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October 29, 2021

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Quarterly Project Status Report Entitled "Improving EOR Performance Through Data Analytics and Next-Generation Controllable Completions"
Agreement No. is G-050-97; EERC Fund 24377

Attached is a copy of the subject project status report for the period of July 1 through September 30, 2021.

If you have any questions, please contact me by phone at (701) 777-5120 or by e-mail at nazzolina@undeerc.org.

Sincerely,

Nicholas A. Azzolina

Nicholas A. Azzolina
Principal Hydrogeologist & Statistician

NAA/rlo

Attachment

c/att: Brent Brannan, North Dakota Industrial Commission

IMPROVING EOR PERFORMANCE THROUGH DATA ANALYTICS AND NEXT-GENERATION CONTROLLABLE COMPLETIONS

Quarterly Project Status Report

(for the period of July 1, 2021, through September 30, 2021)

Prepared for:

Karlene Fine

North Dakota Industrial Commission
State Capitol, 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Agreement No. is G-050-97

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October 2021

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IMPROVING EOR PERFORMANCE THROUGH DATA ANALYTICS AND NEXT-GENERATION CONTROLLABLE COMPLETIONS
Quarterly Progress Report
July 1 – September 30, 2021

EXECUTIVE SUMMARY

The Energy & Environmental Research Center and project partners are conducting a project to field-test an advanced machine learning approach integrating controllable completions (interval control valves [ICVs]) to enable active well control during carbon dioxide (CO_2) enhanced oil recovery (EOR). The CO_2 EOR pilot test will be conducted in Denbury Onshore, LLC's Cedar Hills South Unit Field, which is part of the Cedar Creek Anticline located in southwestern North Dakota. The project goals are to 1) implement controllable completions through a rigorously monitored field test in a reservoir that has undergone primary and secondary recovery but has yet to pursue tertiary recovery, 2) apply advanced data analytics and machine learning to evaluate the test performance and develop a semiautonomous active control system, and 3) assess various business case scenarios to accelerate the development and application of this system for commercial EOR.

The project length and goals will be accomplished over 6 years, which includes three budget periods (BPs): BP1: October 1, 2019 – January 31, 2022; BP2: February 1, 2022 – January 31, 2024; and BP3: February 1, 2024 – September 30, 2025. A go/no-go decision point will follow BP1, contingent upon the successful deployment and testing of the controllable completion technology. The project is organized into five tasks: Task 1: Project Management, Planning, and Reporting; Task 2: ICV Pilot Systems Design; Task 3: Operation and Monitoring; Task 4: Active Control System Development; and Task 5: Business Case Development. Task 4 and 5 activities do not start until BP2; therefore, this quarterly summary describes accomplishments achieved within Tasks 1, 2, and 3 over the preceding calendar quarter and reports the status of project milestones or deliverables in accordance with the PMP (project management plan).

The following accomplishments were achieved during the preceding calendar quarter: the three-dimensional (3D) seismic data that were acquired from the test pattern were processed, interpreted, and have begun initial integration into the test pattern geologic model.

Progress on project milestones and deliverables will continue to be tracked and reported in accordance with the PMP.

IMPROVING EOR PERFORMANCE THROUGH DATA ANALYTICS AND NEXT-GENERATION CONTROLLABLE COMPLETIONS

INTRODUCTION

The Energy & Environmental Research Center (EERC) and project partners are conducting a project to field-test an advanced machine learning approach integrating controllable completions (interval control valves [ICVs]) to enable active well control during carbon dioxide (CO_2) enhanced oil recovery (EOR). The CO_2 EOR pilot test will be conducted in Denbury Onshore, LLC's (Denbury's) Cedar Hills South Unit Field (CHSU), which is part of the Cedar Creek Anticline located in southwestern North Dakota. The project goals are to 1) implement controllable completions through a rigorously monitored field test in a reservoir that has undergone primary and secondary recovery but has yet to pursue tertiary recovery, 2) apply advanced data analytics and machine learning to evaluate the test performance and develop a semiautonomous active control system, and 3) assess various business case scenarios to accelerate the development and application of this system for commercial EOR.

