

QUARTERLY PROGRESS REPORT

**To
DOE-NETL
David P. Cercone, Program Manager
Award Number: DE-FE0006821**

**SMALL SCALE FIELD TEST DEMONSTRATING CO₂ SEQUESTRATION IN
ARBUCKLE SALINE AQUIFER AND BY CO₂-EOR AT WELLINGTON FIELD,
SUMNER COUNTY, KANSAS**

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**Recipient: University of Kansas Center for Research &
Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047**

**Project/Grant Period: 10/1/2011 through 9/30/2017
Twenty Fourth Quarterly Report
Period Covered by the Report: June 30, 2017 through September 30, 2017**

Signature of Submitting Official:

Yevhen 'Eugene' Holubnyak

EXECUTIVE SUMMARY

PROJECT OBJECTIVES

The objectives of this project are to understand the processes that occur when a maximum of 70,000 metric tonnes of CO₂ are injected into two different formations to evaluate the response in different lithofacies and depositional environments. The evaluation will be accomplished through the use of both in situ and indirect MVA (monitoring, verification, and accounting) technologies. The project will optimize for carbon storage accounting for 99% of the CO₂ using lab and field testing and comprehensive characterization and modeling techniques.

CO₂ will be injected under supercritical conditions to demonstrate state-of-the-art MVA tools and techniques to monitor and visualize the injected CO₂ plume and to refine geomodels developed using nearly continuous core, exhaustive wireline logs, and well tests and a multi-component 3D seismic survey. Reservoir simulation studies will map the injected CO₂ plume and estimate tonnage of CO₂ stored in solution, as residual gas, and by mineralization and integrate MVA results and reservoir models shall be used to evaluate CO₂ leakage. A rapid-response mitigation plan will be developed to minimize CO₂ leakage and provide comprehensive risk management strategy. A documentation of best practice methodologies for MVA and application for closure of the carbon storage test will complete the project. The CO₂ shall be supplied from a reliable facility and have an adequate delivery and quality of CO₂.

SCOPE OF WORK

Budget Period 1 includes updating reservoirs models at Wellington Field and filing Class II and Class VI injection permit application. Static 3D geocellular models of the Mississippian and Arbuckle shall integrate petrophysical information from core, wireline logs, and well tests with spatial and attribute information from their respective 3D seismic volumes. Dynamic models (composition simulations) of these reservoirs shall incorporate this information with laboratory data obtained from rock and fluid analyses to predict the properties of the CO₂ plume through time. The results will be used as the basis to establish the MVA and as a basis to compare with actual CO₂ injection. The small scale field test shall evaluate the accuracy of the models as a means to refine them in order to improve the predictions of the behavior and fate of CO₂ and optimizing carbon storage.

Budget Period 2 includes completing a Class II underground injection control permit; drilling and equipping a new borehole into the Mississippian reservoir for use in the first phase of CO₂ injection; establishing MVA infrastructure and acquiring baseline data; establishing source of CO₂ and transportation to the injection site; building injection facilities in the oil field; and injecting CO₂ into the Mississippian-age spiculitic cherty dolomitic open marine carbonate reservoir as part of the small scale carbon storage project.

In Budget Period 3, contingent on securing a Class VI injection permit, the drilling and completion of an observation well will be done to monitor injection of CO₂ under supercritical conditions into the Lower Ordovician Arbuckle shallow (peritidal) marine dolomitic reservoir.

Monitoring during pre-injection, during injection, and post injection will be accomplished with MVA tools and techniques to visualize CO₂ plume movement and will be used to reconcile

simulation results. Necessary documentation will be submitted for closure of the small scale carbon storage project.

PROJECT GOALS

The proposed small scale injection will advance the science and practice of carbon sequestration in the Midcontinent by refining characterization and modeling, evaluating best practices for MVA tailored to the geologic setting, optimize methods for remediation and risk management, and provide technical information and training to enable additional projects and facilitate discussions on issues of liability and risk management for operators, regulators, and policy makers.

The data gathered as part of this research effort and pilot study will be shared with the Southwest Sequestration Partnership (SWP) and integrated into the National Carbon Sequestration Database and Geographic Information System (NATCARB) and the 6th Edition of the Carbon Sequestration Atlas of the United States and Canada.

