Energy & Environmental Research Center
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April 28, 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. G-050-97; EERC Fund 24377

Attached is a copy of the subject project status report for the period of January 1 through March 31, 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
Principal Hydrogeologist & Statistician

NAA/kal

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 January 1, 2021, through March 31, 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. G-050-97

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April 2021

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DOE DISCLAIMER

NDIC DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

IMPROVING EOR PERFORMANCE THROUGH DATA ANALYTICS AND NEXT-GENERATION CONTROLLABLE COMPLETIONS
Quarterly Progress Report
January 1 – March 31, 2021

EXECUTIVE SUMMARY

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 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.

In concurrence with and upon advisement from the U.S. Department of Energy (DOE) Project Manager, DOE Technology Manager, and DOE Contracts Specialist, the EERC submitted updated project management plan (PMP), statement of project objectives (SOPO), budget justification, and no-cost time extension (NCTE) documents to justify and extend Budget Period (BP) 1 and the project performance date by 1 year. Pending execution to the contract modification submitted this quarter, the project length and goals will be accomplished over 6 years. This will include three BPs: BP1: October 1, 2019 – January 31, 2022 (revised); BP2: February 1, 2022 – January 31, 2024; and BP3: February 1, 2024 – September 30, 2025 (revised). 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. 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 PMP.

The following accomplishments were achieved during the preceding calendar quarter: 1) the three-dimensional (3D) seismic data that were acquired from the test pattern were processed and are currently being interpreted and integrated into the test pattern geologic model; 2) the project team generated initial simulations of the pilot test pattern performance to assess estimates of reservoir behavior with the ICV system; and 3) the project team began planning the upcoming well cleanout, ThruBit logging, and dummy run for the upcoming fieldwork.

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

The EERC holds an unwavering commitment to the health and well-being of its employees, partners and clients, and the global community. As such, precautionary measures have been implemented in response to COVID-19. Staff continue to carry out project-related activities remotely, and personnel supporting essential on-site laboratory and testing activities are proceeding under firm safety guidelines. Travel has been minimized, and protective measures are being undertaken for those who are required to travel. At this time, work conducted by EERC employees is progressing with minimal disruption. Challenges posed by economic variability will be met with open discussion between the EERC, the U.S. Department of Energy Project Manager, and other partners to identify solutions. The EERC is monitoring developments across the nation and abroad to minimize risks, achieve project goals, and ensure the success of our partners and clients.

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 (CCA) 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 (pending agreement and contract execution submitted to the U.S. Department of Energy [DOE] this quarter), 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

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 project management plan (PMP).

ACCOMPLISHMENTS

Task 1.0 – Project Management, Planning, and Reporting

The objectives of Task 1 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 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.

- On January 26, 2021, the EERC held a meeting with the DOE Project Manager, Contract Specialist, and National Energy Technology Laboratory (NETL) Technology Manager to discuss the project milestones and go/no-go decision point. The DOE team advised the EERC to pursue a no-cost time extension (NCTE) for one full calendar year but recommended a follow-up meeting.

- On February 1, 2021, the EERC held a follow-up meeting with the DOE Project Manager and NETL Technology Manager to discuss the project milestones and go/no-go decision point. The DOE team again advised the EERC to pursue an NCTE for one full calendar year.

- On February 2, 2021, the EERC submitted an NCTE to DOE requesting to move the end date for BP1 from January 31, 2021, to January 31, 2022.

- On February 8, 2021, the EERC submitted a revised statement of project objectives (SOPO), PMP, and Budget Justification Workbook to the DOE PM.

- On March 18, 2021, the EERC submitted a revised cost table to the DOE PM to enumerate the budget changes more clearly between the original proposal and the revised spending plan summarized in the February 8 documents.

- On March 19, 2021, the EERC submitted a revised NCTE to DOE requesting both to move the end date for BP1 from January 31, 2021, to January 31, 2022, and to move the project end date from September 30, 2024, to September 30, 2025.

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).

