A Nonconventional CO₂-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

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Reporting Period End Date: 09/30/2017
Report Term: Quarterly
Signature of Submitting Official:

Nathan D. Webb: 

[Signature]
2. ACCOMPLISHMENTS

What was done? What was learned?

Overall, the project is on schedule and within the budget for this quarter. Major accomplishments include:

- Full diameter core was cut from the Long #2 within the Noble Field in May to assess the presence residual oil saturation. A sample from the top of the core was sent to Weatherford Labs for hydrocarbon extraction and GCMS. Initial analyses suggest only a trace amount (less than 0.001 wt.%). It is possible that the location of the Long-2 core was too far off structure and the core is too deep within the water column to capture the suspected ROZ.

What are the major goals of the project and what was accomplished under these goals?

The major goals of the project include identifying and quantifying nonconventional carbon dioxide ($\text{CO}_2$) storage and enhanced oil recovery (EOR) opportunities in the thick Cypress Sandstone in the Illinois Basin through geologic reservoir characterization, three-dimensional geocellular modeling, fluid properties and interaction modeling, and reservoir simulation. A study of the economics of potential storage and EOR programs in the thick Cypress will be made with considerations for production of net carbon negative oil. Field development strategies will be recommended with emphasis on near-term deployment. Accomplishments towards these goals are listed below by task as outlined in the SOPO.

Task 1.0–Project Management and Planning (on schedule)

- Progress on completion of tasks, subtasks, deliverables, and milestones is tracked using Microsoft Project to ensure timely completion. Overall, this project is on schedule.
- Principal investigator (PI) Nathan Webb and co-PI Scott Frailey, along with Nathan Grigsby, met weekly to discuss project management.
- There were regular meetings with the PI and subtask leaders for active subtasks.
- Damon Garner continued to develop a workflow to load all newly measured permeability and porosity data, as well as petrographic descriptions, into a database. The database will provide these data for a static or dynamic Cypress Core webpage.
Task 2.0–Geology and Reservoir Characterization (on schedule)

Subtask 2.1–Literature Review and Oilfield Selection

- Subtask concluded on 6/30/2015.

Subtask 2.2–Petrophysical Analysis

- Nathan Grigsby refined the method of using multiple open-hole well logs to identify and characterize the ROZ at Noble Field.
  - 96 wells were statistically analyzed and used to create maps to ensure consistent results. Parameters expected to be homogenous on the field scale converged on reasonable values (Figure 1) and oil was thickest in the center of the field (Figure 2).
  - Nathan Grigsby and Scott Frailey continued work on a publication tentatively titled “Methodology for using well logs to identify residual oil zones: An example from Noble Field, Illinois.”
- Nathan Grigsby applied the method using open-hole well logs to identify and characterize ROZs developed at Noble Field to nine wells at Kenner West with neutron density porosity logs. Resulting parameters (such as the cementation exponent and oil saturation at the producing oil water contact) and general porosity trends from these wells were used, along with a spontaneous potential derived porosity to calculate water saturation curves for an additional 26 wells drilled in the 1940s that only had e-logs (resistivity and spontaneous potential). Preliminary results indicate that these wells with old e-logs can be used to estimate the initial saturation and fluid contacts (the location of oil and water within the thick Cypress).

Subtask 2.3–Geologic Model Development

- Nathan Webb and Kalin Howell described and sampled the Long #2 core that was cut from Noble Field in May (Figure 3).
  - 45 plugs were drilled from the whole core for porosity, permeability, and determination of residual oil saturation. 20 samples were collected for mineralogical analysis via x-ray diffraction, and six samples were collected for thin sections.
Data from the Weatherford CMI log was used to create scatter plots for analysis of paleoflow directions to aid in the interpretation of depositional environment. The Long #2 core is strategically placed in a portion of the Illinois Basin lacking thick Cypress sandstones rock samples, and thus supports ongoing efforts to develop a depositional model of thick Cypress Sandstones.

- Nathan Webb continued work on the analogous Pennsylvanian sandstones in Lawrence County. Though texturally dissimilar (Pennsylvanian sandstones are generally coarser grained and have a wider range of grain sizes), The Pennsylvanian sandstones exhibit similar facies associations to the Cypress Sandstone – i.e. both formations are dominated by thick successions of clean, cross bedded to ripple bedded sandstones with similar reservoir properties.