Project Deliverables by Task

- 1.5 Well Drilling and Installation Plan (Can be Appendix to PMP or Quarterly Report)
- 1.6 MVA Plan (Can be Appendix to PMP or Quarterly Report)
- 1.7 Public Outreach Plan (Can be Appendix to PMP)
- 1.8 Arbuckle Injection Permit Application Review go/no go Memo
- 1.9 Mississippian Injection Permit Application Review go/no go Memo
- 1.10 Site Development, Operations, and Closure Plan (Can be Appendix to PMP)
- 2.0 Suitable geology for Injection Arbuckle go/no go Memo
- 3.0 Suitable geology for Injection Mississippian go/no go Memo
- 11.2 Capture and Compression Design and Cost Evaluation go/no go Memo
- 19 Updated Site Characterization/Conceptual Models (Can be Appendix to Quarterly)
- 21 Commercialization Plan (Can be Appendix to Quarterly Report).
- 30 Best Practices Plan (Can be Appendix to Quarterly or Final Report)

CO₂-EOR Accomplishments

1. Day-to-day field operations similar to that reported in previous two quarters (Q22 and Q23) and are a continuation of Tasks 12–15
2. Finalized monitoring of CO₂ plume movement
 - a. Recorded volumes of CO₂ produced, oil, and brine recovered
3. The primary CO₂ plume has been managed by pressure maintenance including use of two nearby injection wells and targeted fluid withdrawal in eight surrounding wells. The CO₂ injection conforms largely to the stratigraphic architecture recorded in the geocellular model.
4. On September 30, 2017 the daily CO₂ amount recorded was 1-5 MCFD. As of September 30, 2017, the cumulative produced CO₂ accounts for 18% of the injected volume (no substantial change from June, 2017).
5. Analysis of the active source seismic (2D and 3D data) has been finalized and will be provided in the final report.

6. Induced seismicity monitoring at Wellington Field and surrounding area has continued with over 2300 earthquakes have been documented from April 2015 to present, ranging in magnitude from 0.4 to 2.5
7. Data collected for the project is updated and pre-processed for uploading into web-based interactive database catalogue at KGS and DOE NETL EDX.

Geological storage and Class VI Permit Accomplishments

1. Wellington project UIC Class VI permit was put on hold and the well is classified as temporary abandoned UIC Class II well.

Q24 TASKS

Wellington Field Site Closure

2. 3 shallow water monitoring wells located in section 28 and perforated at 100 ft, 200 ft, and 50 ft depth were properly plugged and abandoned
3. Well site locations were restored
 - a. KGS 1-32, 2-32, and 1-28 sites to be restored, but wells to be left open for future work and reentry. Berexco will not do anything with the wells for at least a year.
 - b. Berexco assumed responsibility to plug/recomplete all 3 wells.
 - c. Removed shallow and deep monitoring gauges and other equipment.
 - d. Returned all leased equipment.
4. Seismometer network left in the field as-is with permission from operator and land owner.
5. Wellington seismometer array is on loan by IRIS-PASSCAL until September 30, 2018 with the possibility of extension per Pnina Miller.

Final Reporting Plan

1. Mississippian Geochemistry from Wellington Field:
 - a. Geochemical data from Mississippian CO₂ EOR operations will be assembled and processed.
 - b. The data will be compiled and available through a KGS online webpage and prepare for archiving and publication.
 - c. Filed notes will be reviewed and archived: details and location of supplies provided in the field-book and notes will be added to an online database.
2. Updated Site Characterization/Modeling will be included in final technical report
 - a. Mississippian models in progress or nearly complete with inputs from team and final review of observed data will be finalized.
3. Data Transfer report
 - a. Description of data and data processing methodologies will be provided
 - b. Explanation for data management strategies will be included

- c. All project relevant data will be uploaded to NETL EDX portal
- 4. Development of a Final Technical Report
 - a. Reports on enhanced production from CO₂ injection will be combined.
 - b. Decline curves analysis will be finalized.
 - c. Technical reports on relative permeability and capillary pressure calculation, well testing, and well log analysis will be prepared and will be included as appendices for the main technical report.
 - d. Active and passive seismic technologies developments and observations report will be prepared.
- 5. Best Practices Manual and Lessons Learned report to be prepared
 - a. Lessons learned from UIC Class VI application process.
 - b. All Class VI documents to DOE with overview of process will be compiled and provided.
 - c. Summary of communication and requests for information from EPA and a compilation of email communication was delivered or will be delivered to DOE.
 - d. Highlight issues with USDW determination and water wells, QASP finalization, and complications with requirements for the permit document (e.g. GS Data Tool) will be provided.
- 6. Commercialization Plan
 - a. Pressure observations and regional disposal will be incorporated into this work.
 - b. Findings from ongoing studies regarding induced seismicity and risk will be combined with existing Kansas policy to develop a feasible plan.
- 7. Technology Transfer
 - a. Compilation of all quarterly reports to be published on KGS website.
 - b. All presentations and posters given to be published on KGS website related to DEFE0006821.