The project goals will be accomplished over 6 years, which includes three budget periods (BPs): BP1 – October 1, 2019 – January 31, 2022; BP2 – February 1, 2022 – January 31, 2024; and BP3 – February 1, 2024 – September 30, 2025. A go/no-go decision point will follow BP1, contingent upon the successful deployment and testing of the controllable completion technology. The project is organized into five tasks:

- Task 1 – Project Management, Planning, and Reporting
- Task 2 – ICV Pilot Systems Design
- Task 3 – Operation and Monitoring
- Task 4 – Active Control System Development
- Task 5 – Business Case Development

Tasks 4 and 5 activities do not start until BP2; therefore, this quarterly summary describes accomplishments achieved within Tasks 1, 2, and 3 over the preceding calendar quarter and reports the status of project milestones or deliverables in accordance with the project management plan (PMP).

ACCOMPLISHMENTS

Task 1.0 – Project Management, Planning, and Reporting

The objectives of Task 1.0 are for the EERC to manage and direct the project in accordance with the PMP to meet all technical, schedule, and budget objectives and requirements. Significant accomplishments for Task 1.0 during the reporting period include the following:

- Throughout the reporting period, the EERC participated in several project update meetings with Denbury and NCS Multistage, LLC (NCS Multistage). The EERC, Denbury, and NCS Multistage comprise the core design team for the project.

Next steps to accomplish the goals under Task 1.0 include the following:

- Progress on project milestones and deliverables will continue to be tracked (see Tables 1 and 2).

Task 2.0 – ICV Pilot Systems Design

Task 2.0 includes four subtasks: 1) screening and selection of a test pattern, 2) field and laboratory characterization of the test pattern, 3) baseline modeling and simulation to support the preliminary pilot design, and 4) pilot design. The four subtasks within Task 2.0 will result in a final pilot design that will be implemented in Task 3.0. Significant accomplishments for each subtask within Task 2.0 during the reporting period are detailed below.

Table 1. Milestone Status Report

Milestone (M) Number	Milestone Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments
M1	Screening and Selection of Pilot Test Pattern Complete	01/31/20	11/30/19	Reported in subsequent quarterly report	Completed
M2	Field Characterization Activities Complete	12/31/21		E-mail verification to DOE* PM**	Revised date based on NCTE***
M3	Laboratory Characterization Activities Complete	10/31/20	10/20/20	Reported in subsequent quarterly report	Revised date based on NCTE
M4	ICV Installation and Initial Testing Complete	01/31/22		Reported in subsequent interim report	Revised date based on NCTE
M5	Tracer Study Initiated	09/30/22		E-mail verification to DOE PM	Revised date based on NCTE
M6	Initial Active Control System Design Complete	01/31/23		Reported in subsequent quarterly report	Revised date based on NCTE
M7	Active Control System Design Complete	01/31/24		Reported in subsequent interim report	Revised date based on NCTE
M8	Geologic Model Complete	01/31/24		Reported in subsequent quarterly report	Revised date per NCTE
M9	Transfer of Operational Ownership of ICV Pilot to Field Operator Initiated	11/01/24		E-mail verification to DOE PM	Revised date based on NCTE
M10	Numerical Simulation Complete	01/31/25		Reported in subsequent quarterly report	Revised date based on NCTE

* U.S. Department of Energy.
** Project manager.
*** No-cost time extension.

Table 2. Project Deliverables

Deliverable (D) Number	Deliverable Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments
D1	Updated PMP	02/26/20	02/25/20	PMP file submitted	Completed
D2	Workforce Readiness Plan	11/01/20	09/28/20	Plan submitted	Completed
D3	Data Management Plan	01/27/20	12/18/19	Plan submitted	Completed
D4	Interim Field Performance Summary Report	08/31/23		Summary report submitted	Revised date based on NCTE
D5	Business Cases for Commercial Deployment of ICV Systems for	09/30/24		Final technical report submitted	Revised date based on NCTE
D6	Development Strategy Plan	07/31/25		Plan submitted	Revised date based on NCTE
D7	Data Submitted to NETL* EDX**	09/30/25		Data uploaded to EDX	Revised date based on NCTE

* National Energy Technology Laboratory.
** Energy Data eXchange.

