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A Nonconventional CO_2-EOR Target in the Illinois Basin: Oil Reservoirs of the Thick Cypress Sandstone

Nathan D. Webb, M.S. (PI), ndwebb2@illinois.edu
Scott Frailey, Ph.D. (Co-PI), sfrailey@illinois.edu
Hannes Leetaru, Ph.D. (Co-PI), hleetaru@illinois.edu
Phone: (217) 244-2426

David W. Richardson, AVCR-Director
Email: gcoaward@illinois.edu
Phone: (217) 333-2187
Fax: (217) 333-6830

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1901 S. First Street, Suite A
Champaign, Illinois 61820

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Reporting Period End Date: 12/31/2017
Report Term: Quarterly

Signature of Submitting Official:

Nathan D. Webb: 

2. ACCOMPLISHMENTS

What was done? What was learned?

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

- Ambient condition core flow-through experiments have begun to determine the residual saturation in core plugs using surrogate fluids. These experiments are necessary to (1) determine the theoretical Residual Oil Saturations (S_{OR}) that may be present in a Cypress ROZ, and (2) provide a means to calibrate well log derived fluid saturations.

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 (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, resistivity data, and core and 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 applied the method of using open-hole well logs to identify and characterize ROZs developed at Noble and Kenner West Fields to targeted wells around the basin in order to locate areas that potentially contain ROZs.
- 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."
- Peter Berger directed undergrad students and a recent hire (Micah Awe) in the creation of new, low pressure, core-flood systems to determine residual oil saturation and resistivity of Cypress core plugs.

Subtask 2.3–Geologic Model Development

- Sample analyses of the Long #2 core from Noble Field have completed. Analyses include porosity, permeability, residual saturation, and resistivity of core plugs, clay mineralogy of complimentary samples, and grain size analyses of thin sections.
- Nathan Webb is working with Dr. Liliana Lefticariu, a geochemist from Southern Illinois University, Carbondale, to analyze carbonate cements within the Cypress Sandstone via isotopic analyses and petrography to test the hypothesis that some cements form at the oil-water contact as a possible result of natural waterflooding during the ROZ forming process, and thus may be a newly discovered ROZ indicator.
- Kalin Howell completed the first draft of a manuscript entitled "The sedimentology of a large Carboniferous fine-grained river: facies, paleohydraulics, and implications for reservoir heterogeneity" which is based on his MS thesis.
- Nathan Webb continued work on analogous Pennsylvanian sandstones in Lawrence County. Though texturally dissimilar to the Cypress (Pennsylvanian sandstones are generally coarser grained and have a wider range of grain sizes), they exhibit similar facies associations – i.e. both formations are dominated by thick successions of clean, cross bedded to ripple bedded sandstones with similar reservoir properties.

- John Grube completed cross sections and mapping of the thick Cypress in the southern portion of Loudon Oil Field in order to better understand the stratigraphic relationship of the thick sandstone to the remainder of the formation near the facies boundary of the thick sandstone fairway.
- Mingyue Yu continued research on the relationship between fluorescence emission of hydrocarbon fluid inclusions in petrographic thin sections and API gravity of the oil and whether the study of these fluid inclusions can provide information on the migration pathway of different API gravity oils. 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.

Task 3.0–Geocellular and Reservoir Modeling (on schedule)

Subtask 3.1–Historical Production and Injection Data Analysis

- Subtask concluded 3/31/2016.

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO_2 Fluid Property Characterization

- Peter Berger performed two further slim-tube tests to determine the minimal miscible pressure of the collected Cypress oil sample from Noble Field but had difficulty obtaining reliable results due to problems with the slim tube apparatus. Peter arranged for the collection of more oil samples for analysis once the slim tube issues are resolved.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Nathan Grigsby and Nathan Webb received comments and resubmitted a report to ISGS internal review titled "Assessing the Cypress Sandstone for CO_2-Enhanced Oil Recovery and Carbon Storage: Part II - Leveraging geologic characterization to develop a representative geocellular model for Noble Oil Field, Western Richland County, Illinois" for internal review.

Subtask 3.4–Reservoir Modeling

- Fang Yang attempted running baseline continuing current operation, CO_2 injection in "as-is" pattern, five spot pattern floods, and horizontal well scenarios for Noble Field.

Task 4.0–CO_2 EOR and Storage Development Strategies (on schedule)

Subtask 4.1–Field Development Strategies

- Fang Yang, Roland Okwen, Nathan Webb, Nathan Grigsby, and Scott Frailey continued writing a joint topical report/SPE conference paper entitled CO_2-EOR Development Guidelines for Brown Field Residual Oil Zones in A Fluvial Sandstone.

