements, and Technology Improvements for CO₂ Storage in Non-Conventional CO₂-EOR Targets – Residual Oil Zones (ROZs)
Benefit to DOE Program: Benefits Statement

• Field development guidelines will be developed to maximize economic oil recovery and CO$_2$ storage efficiency.

• It is projected that CO$_2$-EOR is an effective means of recovering additional oil from a formation that has historically low primary production and no waterflooding or EOR attempts. The formation is expected to have a high CO$_2$ storage (i.e. net utilization) compared to conventional CO$_2$-EOR.

• Through the application of these techniques, guidelines can be recommended for CO$_2$-EOR development (e.g., well patterns, spacing, and orientations as well as CO$_2$ injection profiles) of the thick Cypress (and similar formations) with the end result of maximized incremental recovery and CO$_2$ storage.
Program and Project Overview: Goals

DOE Program

• Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness

• Develop and advance technologies to significantly improve the effectiveness and reduce the cost of implementing carbon storage

• Adapt and apply existing technologies that can be utilized in the next five years while developing innovative and advanced technologies that will be deployed in the next decade and beyond

ncCO₂-EOR TC ILB

• Identify and quantify nonconventional CO₂ storage and EOR opportunities in the thick Cypress Sandstone in the Illinois Basin
  • Economics/NCNO
  • Field development strategies
  • Near term deployment
# Program and Project Overview: Objectives

## DOE Program
- Detailed characterization
- ROZ fairway locations; CO$_2$ storage and EOR resource
- Field and lab tests
- Development methods for increasing CO$_2$ storage and improving oil recovery

## ncCO$_2$-EOR TC ILB
- Correlate oil production to key geologic/reservoir properties
- Map CO$_2$ storage and EOR resource fairway (e.g. oil recovery)
- Obtain and analyze new core, logs, and fluid samples
- Develop screening and selection criteria; full field development strategies; economics and NCNO
Methodology

Background: Thick Cypress Ss

- Thick Cypress Sandstone presents an opportunity for ncCO$_2$-EOR and storage
  - Large NE-SW trending fairway though the center of the Illinois Basin
Methodology
Background: Thick Cypress Sandstones

• Thin Oil Zones in Thick Aquifer Sandstones
  – Residual and mobile oil above thick saline aquifer
  – Fining upward (grain size) sequence / increasing permeability with depth
  – Difficult to produce economically due to water coning and water management

• Nonconventional CO$_2$-EOR
  – Largely bypassed resource due to historical production difficulty
  – Sandstones 30+ meters thick and mostly saline aquifer
  – Saline storage potential of 0.2 to 2.3 Gt of CO$_2$ (DOE/MGSC, 2012)
Methodology

- Oilfield Selection
- Data Synthesis & Analysis
- Petrophysics
- Geologic Modeling
- Geocellular Modeling
- Fluid Analysis & Geochem Model
- Reservoir Simulation
- Economics
- Development Guidelines & Resource Estimate

Illinois State Geological Survey
Oilfield Selection

- Chose eight oilfields to investigate
- Assessed the type and quality of data for each oilfield
Oilfield Selection

- Compared geologic and reservoir data attributes of oilfields to identify favorable conditions for study.

