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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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Signature of Submitting Official:

Nathan D. Webb: 

2. ACCOMPLISHMENTS

What was done? What was learned?

Major accomplishments include:

- Reservoir simulations of 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)

- Manuscripts developed over the course of the project have been 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.

Subtask 2.3–Geologic Model Development

- Subtask concluded on 2/28/2018.

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

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

- Roland Okwen completed reservoir simulations of 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).
- The following conclusions can be drawn from the Noble Field simulation results presented herein:
    - Of the injection design cases, WAG has the highest oil recovery.
    - For low injection rates, flooding the MPZ and ROZ separately has higher oil recovery.
    - For WAG cases, the 80-acre 5-spot pattern has higher oil recovery than the 40-acre 5-spot pattern in the MPZ; the inverse is true for the ROZ.
    - ROZ floods have higher oil recovery when producers are perforated in the bottom 10 ft of the ROZ.
    - High continuous CO_2 injection rate increases oil recovery from the ROZ.

    - In terms of carbon balance, 21 of the cases are NCNO or carbon neutral.
- The elements of a development strategy for CO_2-EOR in the Noble Field (and presumably other similar brownfield ROZs) are as follows:
    - 80-acre injection pattern
    - MPZ and ROZ injection or MPZ only
    - High injection rates (leading to out-of-pattern CO_2)
    - WAG if using low injection rates
    - Continuous injection if using high injection rates

Subtask 4.2–CO_2 EOR and Storage Resource Assessment

- 27 potential ROZ prospects were identified throughout the thick Cypress fairway. They:
    - Contain approximately 290.8 million m3 (1.8 billion barrels) of oil in place (using a median SOR = 23%).
- Applying two unique CO_2-EOR development strategies derived from economic analyses of the results from reservoir simulation:
    - 31.1 million m^3 (196 million barrels) of oil is estimated to be recoverable using the 80-acre blanket WAG development strategy (which favors EOR and economic metrics, but is carbon positive)
    - 21.3 million m^3 (144 million barrels) of oil is estimated to be recoverable using the 40-acre high CO_2 injection rate development strategy (which favors storage and economic metrics and results in net carbon negative oil production).
    - Storage of CO_2 associated with EOR in these ROZ prospects alone, not accounting for associated main pay zones or underlying brine formation, is estimated to be up to 10.4 billion tonnes using the latter development strategy.

Subtask 4.3–Economic Analysis

- Scott Frailey completed the economic analysis of the reservoir simulation results. Based on the economic results of the cases simulated, traditional flooding approaches (scenario: injection pattern and spacing) that minimize CO_2 leaving the outer patterns (i.e. moving down dip away from the oil reservoir) did not have high economic metrics, while cases

with relatively higher injection rates that had more significant CO_2 move out of pattern had higher metrics. ROZ only CO_2-EOR without substantial CO_2 storage revenue (e.g. tax credits) had the lowest metrics and were uneconomic. Like traditional CO_2-EOR, WAG process had higher metrics for MPZ and ROZ CO_2-EOR.

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

Nothing to report

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 revision*, 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?

Nothing to report. Project has concluded.

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	Submitted to DOE 7/31/2019	Complete final report	100% Complete

3. PRODUCTS

What has the project produced?

a. Publications, conference papers, and presentations

Presentations and manuscripts listed on pages 4-5.

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

*FY19-Q3 number not yet available from University of Illinois as of 7/31/2019