Subtask 4.2–CO_2 EOR and Storage Resource Assessment

- Nathan Grigsby and Nathan Webb analyzed 170 candidate wells from around the basin and selected 47 with adequate logs to have digitized for oil saturation determination.
- Zohreh Askari used 30 wells from Madison County to expand the growing database of thickness information for the CO_2-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 continued to enter modeling data into the spreadsheets for use in economic analysis based on the results of the simulated CO_2-EOR scenarios.

What opportunities for training and professional development has the project provided?

Three undergraduate students and one recent MS graduate 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 recent MS graduate is organizing his research findings into a manuscript for publication in a peer reviewed journal.

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.
- Zohreh Askari presented a poster entitled "Stratigraphic variability and reservoir characterization of the Mississippian Cypress Sandstone in the deep area of the Illinois Basin" at the annual Geological Society of America Meeting in Seattle, WA, October 22-25, 2017.
- Kalin Howell presented a talk entitled "The sedimentology of a large Carboniferous fine-grained river: facies, paleohydraulics, and implications for reservoir heterogeneity" as part of the weekly ISGS seminar series on November 6, 2017.
- Nathan Webb presented a talk entitled "Studies and Field Data on a Cypress Sandstone ROZ in Illinois" at the CO_2 and ROZ Conference in Midland, TX, on December 6, 2017.
- Draft manuscripts include:
    - Giannetta, L.G., N.D. Webb, S.K. Butler, and N.P. Grigsby, Using clay microporosity to improve formation evaluation in potential residual oil zones: Cypress Sandstone, Illinois Basin.
    - 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, A method for developing the production history of Illinois Basin geologic formations.
    - Grigsby, N.P., and N.D. Webb, Assessing the Cypress Sandstone for CO2-Enhanced Oil Recovery and Carbon Storage: Part II - Leveraging geologic characterization to develop a representative geocellular model for Noble Oil Field, Western Richland County, Illinois.

- Howell, K.J., Sedimentology of multistory fluvial sandstones of the Mississippian Cypress Formation, Illinois, USA: MS Thesis.
- Howell, K.J., N.D. Webb, J.L. Best, and E.W. Prokocki, The Sedimentology of a Large Carboniferous Fine-Grained River: Facies, Paleohydraulics, and Implications for Reservoir Heterogeneity
- Webb, N.D., and N.P. Grigsby, Assessing the Cypress Sandstone for CO2-Enhanced Oil Recovery and Carbon Storage: Part I - Reservoir Characterization of Noble Oil Field, Western Richland County, Illinois.
- Yang, F., R.T. Okwen, N.D. Webb, N.P. Grigsby, and S.M. Frailey, CO_2-EOR Development Guidelines for Brown Field Residual Oil Zones in A Fluvial Sandstone.

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 the 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 will expand the application of the method of using open-hole well logs to identify and characterize ROZs to additional wells across the basin.
- 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

- Geologic model development will conclude following the completion of characterization efforts in Noble, Kenner West, Dale, and Loudon Fields.
- 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 concluded on 3/31/2016.

Subtask 3.2–Illinois Basin Crude Oil/Brine-CO_2 Fluid Property Characterization

- Peter Berger plans troubleshoot problems with the slim tube apparatus, attempt to correct the errors and complete the final slim tube experiment for minimum miscibility pressure.
- Mingyue Yu plans to compile API gravity findings into maps that correlate same API gravity with data from Arc GIS for well location and complete reports of fluorescence and hydrocarbon inclusions within section study.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Nathan Grigsby and Nathan Webb will submit "Assessing the Cypress Sandstone for CO_2-Enhanced Oil Recovery and Carbon Storage: Part II - Leveraging geologic characterization to develop a representative geocellular model for Noble Oil Field, Western Richland County, Illinois" for external peer review.

Subtask 3.4–Reservoir Modeling

- Roland Okwen and Fang Yang will finish modeling CO_2-EOR scenarios at Kenner West and Noble Fields, respectively, including various well type, injection pattern, and perforation intervals.

Task 4.0–CO_2 EOR and Storage Development Strategies (on schedule)

Subtask 4.1–Field Development Strategies

- Roland Okwen is currently performing analysis and interpretation of reservoir simulation results, which will be used to predict performance of CO_2-EOR at Kenner West.
- Fang Yang will analyze simulation results and predict CO_2-EOR performance at Noble Field.
- Fang Yang, Roland Okwen, Nathan Webb, Nathan Grigsby, and Scott Frailey will finalize and submit (to DOE and SPE, respectively) a joint topical report/SPE conference paper entitled CO_2-EOR Development Guidelines for Brown Field Residual Oil Zones in A Fluvial Sandstone.