Subtask 2.1 – Screening and Selection of Test Pattern

As described in the April 2020 quarterly summary, the project team identified wells that met a set of screening criteria, and a final selection was made for the pilot test. The candidate injection well was selected: CHSU-43-18NH-15 (API 3301101001). The selection of a candidate injection well satisfies M1 – Screening and Selection of Pilot Test Pattern Complete, and Subtask 2.1 is complete.

Subtask 2.2 – Characterization

Laboratory Characterization

As described in the October 2020 quarterly summary, laboratory analyses of core plug samples of the Red River "B" main pay zone interval are complete (M3 – Laboratory Characterization Activities Complete), and no additional laboratory activities are planned for the project.

Field Characterization

Well logging: The project team finalized the logging plan for the injection well, and the planned logging tools currently include Schlumberger's ThruBit quad-combo suite (gamma ray, induction, neutron porosity, density, and dipole sonic) and fullbore formation microimager. The revised field schedule anticipates conducting well logging in Quarter (Q)4 2021. The fieldwork will include a well cleanout with a larger workover rig than the October 2020 field event and will be immediately followed by ThruBit logging.

Baseline 3D seismic: A baseline three-component, three-dimensional (3C3D) seismic survey was acquired from the test pattern area on November 1–14, 2020. During the reporting period, processing of the acquired 3C3D seismic data included PP prestack time migration (PSTM) and converted wave (PS) processing and registration were completed.

IHS Kingdom and OpendTect Pro software packages were utilized to derive attributes from the seismic survey. These attributes include curvature, curvedness, similarity, variance, dip azimuth, and chaotic reflection. Curvature, curvedness, and chaotic reflection indicate that a seismic feature, such as a fault, could potentially be present in the Precambrian basement (Figure 1) and affect Red River Formation geology.