<table>
<thead>
<tr>
<th>Oilfield Name</th>
<th>Location</th>
<th>Average Depth to Cypress (ft)</th>
<th>Average Cypress Thickness (ft)</th>
<th>Oil zone present? (thickness, ft)</th>
<th>Reservoir Data</th>
<th>Production History</th>
<th>Active Drilling (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loudon</td>
<td>Fayette Co., T7N, R3E</td>
<td>1500</td>
<td>70</td>
<td>Yes &gt;10</td>
<td>Many electric logs and porosity logs, several cores, some core analysis data</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bible Grove</td>
<td>Clay Co., T5N, R7E</td>
<td>2500</td>
<td>100</td>
<td>Yes &gt;10</td>
<td>Many electric logs, a few cores nearby, little core analysis data</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Nichols</td>
<td>Clay Co., T4N, R8E</td>
<td>2700</td>
<td>150</td>
<td>Yes &gt;10</td>
<td>Many electric logs, no cores, little core analysis data</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Noble</td>
<td>Richland Co., T3N, R9E</td>
<td>2600</td>
<td>150</td>
<td>Yes &gt;10</td>
<td>Many electric logs and porosity logs, a few cores, abundant core analysis data</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Clay City</td>
<td>Clay and Wayne Co., T2N, R8E</td>
<td>2700</td>
<td>90</td>
<td>Yes &lt;10</td>
<td>Many electric logs and porosity logs, no cores, some core analysis data</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Parkersburg</td>
<td>Richland/Edwards Co., T2N, R14W</td>
<td>2800</td>
<td>-</td>
<td>No*</td>
<td>Many electric logs and porosity logs, no cores, some core analysis data</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Centralia</td>
<td>Clinton Co., T1N, R1W</td>
<td>1200</td>
<td>-</td>
<td>No*</td>
<td>Many old electric logs with many that do not penetrate the entire Cypress, a few cores, some core analysis data</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Dale 1 &amp; 2</td>
<td>Hamilton Co., T6S, R5E &amp; T6S R7E</td>
<td>2700–2900</td>
<td>70–90</td>
<td>Yes &lt;10</td>
<td>Many electric logs, A few cores, no core analysis data</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

*The oil zone may be very thin, if present, and is difficult to detect because of the transitional nature of the Cypress Sandstone in the Centralia and Parkersburg areas.

Illinois State Geological Survey
Oilfield Selection

- Inventoried all available data
- Assessed the relative importance of data types
- Reviewed all existing Cypress Sandstone studies
- Selected Noble Field for study

Reservoir Data
- Wells with logs
- Cores and core analysis data

Acceptable

Production History
- Records showing behavior of thick Cypress Sandstone production

Ideal

Difficult

Active Drilling
- Operators drilling through the thick Cypress to deeper formations willing to take core and run geophysical tools
Data Synthesis and Analysis

• Derived Noble Field production history from pipeline reports
• Assigned production history to each well
• Constructed annual and cumulative production curves for Noble Field for all producing formations
Data Synthesis and Analysis

- Studied Noble Field historical drilling activity to understand relative productivity of all formations
  - Next Step: Assign proportion of thick Cypress production to each well
Petrophysics

Selected wells within thick Cypress Sandstone fairway
- Wells represent a range of geologic and reservoir characteristics both within and outside of oilfields

Testing methods to assess the oil/water contact (OWC) and the presence of ROZ
- The apparent water resistivity and resistivity-derived porosity methods are being attempted

Next step: Develop algorithm based on petrophysical analysis to identify ROZs

Illinois State Geological Survey
Geological Modeling

• Mapping log and core indicated features of the thick Cypress Sandstone at Noble Field
  – Upper/lower formation contacts, baffles (shaly zones, cemented zones), OWC
  – Defining volumetric parameters of reservoir and nature of OWC
    • OWC is tilted implying current hydrodynamic forces indicating possible ROZ
Geological Modeling

- Examining thick Cypress Sandstone sample sets in and near Noble Field
  - Documenting trends
    - Lithology, texture, oil saturation
  - Identifying potential baffles to fluid movement
Geological Modeling

- Describing available cores and sampling for porosity, permeability, mineralogy, trace elements, SEM, and thin sections
  - Defining sedimentary facies and developing an interpretation of depositional environment
  - Investigating scales of and controls on reservoir heterogeneity
- Next Step: Integrate core and log data to map individual reservoir facies
Geocellular Modeling

- Developed a porosity-permeability transform from core data for Noble Field and vicinity
- Digitizing and collecting additional core analysis data to include in the database to refine the porosity-permeability transform
Geocellular Modeling

- Developed a geocellular model based on well locations and the preliminary isopach map of the thick Cypress Sandstone in Noble Field
  - Simplified representation of reservoir geology used to approximate the depth and dimensions for reservoir simulations
- Next Step: Integrate log and core data into rigorous Noble Field thick Cypress Sandstone geocellular model to represent reservoir heterogeneity

Porosity model. Roughly 0.5 x 0.5 mi.
50x vertical exaggeration
Fluid Analysis and Geochemical Modeling

• Constructed a database of current known reservoir fluid properties from Cypress Sandstone samples
• Collected oil and brine samples from Noble Field with the assistance of Citation Oil and Gas
• Next Step: Conduct laboratory experiments to assess properties of oil and brine samples
  – Oil: MMP
  – Brine: Composition
Reservoir Simulation