Subtask 4.2–CO_2 EOR and Storage Resource Assessment

- Nathan Webb, Chris Korose, and Nathan Grigsby will begin the regional play analyses of the Cypress ROZ. This this will include estimates of CO_2-EOR and storage potential and economic analysis of implementing the program.

Subtask 4.3–Economic Analysis

- Haley Anderson and Scott Frailey continued to enter modeling data into the spreadsheets for use in economic analysis based on the results of the simulated CO2-EOR scenarios.

Project Milestone Log

Task	Calendar Year	Milestone Title/Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments
1.0	1	Project Management Plan	12/31/2014	12/15/2014	PMP File	100% Complete
1.0	1	Kickoff Meeting	12/31/2014	12/4/2014	Presentation File	100% Complete
2.0	2	Final selection of oilfields for study	3/31/2015	3/20/2015	Agreement between ISGS and DOE project manager to proceed with specific areas of study	100% Complete
2.0	2	Oilfield data synthesis and analysis	10/31/2015	10/21/2015	Wells/leases grouped into classes representing relative degree of productivity	100% Complete
2.0	3	Analogous Lower Pennsylvanian study areas selected	4/30/2016	4/29/2016	Agreement between ISGS and DOE project manager to proceed with specific areas of study	100% Complete
2.0, 3.0	3	Complete petrophysical analysis, geologic and geocellular modeling of the thick Cypress	10/31/2016	10/31/2016	Completion of draft topical report on geology of the thick Cypress in the ILB	100% Complete
2.0	4	Complete new coring near outcrop belt	9/30/2017	9/21/2017	Send DOE confirmation that core has been obtained and is in ISGS warehouse	100% Complete
4.0	3	Complete guidelines to develop thin oil zones and store CO_2 in the thick Cypress	12/31/2017		Completion of draft topical report on guidelines to develop thin oil zones in the thick Cypress	95% Complete
4.0	4	Complete estimates of CO_2-EOR and storage potential and economic analysis of implementing program	8/30/2018		Completion of draft topical report on CO_2-EOR, storage, and economics of the thick Cypress in the ILB	35% Complete
All	4	Document project results	10/31/2018		Complete final report	In progress

3. PRODUCTS

What has the project produced?

a. Publications, conference papers, and presentations

Presentations listed on pages 6-7.

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

Baseline Reporting	Budget Period 1 11/01/14 - 10/31/17													Budget Period 2 11/01/17 - 10/31/18					Total
	FY15 Q1	FY15 Q2	FY15 Q3	FY15 Q4	FY16 Q1	FY16 Q2	FY16 Q3	FY16 Q4	FY17 Q1	FY17 Q2	FY17 Q3	FY17 Q4	FY18 Q1	FY18 Q1	FY18 Q2	FY18 Q3	FY18 Q4	FY19 Q1	
Baseline Federal Share	192,267	192,267	192,265	193,061	205,360	205,360	205,360	205,359	121,852	121,852	121,853	121,852	58,543	117,085	175,628	175,628	117,085	58,544	2,781,221
Baseline non-Federal Share	30,889	46,334	46,334	46,334	44,028	44,028	44,028	44,028	44,028	44,028	44,028	44,028	15,444	29,253	43,880	43,880	43,880	14,627	713,079
Total Baseline Cumulative Cost	223,156	238,601	238,599	239,395	249,388	249,388	249,388	249,387	165,880	165,880	165,881	165,880	73,987	146,338	219,508	219,508	160,965	73,171	3,494,300
Actual Federal Share	9,661	82,633	112,827	147,250	124,049	114,637	164,036	164,146	158,143	177,806	251,648	147,697	78,072	143,560					1,876,165
Actual non-Federal Share	29,328	48,918	47,155	43,688	43,603	48,447	44,874	45,329	45,391	45,680	37,277	34,701	11,711	23,423					549,523
Total Actual Cumulative Cost	38,989	131,551	159,982	190,937	167,652	163,083	208,909	209,475	203,534	223,486	288,925	182,398	89,784	166,983	0	0	0	0	2,425,689
Variance Federal Share	182,606	109,634	79,438	45,811	81,311	90,723	41,324	41,213	(36,291)	(55,954)	(129,795)	(25,845)	(19,529)	(26,475)	175,628	175,628	117,085	58,544	905,056
Variance non-Federal Share	1,561	(2,584)	(821)	2,646	425	(4,419)	(846)	(1,301)	(1,363)	(1,652)	6,751	9,327	3,733	5,830	43,880	43,880	43,880	14,627	163,556
Total Variance Cumulative Cost	184,167	107,050	78,617	48,458	81,734	86,305	40,478	39,912	(37,654)	(57,606)	(123,044)	(16,518)	(15,797)	(20,645)	219,508	219,508	160,965	73,171	1,068,611