- Mingyue Yu continued research on the relationship between fluorescence emission of hydrocarbon fluid inclusions in petrographic thin sections and API gravity of the oil. He examined and performed UV Raman Spectroscopy on thin sections collected from multiple wells with assistance from University of Illinois Material Research Lab staff member, Dr. Julio Soares.
  - Mingyue analyzed the resulting fluorescence data and created analysis tools for comparing the API gravity of fluid inclusion to that of produced oil in the field may reveal generations of oil migration because of ROZ formation.

Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO2 Fluid Property Characterization

- Peter Berger performed a fourth slim-tube test to determine the minimal miscible pressure of the collected Cypress oil sample from Noble Field.
- Donna Willette did detailed aromatic compound geochemical analyses on the Carrie Winter #5 well from Noble Field to bracket maturity indicators and paleoenvironmental source rock conditions.
  - Triaromatic steroids (TAS) ratio indicates a $R_o$ equiv. of 0.74 – a higher maturity value than indicated by the whole-oil GC chromatogram. Vitrinite reflectance
(R<sub>o</sub>) is a measurement taken on vitrinite macerals to ascertain maturity. There are a variety of geochemical indicators to determine a R<sub>o</sub> equivalent value. (Figure 4)

- The ratio of TAS to monoaromatic steroids (MA) also indicates a higher maturity value than determined from whole-oil GC chromatogram – 0.65 R<sub>o</sub> equiv. (Figure 4)
- R<sub>o</sub> derived by Genesis modeling (GEN) and values determined from the methylphenanthrenes and dibenzothiophenes aromatic markers are probably not reliable (Figure 5). Ro calculated from Genesis modeling relies on a robust time/temperature relationship during burial of source intervals. The calculated Ro was much too high when compared to other maturity indicators, suggesting that the time/temperature relationship needs to be constrained and re-analyzed for better results. The aromatic markers (when compared with measured Ro values, HI and TMAX maturity indicators) also indicated levels of maturity that were inconsistent in comparison with other geochemical and aromatic markers.

- Donna Willette had two plugs from the Long-2 core (depth 2323’) extracted to see if any residual hydrocarbons were present. Initial analyses suggest only a trace amount (less than 0.001 wt.%). The whole-oil GC chromatograms indicated measureable n-alkanes present up to nC-34. Further analyses of markers needs to be completed to gain insight if the extracts suggest some degree of biodegradation.

**Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics**


**Subtask 3.4–Reservoir Modeling**

- Fang Yang finished history matching production data at Noble Field by adjusting initial water saturation profile, relative permeability curve exponents, and well bottom hole pressure constraints.
- Fang Yang ran baseline continuing current operation scenario and CO<sub>2</sub> injection in “as-is” pattern scenario for Noble Field.
Task 4.0—CO₂ EOR and Storage Development Strategies (on schedule)

Subtask 4.1—Field Development Strategies

- Fang Yang began simulating field development strategies, including different patterns and conformance scenarios, for the thick Cypress in Noble Field.

Subtask 4.2—CO₂ EOR and Storage Resource Assessment

- Zohreh Askari used 68 wells from Washington and Perry Counties to expand the growing database of thickness information for the CO₂-EOR and Storage Resource assessment. Only those wells with reliable geophysical logs were selected. Askari determined top, base, formation thickness, and net sandstone thickness of the Cypress Sandstone in the selected wells and incorporated them to the regional map.