- Conducting sensitivity analyses of oil saturation distribution within the transition zone and ROZs
- Simulating reservoir conditions using the simple geocellular model to identify and test methods for representing initial oil saturation in a ROZ
- Generating simulation input files that closely replicate production and injection history at Noble Field
- Reviewing literature of EOR techniques in nonconventional ROZs
- Next Step: Conduct simulations to match production history to the rigorous Noble Field thick Cypress Sandstone geocellular model
Resource Estimate

- Refining regional isopach map
- Classifying regional isopach map by facies to define CO$_2$ storage resource in the thick Cypress Sandstone
- Next Step: Integrate mapping, geology, petrophysics, and reservoir simulation to identify areas with nonconventional CO$_2$-EOR potential
Synergy Opportunities

• All projects focusing on CO$_2$-EOR would benefit from including NCNO as screening criteria

• Once an algorithm for finding ROZs in mature/well developed basins as part of this study, we look forward to comparing the results with findings from the Williston and powder River Basins

• Findings from this study will advance knowledge and awareness of the thick Cypress Sandstone as an ncCO$_2$-EOR resource and should provide the framework for an eventual field demonstration
Summary

• Key Findings
  • Tilted OWC in Noble Field implies current hydrodynamic forces and is a key indicator of possible ROZ

• Lessons Learned
  • Difficulty in obtaining new data due to economics of oil industry – new drilling in the basin has decreased

• Future Plans
  • Continue geologic characterization of the thick Cypress Sandstone at Noble Field and elsewhere to understand the range or reservoir conditions in the basin where ROZs may exist
Acknowledgments

• Through a university grant program, IHS Petra and Landmark Software was used for the geologic and reservoir modeling
Appendix: Organization Chart

U.S. Department of Energy
Bruce Brown

Scott Frailey
Co-P.I.

ISGS
Nathan Webb
Pi.

Hannes Leetaru
Co-P.I.

A. Bernard
Prog. Coordinator

D. Klen
Science Editor

Task 2 - Geology and Reservoir Characterization

Oilfield Selection
John Grube

G. Asquith
J. Best
J. Freiberg
N. Grigsby
H. Leetaru
R. Okwen
N. Webb
Grad Student
Undergrad
Student
Task 2.1

J. Crockett
S. Frailey
B. Huff
Z. Askari
Y. Lasemi
H. Leetaru
R. Okwen
B. Seyler
N. Webb
Task 2.2

Petrophysics
Scott Frailey

Geologic Modeling
Nathan Webb

Data Synthesis and
Analysis
Nathan Grigsby

Fluid Analysis and
Geochemical Modeling
Peter Berger

Geocellular Modeling
Nathan Grigsby

Reservoir Simulation
Roland Okwen

Resource Estimate
Chris Monson

Economics
Charles Monson

Task 3 - Geocellular and Reservoir Modeling

Task 4 - CO2-EOR and Storage Development Strategies

Task 2.1 & 3.1

G. Asquith
J. Best
D. Byers
J. Freiberg
J. Grube
B. Huff
Z. Askari
Y. Lasemi
H. Leetaru
B. Seyler
Grad Student
Undergrad
Students
Task 2.1 & 3.1

J. Crockett
J. Grube
J. damico
D. Garner
B. Huff
Z. Askari
C. Melchi
A. Metcalf
N. Webb
F. Yang
Grad Student
Task 3.2

S. Frailey
J. Freiberg
R. Okwen
N. Webb
F. Yang
Task 3.2

J. Best
N. Grigsby
J. Grube
Z. Askari
H. Leetaru
B. Seyler
N. Webb
Grad Student
Task 3.3

S. Frailey
N. Grigsby
N. Webb
F. Yang
Task 3.4 & 4.1

Task 3.3

S. Frailey
N. Grigsby
N. Webb
F. Yang
Task 3.2

Task 4.1

S. Frailey
J. Grube
C. Monson
B. Seyler
N. Webb
Grad Student
Task 4.2

Task 4.3

S. Frailey
J. Grube
B. Seyler
N. Webb
Grad Student
Task 4.3

Illinois State Geological Survey 27
Appendix: Gantt Chart
Appendix: Bibliography