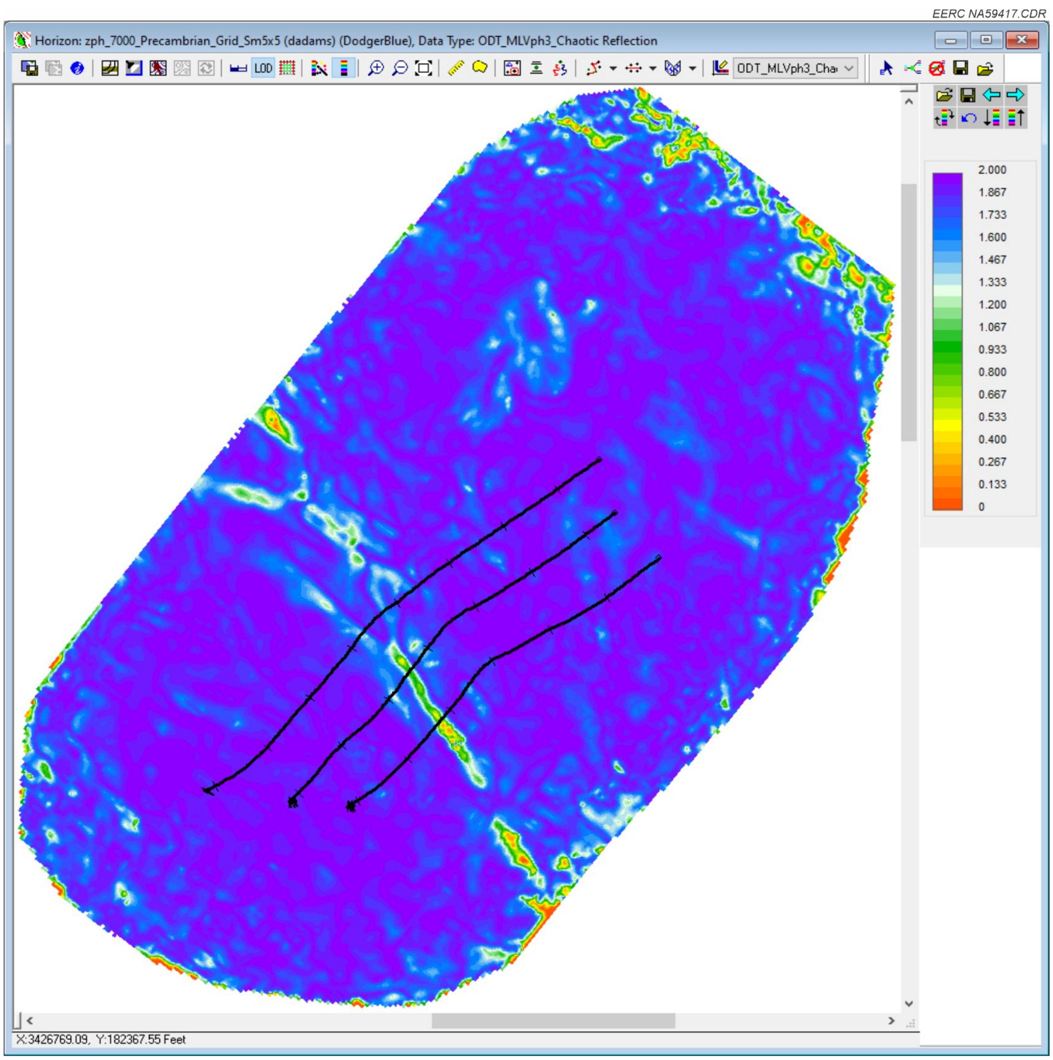

Figure 1. Chaotic reflection attribute displayed at the top of the Precambrian basement. A northwest–southeast trending feature, indicated by warmer colors near the center of the attribute, could indicate the presence of a seismic feature, such as a fault or fracture in the Precambrian basement. The black lines in the panel indicate the candidate injection well (CHSU-43-18NH-15, middle line) and the two offset production wells (CHSU 13D-17NH 15 and CHSU 33B-18NH 15).

The seismic attributes that have been generated have been imported and begun integration into a Petrel project for use with Petrel's "ant tracking" algorithm. The ant-tracking algorithm will be used to further illuminate features that could be used to model a potential fracture network within the Red River Formation and zone of interest. These features will guide the final ICV system design by targeting specific wellbore intervals for packer placement. Ant tracking is sensitive to several characteristics within the seismic data and attributes, including the dip of potential features, how much variance is encountered within each attribute, and the resolution and quality of the data itself. A sensitivity analysis will be conducted to quantify the effect of these characteristics on the ant-tracking product.

Next steps: Complete the ant-tracking process, and generate a potential fracture network for integration with the static geologic model. Integration will also include reformatting of a discrete fracture network to a format useable by the embedded discrete fracture model (EDFM) for simulation purposes. After integration is complete, begin numerical simulations to conduct performance testing of ICVs and effects of fracture networks on predictive simulation results.

Subtask 2.3 – Baseline Modeling

Baseline Geomodel

The full-field geologic model (geomodel) was clipped to the test pattern area to create a sector model for the reservoir simulations. The reservoir matrix and fracture properties of the current sector model reflect the broader full-field geomodel (Baseline Geomodel Version 1). The matrix and fracture properties will be updated after completion of the field characterization (Baseline Geomodel Version 2).

Baseline Reservoir Simulations

Using the Baseline Geomodel Version 1, an initial pattern-level STARS model was developed to study flow behavior in the pilot test pattern (STARS Version 1). The model includes one water/CO_2 injector (Well CHSU 43-18NH 15) and two offset producers (CHSU 13D-17NH 15 and CHSU 33B-18NH 15). The production and injection data of the three wells were processed and integrated into the simulation model. Different boundary conditions, including aquifer support and constant fluid influx, are being tested to match the production and injection history.

The reservoir simulations are using the Computer Modelling Group module, FlexWell, within STARS to segment the injection well into zones using flow control devices (FCDs). The FCD zones will mirror the ICV system that will be deployed into the injection well.