Subtask 4.3—Economic Analysis

- Haley Anderson and Scott Frailey entered modeling data into the spreadsheets for use in economic analysis based on the results of the simulated CO₂ EOR scenarios.
Figure 1. Box and whisker plots for oil saturation for each interval (MPZ, ROZ, all Cypress) and at the POWC. The plots were constructed using median values for each interval based on the petrophysical analysis of 96 wells at Noble Field. These results indicate that the analysis produced consistent and reasonable results, with decreasing oil saturation with depth and distinct oil saturation between each interval. The values converging at the POWC and within the ROZ indicates that the oil saturation necessary to be mobile and residual oil saturations are between 37-45% and 20-26%, respectively.
Figure 2. Map of the oil thickness (MPZ+ROZ) at Noble Oil Field. Boundary of the field is shown with a black line. Oil thicknesses are based on water saturation curves from 96 wells (red dots). Oil is thickest in the center of the field and reduces to zero at the periphery.
Figure 3. Graphical log of the Long-2 Core from Noble field showing subtle fining upward of the lowermost sandstone overlain by another sandstone body that meets it along an erosional contact. Channel bases in the Cypress Sandstone such as this generally exhibit a subtle grain size increase that correlates with an increase in permeability. This relationship has been observed in cores across the basin as well as in outcrop.
Figure 4. GC-MS of ion mass 231.30 – tri/monoaromatic steroids. Annotated ratios included on fragmentogram.

Figure 5. Comparison of measured and calculated Ro values with selected aromatic markers. Aromatic markers utilized in parentheses.
What opportunities for training and professional development has the project provided?

Three undergraduate students and one MS student have been involved in research on the project during the quarter. Under advisement of project staff and University of Illinois professors, each student is developing skills in a particular discipline, such as routine and advanced core analysis, thin section petrography, and stratigraphy and sedimentology. The students are learning various techniques for their respective disciplines, and they are meeting and sharing findings with each other to better understand their roles in the larger framework of the project and to gain experience in presenting their research.

A few specific examples include the following:

- Erich Ceisel and Dmytro Lukhtai, undergraduate students, are developing protocols and procedures to conduct core flood experiments with core plugs that are saturated with a surrogate oil (representative of oil samples from the Cypress) and systematically flushed with brine to determine the number of pore volumes necessary to reach residual oil saturation. These core floods, in combination with resistivity measurements will be key to determining the expected oil saturations in Cypress ROZs and their resultant electrical properties for identification via petrophysical methods.

- Kalin Howell, a graduate student, recently completed his MS and is organizing his research findings into a manuscript for publication in a peer reviewed journal.

A Vinci Technologies representative, J. Moreau, from France was at the ISGS for the purpose of setting up the new Capillary Pressure/Resistivity equipment and training ISGS staff. The training was about a week. Staff were acquainted with the machine and all the necessary procedures involved with operating and maintaining the device.

How have the results been disseminated to communities of interest?

- The project website (http://isgs.illinois.edu/research/ERD/NCO2EOR) hosts a project summary, staff bios, and downloadable reports and presentations to disseminate project information and findings to the public and other interested parties.

- Several presentations were made this quarter, including:


Draft manuscripts include:


Grigsby, N.P, and S.M Frailey, Methodology for using well logs to identify residual oil zones: An example from Noble Field, Illinois.


Grigsby, N.P., and N.D. Webb, Using detailed geologic characterization to construct a representative geocellular model of the thick Cypress Sandstone in Noble Oil Field, Illinois, for CO2-EOR and storage.


Webb, N.D., and N.P. Grigsby, Geologic characterization of the Cypress Sandstone in the Kenner West Oil Field, Western Richland County, Illinois, for nonconventional CO2-enhanced oil recovery and storage.

Webb, N.D., and N.P. Grigsby, Geologic characterization of the Cypress Sandstone in the Noble Oil Field, Western Richland County, Illinois, for nonconventional CO2-enhanced oil recovery and storage.

What do you plan to do during the next reporting period to accomplish the goals?

Task 1.0–Project Management and Planning (on schedule)

- Progress on completion of tasks, subtasks, deliverables, and milestones will continue to be tracked using Microsoft Project to ensure timely completion.
- The PI and co-PIs will continue to meet weekly to discuss project management.
- Regular meetings with the PI and subtask leaders will continue for active subtasks.
- Work will continue to build the database for an online core visualization website.

Task 2.0–Geology and Reservoir Characterization (on schedule)

Subtask 2.1–Literature Review and Oilfield Selection

- Subtask concluded on 6/30/2015.