SUMMARY

1. Produced (i.e., vented) CO₂ accounts for 18% of the CO₂ injected, no significant changes from previous quarter.
2. The Wellington seismometer array provides a dependable earthquake catalog and is updated on a weekly basis.
3. Additional confirmations of Arbuckle saline aquifer regional pore pressure increase are continue to arrive from various sources
4. Mapping of fracture density and orientation in the Mississippian reservoir and the Arbuckle saline acquirer was performed and it is currently in agreement with field performance and geochemistry data.
5. Site closure activities were successfully performed, injection site was restored and wells were plugged and abandoned according to existing state regulations.
6. Team is preparing reports and closing documents for submission to DOE NETL EDX in late December 2017.

PROJECT SCHEDULE

Wellington project ended on September 30, 2017.

MILESTONE STATUS REPORT

Task	Budget Period	Number	Milestone Description	Status
Task 2.	1	1	Site characterization of Arbuckle Saline Aquifer System – Wellington Field	Completed
Task 3.	1	2	Site Characterization of Mississippian reservoir for CO ₂ EOR – Wellington Field	Completed
Task 10.	2	3	Pre-injection MVA – establish background baseline readings	Completed
Task 13.	2	4	Retrofit Arbuckle injection well (#1-28) for MVA tool installation	Completed
Task 18.	3-yr1	5	Compare simulation results with MVA Data and analysis and submit update of site characterization, modeling, and monitoring plan	Completed
Task 22.	3-yr1	6	Recondition Mississippian boreholes around Mississippian CO ₂ -EOR injector	Completed
Task 27.	3-yr2	7	Evaluate CO ₂ geologic storage potential of CO ₂ EOR pilot	Completed
Task 28.	3-yr2	8	Evaluate potential of incremental oil recovery and CO ₂ geologic storage by CO ₂ EOR – Wellington Field	Completed

PRODUCTS

Publications, conference papers, and presentations (* indicates student presenter)

Birdie T., Holubnyak Y., Watney W., and Hollenbach J., Assessing Induced Seismicity Risk at the Wellington Geologic Sequestration Site, DOE NETL Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA, August 1-3, 2017.

Birdie T., Holubnyak Y., Watney W., and Hollenbach J., U.S. EPA Class VI Injection Permit: Regulatory Challenges and Lessons Learnt from the Wellington, KS, Project DOE NETL Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA, August 1-3, 2017.

Graham, B. L. *, Haga, L. N. *, Nolte, K. A. *, Tsoflias, G. P., and W. L. Watney (2017), Fracture Mapping and Feasibility of Monitoring CO₂ in situ From Seismic Data at the Mississippian Carbonate Reservoir, Wellington Oil Field, South-Central Kansas, in DOE NETL Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA, August 1-3, 2017.

Molina Z.*, Nolte K.* and G. Tsoflias (2017), An Overview of Injection Induced Seismicity in Kansas and Oklahoma, SACNAS National Conference, Salt Lake City, UT., USA, Oct. 19 - 21, 2017.

Molina Z.*, Nolte K.* and G. Tsoflias (2017), Injection Induced Seismicity in Sumner County, Kansas, KU Undergraduate Research Symposium, Lawrence, Kansas, July 28, 2017.

Holubnyak Y., Watney W., Birdie T., and Hollenbach J., Small Scale Field Test Demonstrating CO₂ Sequestration in Arbuckle Saline Aquifer and by CO₂-EOR at Wellington Field Sumner County, Kansas DE-FE0006821, DOE NETL Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA, August 1-3, 2017.

Holubnyak Y., Watney W., Rush J., Fazelalavi M., Wreath, D., Bidgoli T.S., Reservoir Modeling for CO₂ EOR in Mississippian Carbonate Reservoir at Wellington Field in South-Central Kansas, AAPG Mid-Continent Annual Meeting, October 2, 2017

Nolte K.A., Tsoflias G.P., Bidgoli T.S. and L.W. Watney, Shear-Wave Anisotropy Reveals Pore Fluid Pressure Induced Seismicity in the US Midcontinent, Science Advances (in review).

Nolte K. A.*, Tsoflias G. P., Bidgoli T. S., and W. L. Watney (2017), Monitoring Seismicity Near an Active CO₂ EOR Injection, in DOE NETL Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA, August 1-3, 2017.

Personnel and additional cost-share funding sources

George Tsoflias, Professor, KU Department of Geology, Geophysics

3D AVAZ analysis: Brandon Graham, MS graduate student, Graduate Research Assistantship (GRA) funded by DOE and Kansas Interdisciplinary Carbonates Consortium (KICC).

