US Department of Energy
National Energy Technology Laboratory (NETL)

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

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Reporting Period End Date: 03/31/2019
Report Term: Quarterly

Signature of Submitting Official:

Nathan D. Webb: 

2. ACCOMPLISHMENTS

What was done? What was learned?

Major accomplishments include:

- Reservoir simulations of eight full-field development scenarios for Noble Field were completed that varied injection pattern (40-acre 5-spot, 80-acre 5-spot, peripheral, soak-alternating-gas (SAG) and pattern re-alignment and expansion (PRE)), placement of injection/production perforations (MPZ only, ROZ only, MPZ and ROZ). Preliminary results indicate relatively low oil recovery factor. Because gravity is the dominant displacement mechanism, an oil bank (low saturation) develops as CO_2 rises to the top of each zone while displacing oil and water downwards. However, application of the PRE method shows the most promising results (9.8% EOR).

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.
- Manuscripts developed over the course of the project are being compiled into the project final report.

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

- Subtask concluded 10/31/2017.
- Nathan Grigsby and Scott Frailey continued work on a publication titled "Methodology for using well logs to identify residual oil zones: An example from Noble Field, Illinois." This method provides a screening tool to assess ROZ potential using existing well logs.

Subtask 2.3–Geologic Model Development

- Subtask concluded on 2/28/2018.
- Nathan Webb continued work with collaborators from the University of Illinois Geology department on a manuscript titled "The Sedimentology of a Large Fine-Grained Carboniferous River: Facies, Palaeohydraulics, and Implications for Reservoir Heterogeneity"

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

- Subtask concluded on 2/28/2018
- Capillary pressure tests were performed on three samples that were also core flooded in order to correlate the residual saturation values of the two techniques. The results are being analyzed.

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Subtask concluded on 3/1/2018.

Subtask 3.4–Reservoir Modeling

- Subtask concluded on 4/3/2018.

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

Subtask 4.1–Field Development Strategies

- History matching of the Noble Field model is complete.
- Roland Okwen conducted reservoir simulations of eight full-field development scenarios for Noble Field that varied injection pattern (40-acre 5-spot, 80-acre 5-spot, peripheral, soak-alternating-gas (SAG) and pattern re-alignment and expansion (PRE)), placement of injection/production perforations (MPZ only, ROZ only, MPZ and ROZ). Preliminary results indicate relatively low oil recovery factor. Because gravity is the dominant displacement mechanism, an oil bank (low saturation) develops as CO_2 rises to the top of each zone while displacing oil and water downwards. However, application of the PRE method shows the most promising results (9.8% EOR).

Subtask 4.2–CO_2 EOR and Storage Resource Assessment

- Subtask concluded 9/30/2018
- Nathan Webb and Nathan Grigsby are analyzing additional data to provide higher confidence of ROZ prospect dimensions and saturations in order to revise the CO_2-EOR and storage estimates for the final version of the CO_2 Storage and EOR Resource Assessment of the Cypress Sandstone Residual Oil Zone Play in the Illinois Basin.

Subtask 4.3–Economic Analysis

- Scott Frailey analyzed the economic implications of the reservoir simulation results. Most scenarios have favorable rate of return (>15%) with flat oil prices at $50/bbl and CO_2 tax credit wherein new CO_2 to project had no cost ($0/tonne). Project life is 5-10 years due to costs of recycling CO_2, which causes negative annual net cash flow.

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

Three undergraduate students and one recent BS 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 discipline, such as routine and advanced core analysis, thin section petrography, and stratigraphy and sedimentology. The students are learning various techniques and are meeting and sharing findings with project staff to better understand their roles in the larger framework of the project and to gain experience in presenting their research.

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.
- Draft manuscripts include:
    - Giannetta, L.G., N.D. Webb, S.K. Butler, and N.P. Grigsby, *in review*, 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, *in press*, 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.
    - Henderson, S.K., and Asquith, G.B., Methods for Identifying Fluid Contacts and Characterizing an ROZ using Conventional Well Logs, Mississippian Thick Cypress Sandstone, Illinois Basin
    - 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, *in press*, Assessing the Cypress Sandstone for CO_2-Enhanced Oil Recovery and Carbon Storage: Part I - Reservoir Characterization of Noble Oil Field, Western Richland County, Illinois.
- Webb, N.D., N.P. Grigsby, and S.M. Frailey, CO_2 Storage and EOR Resource Assessment of the Cypress Sandstone Residual Oil Zone Play in the Illinois Basin
- 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.

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

- Subtask concluded 10/31/2017.
- Nathan Grigsby and Scott Frailey will continue to work on a paper tentatively titled "Methodology for using well logs to identify residual oil zones: An example from Noble Field, Illinois."

Subtask 2.3–Geologic Model Development

- Subtask concluded 2/28/2018.
- Nathan Webb will continue work with collaborators from the University of Illinois Geology department on a manuscript titled "The Sedimentology of a Large Fine-Grained Carboniferous River: Facies, Palaeohydraulics, and Implications for Reservoir Heterogeneity"

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

- Subtask concluded on 2/28/2018

Subtask 3.3–Geocellular Modeling of Interwell Reservoir Characteristics

- Subtask concluded on 3/1/2018.

Subtask 3.4–Reservoir Modeling

- Subtask concluded on 4/3/2018.

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

Subtask 4.1–Field Development Strategies

- Subtask concluded 7/31/2018
- Roland Okwen will conclude the reservoir simulations of the CO_2-EOR scenarios and analyze the results.

Subtask 4.2–CO_2 EOR and Storage Resource Assessment

- Subtask concluded 9/30/2018

Subtask 4.3–Economic Analysis

- Scott Frailey will conclude the economic analysis once the results of the simulated CO_2-EOR scenarios are finalized.

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	1/31/2018	Completion of draft topical report on guidelines to develop thin oil zones in the thick Cypress	100% Complete
4.0	4	Complete estimates of CO_2-EOR and storage potential and economic analysis of implementing program	8/31/2018	8/31/2018	Completion of draft topical report on CO_2-EOR, storage, and economics of the thick Cypress in the ILB	100% Complete
All	4	Document project results	4/30/2019		Complete final report	In progress

3. PRODUCTS

What has the project produced?

a. Publications, conference papers, and presentations

Presentations and manuscripts listed on pages 5-6.

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													Budget Period 2							Total
	11/01/14 - 10/31/17													11/01/17 - 4/30/19							
	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	FY19-Q2	FY19-Q3	
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	165,525	173,034	142,424	147,159	217,442		2,721,749
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	34,419	38,146	39,916	44,187	14,246		720,437
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	199,943	211,180	182,340	191,346	231,688		3,442,1868
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)	10,103	2,594	(25,339)	(88,615)	(217,442)		59,473
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	9,461	5,734	3,964	(29,560)	(14,246)		(7,358)
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)	19,564	8,328	(21,375)	(118,175)	(231,688)		52,114