Subtask 2.2–Petrophysical Analysis

- Nathan Grigsby and Scott Frailey will continue to work on a report tentatively titled “Methodology for using well logs to identify residual oil zones: An example from Noble Field, Illinois.” This method should be a quick and inexpensive screening tool to assess ROZ potential using existing well logs.
- The method of using open-hole well logs to identify ROZs will be applied to other fields around the Illinois Basin to determine if they contain ROZs.

Subtask 2.3–Geologic Model Development

- Complete the analyses of samples from the Long #2 core from Noble Field.
- Nathan Webb and Kalin Howell will conclude the oilfield-scale studies of the Cypress Sandstone and shift focus to the regional geology in preparation for the regional resource assessment.
- Kalin Howell plans to use a drone to photograph outcrops of Cypress Creek to better access and describe features inaccessible from ground level.
- Mingyue Yu plans to compile findings of the relationship between UV spectroscopy and hydrocarbon inclusions’ API gravity in thin sections, and finish report.
Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis


Subtask 3.2–Illinois Basin Crude Oil/Brine-CO₂ Fluid Property Characterization

- Peter Berger plans to contribute the following work:
  - Complete the slim-tube testing and determine the minimum miscibility pressure of oil samples from the Cypress in Noble Field.
  - Continue working on the geochemical model of earlier core flood work.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Geocellular models will be updated as deemed necessary, as history matching progresses.

Subtask 3.4–Reservoir Modeling

- Fang Yang will finish modeling CO₂ EOR scenarios at Noble field including various well type, injection pattern, and perforation intervals.

Task 4.0–CO₂ EOR and Storage Development Strategies (on schedule)

Subtask 4.1–Field Development Strategies

- Roland Okwen is currently performing analysis of reservoir simulation results, which will be used to predict performance of CO₂-EOR at Kenner West.

- Fang Yang will analyze simulation results and predict CO₂-EOR performance at Noble field.

- Fang Yang, Roland Okwen, Nathan Webb, Nathan Grigsby, and Scott Frailey will continue writing a topical report CO₂-EOR Development Guidelines for Brown Field Residual Oil Zones in A Fluvial Sandstone.

Subtask 4.2–CO₂ EOR and Storage Resource Assessment

- Zohreh Askari will continue revising the basin–wide Cypress isopach map, which will include screening more wells.

- Work will begin to develop estimates of CO₂-EOR and storage potential and economic analysis of implementing the program.

Subtask 4.3–Economic Analysis
Haley Anderson and Scott Frailey will find current well completion, drilling and abandonment costs to use in CO$_2$-EOR economics.
## Project Milestone Log

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<th>Task</th>
<th>Calendar Year</th>
<th>Milestone Title/Description</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
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<td>Agreement between ISGS and DOE project manager to proceed with specific areas of study</td>
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<td>Oilfield data synthesis and analysis</td>
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<td>Wells/leases grouped into classes representing relative degree of productivity</td>
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<td>Complete petrophysical analysis, geologic and geocellular modeling of the thick Cypress</td>
<td>10/31/2016</td>
<td>10/31/2016</td>
<td>Completion of draft topical report on geology of the thick Cypress in the ILB</td>
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<td>Complete new coring near outcrop belt</td>
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<td>9/21/2017</td>
<td>Send DOE confirmation that core has been obtained and is in ISGS warehouse</td>
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3. PRODUCTS

What has the project produced?

a. Publications, conference papers, and presentations

Presentations listed on pages 11-12.

b. Website(s) or other Internet site(s)

The project website is located at http://www.isgs.illinois.edu/research/erd/nco2eor.

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Nothing to report.

5. IMPACT

Nothing to report.

6. CHANGES/PROBLEMS

Changes in approach and reasons for change

There have been no changes in approach on this project.

Actual or anticipated problems or delays and actions or plans to resolve them

There are currently no anticipated problems or delays in the project.

Changes that have a significant impact on expenditures

As no changes have been made or are anticipated, none are expected to impact expenditures.

Significant changes in use or care of human subjects, vertebrate animals, and/or Biohazards

Not applicable.

Change of primary performance site location from that originally proposed

Not applicable.

7. Special Reporting Requirements

Nothing to report.
## 8. Budgetary Information

### Financial Reporting Table

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