An EDFM technique is being used to model natural fractures in the reservoir. The preliminary pattern-level reservoir simulations using Baseline Geomodel Version 1 assume a stochastic fracture network. The stochastic fracture network was converted into fractured grids using SimTech LLC's EDFM software and integrated into the STARS simulation model (STARS Version 2).

Next steps: After completion of the field characterization, the Baseline Geomodel Version 1 will be updated to Baseline Geomodel Version 2. At that time, the STARS Version 2 model will be updated to reflect the updated matrix and fracture properties observed in the test pattern area (STARS Version 3). The STARS Version 3 model will then be used for additional reservoir simulations under Subtask 2.3 and for the Task 5.0 scope of work.

Subtask 2.4 – Pilot Design

The project team has adapted the NCS Qumulus™ Ultimate Recovery System to accommodate a horizontal injection well and site-specific wellbore considerations. The current ICV pilot system design for the injection well includes a 4.5-inch, 12.6-pound tubing (upper section) and 2⅞-inch, 6.4-pound tubing (lower/horizontal section). The project team will reevaluate the ICV design after completion of the fieldwork under Subtask 2.2.

Next steps: The project team will continue to evaluate the ICV pilot system design and work toward a final design prior to installing and testing the system in BP2.

Task 3.0 – Operation and Monitoring

Task 3.0 entails installation and testing of the pilot design and the operation and monitoring of the ICV system. The objectives of Task 3.0 are to 1) install a set of up to ten ICVs into the CO_2 injection well, and evaluate performance of virtual ICV applications to the offset production wells; 2) execute a tracer study using ICV interval-specific tracers to quantify connectivity within the reservoir, and inform the subsequent operational designs; and 3) operate the ICVs, and quantitatively show that the deployment of the ICVs can reduce premature breakthrough of injected fluids, increase CO_2 sweep efficiency, and improve incremental production.

Over the reporting period, the project team participated in several discussions with Denbury and NCS Multistage to review the current ICV system design. The project team will reevaluate the ICV design after completion of the fieldwork under Subtask 2.2.

Next steps: The objectives of Task 3.0 will be completed through two subtasks: Subtask 3.1 – Install and Test Systems and Subtask 3.2 – System Operation and Monitoring. The initiation of Subtask 3.2 is contingent upon the successful go/no-go decision point to move from BP1 into BP2.

PRODUCTS

Nothing to report.

CHANGES/PROBLEMS

As a result of adaptations in the project timeline, in response to the COVID-19 pandemic, macroeconomic conditions, and rig availability/scheduling challenges, the field work necessary to complete the second milestone (M2 – Field Characterization Activities Complete) has been delayed until late-November or early-December 2021. M2 includes a reattempt at well-logging characterization of the pilot injection well and a dummy run that approximates the physical characteristics of the ICV system. These activities are necessary to design the ICV system relative to the pilot injection well characteristics and to demonstrate that total depth can be achieved in advance of fabrication and installation of the ICV system. The EERC continues to work closely with project partners (DOE NETL, Denbury Inc., and NCS Multistage) to coordinate the field work.

SPECIAL REPORTING REQUIREMENTS

Nothing to report.

PARTNERS AND FINANCIAL INFORMATION

This project is sponsored by the North Dakota Industrial Commission (NDIC), DOE, CMG, and Schlumberger. Table 3 shows the total budget of $9,997,024 for this project and expenses through the September 30, 2021.

Table 3. Project-to-Date Financial Report at June 30, 2021

Funding Source	Budget	Current Reporting Period Expenses	Cumulative Expenses as of 6/30/20	Remaining Balance
DOE	$500,000	$0	$500,000	$88,914
NDIC	$7,997,077	$0	$7,997,077	$1,811,204
CMG – In-Kind	$0	$733,304	$733,304	$733,304
Schlumberger – In-Kind	$0	$766,643	$766,643	$508,350
Total	**$8,497,077**	**$1,499,947**	**$9,997,024**	**$3,141,772**