2D CO₂ monitoring: Lauren Haga, MS graduate student, hourly wage from KICC and Tsoflias overhead account, Summer GRA from KICC.

Earthquake monitoring

Alex Nolte, MS graduate student, academic year Graduate Teaching Assistantship (GTA), KU Department of Geology, and summer GRA support from DOE.

Zalma Molina, Undergraduate research assistant, funded by KU Emerging Scholars, Center for Undergraduate Research during academic year. Summer support as hourly undergraduate research assistant from DOE.

Other activities

Wellington project is currently participating in site-twinning activities associated with ENOS European initiative that includes European geological surveys, universities, and research centers (project website: <http://www.enos-project.eu/>)

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

A project organization chart follows (Table 2). The work authorized in this budget period includes office tasks related to preparation of reports and application for a Class VI permit to inject CO₂ into the Arbuckle saline aquifer, and operational field activities relevant to the project.

Table 2. Updated Organizational Chart.

Organizational Structure		
Small Scale Field Test – Wellington Field (FE0006821)		
UNIVERSITY OF KANSAS Center for Research		
Kansas Geological Survey		
Name	Project Job Title	Primary Responsibility
W. Lynn Watney	Joint PI	Geology, Information Synthesis
Yevhen ‘Eugene’ Holubnyak	Joint PI, Project Manager	Reservoir Engineering, Dynamic Modeling, Data Integration, Synthesis, Point of Contact
Tiraz Birdie	Consulting Engineer	Hydrological Engineering, Dynamic Modeling, Injection Permit Application Preparation, Synthesis
John Doveton	Co-PI	Log-petrophysics, geostatistics
Kerry D. Newell	Co-PI	Fluid geochemistry
Tandis Bidgoli	Structural Geologist	Structural geology, induced seismicity
Fatemeh ‘Mina’ FazelAlavi	Engineering Assistant	Log analysis, well test analysis, reservoir engineering
John Victorine	Software Programmer	Database management, well tool design, data processing
KU Department of Geology		
George Tsoflias	Co-PI	Wellington Seismometer Array, Seismic imaging
Jenifer Roberts	Co-PI	Microbial geochemistry
Leigh Sterns	Affiliated Scientist	cGPS processing for InSAR interpretation
Berexco, LLC		
Dana Wreath	Vice President	Management, engineering
Staff at Wellington Field		Daily operations
Berexco Drilling Team		Drilling, completions
Lawrence Berkley National Laboratory		
Tom Daley	Co-PI	Geophysics, crosshole and CASSM data
Barry Freifeld	Co-PI	Mechanical engineering, U-Tube
T.Birdie Consulting		
Trilobite Testing, Inc.		

IMPACT

The response of the CO₂-EOR has been successful. Downhole pressure monitoring is important in validating hypotheses to explain the effects of large scale injection and induced seismicity in Mid. Continent region. All of information requested by EPA by has been submitted for the application of a Class VI injection permit with exception of financial responsibility documents.

BUDGETARY INFORMATION

Cost Status Report

Baseline Reporting Quarter		10/1/16 - 12/31/16 Q21	1/1/17 - 3/31/17 Q22	4/1/17 - 6/30/17 Q23	7/1/17 - 9/30/17 Q24
<u>Baseline Cost Plan</u> <u>(from SF-424A)</u>					
Federal Share		\$0.00	\$0.00	\$0.00	\$0.00
Non-Federal Share		\$0.00	\$0.00	\$0.00	\$0.00
Total Planned (Federal and Non-Federal)		\$0.00	\$0.00	\$0.00	\$0.00
Cumulative Baseline Cost		\$0.00	\$0.00	\$0.00	\$0.00
<u>Actual Incurred Costs</u>					
Federal Share		\$249,972.71	\$148,215.04	\$137,868.80	\$205,636.54
Non-Federal Share		\$0.00	\$18,512.50	\$0.00	\$0.00
Total Incurred Costs- Quarterly (Federal and Non- Federal)		\$249,972.71	\$166,727.54	\$137,868.80	\$205,636.54
Cumulative Incurred Costs		\$249,972.71	\$416,700.25	\$554,569.05	\$760,205.59
<u>Variance</u>					
Federal Share		-\$249,972.71	-\$148,215.04	-\$137,868.80	-\$205,636.54
Non-Federal Share		\$0.00	-\$18,512.50	\$0.00	\$0.00
Total Variance- Quarterly Federal and Non- Federal)		-\$249,972.71	-\$166,727.54	-\$137,868.80	-\$205,636.54
Cumulative Variance		-\$249,972.71	-\$416,700.25	-\$554,569.05	-\$760,205.59