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 per NCTE
M3	Laboratory Characterization Activities Complete	10/31/20	10/20/20	Reported in subsequent quarterly report	Revised date per NCTE
M4	ICV Installation and Initial Testing Complete	01/31/22		Reported in subsequent interim report	Revised date per NCTE
M5	Tracer Study Initiated	09/30/22		E-mail verification to DOE PM	Revised date per NCTE
M6	Initial Active Control System Design Complete	01/31/23		Reported in subsequent quarterly report	Revised date per NCTE
M7	Active Control System Design Complete	01/31/24		Reported in subsequent interim report	Revised date per 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 per NCTE
M10	Numerical Simulation Complete	01/31/25		Reported in subsequent quarterly report	Revised date per NCTE

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 per NCTE
D5	Business Cases for Commercial Deployment of ICV Systems for Managing	09/30/24		Final technical report submitted	Revised date per NCTE
D6	Development Strategy Plan	07/31/25		Plan submitted	Revised date per NCTE
D7	Data Submitted to NETL EDX	09/30/25		Data uploaded to EDX*	Revised date per NCTE

* Energy Data eXchange.

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.

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 Milestone 1 (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 (FMI). The revised field schedule anticipates conducting well logging in Quarter (Q)2 or Q3 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 PSTM (prestack time migration), and PS (i.e., converted wave) processing and registration were completed. The processed P-wave (PP) product and the PS product are currently being interpreted and will be integrated by the EERC and Denbury into the baseline geologic model.

Next steps: The well logging and baseline 3D seismic survey will constitute M2 – Field Characterization Activities Complete and will be reported to DOE in accordance with Table 1. Outputs from the well logging and baseline 3D seismic survey will be integrated into the baseline geologic modeling under Subtask 2.3. The first step in this interpretation and integration is to evaluate data quality for vertical and spatial resolution and parameterize calculations for attribute volumes. These seismic volumes will feed the fracture characterization workflow, and the resulting interpretation will then be integrated with the latest geomodel version. The log data collected will help refine the existing geologic property distribution, provide ground truth, and improve the resolution of the fracture characterization.

Subtask 2.3 – Baseline Modeling

Baseline Geomodel

The full-field geologic model (geomodel) described in the July 2020 quarterly summary 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

Equation-of-State Parameter Tuning

The reservoir simulation team revised the equation-of-state (EOS) parameter tuning based on feedback from Denbury. The revised EOS parameter tuning uses a ten-component model with match points for i) saturation pressure, ii) liquid density and volume, iii) formation volume factor (FVF), iv) gas:oil ratio (GOR), v) oil/gas gravities, and vi) oil/gas viscosity. Over the reporting period, the revised EOS parameter tuning underwent quality assurance/quality control (QA/QC) by EERC senior staff and is now considered final for reservoir simulation.

Preliminary Pattern-Level 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 CMG 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 embedded discrete fracture modeling (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).

Baseline reservoir simulations were conducted using the STARS Version 2 model and FlexWell to emulate the ICV system. The simulations started with production and injection history matching of primary and secondary (waterflood) production performance and then generated forecasts of EOR performance in response to CO_2 injection at the injection well.

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

The EERC is operational and open for business. Personnel that are not essential for on-site operations have transitioned to working from home. Essential project, laboratory, and field-based activities are proceeding with the incorporation of Centers for Disease Control and Prevention (CDC), state of North Dakota, and University of North Dakota guidelines associated with COVID-19, and mitigation measures have been implemented.

In collaboration with project partners, the EERC is continually assessing potential impacts to project activities resulting from COVID-19 and/or the U.S. economic situation.

If potential impacts to reporting, scope of work, schedule, or cost are identified, then they will be discussed and addressed in cooperation with the DOE PM.

No-Cost Time Extension

On February 2, 2021, the EERC submitted a NCTE to DOE requesting to move the end date for BP1 from January 31, 2021, to January 31, 2022. On March 19, 2021, the EERC submitted a revised NCTE to DOE requesting both to move the end date for BP1 from January 31, 2021, to January 31, 2022, and to move the project end date from September 30, 2024, to September 30, 2025.

With an expected decision and announcement regarding commencement of CO_2 pipeline construction in 2021, the project partners have agreed to defer field characterization of the ICV injection well until after that announcement. Therefore, in addition to a BP1 end date of January 31, 2022, allowing for the completion of M2 – Field Characterization Activities Complete and the go/no-go decision point, the new end date will allow the project team to know the status of the CO_2 pipeline construction before the go/no-go decision point. Deferring the BP1 end date benefits all project partners and improves the ability for project partners to share technical risk with potentially increased financial contributions of incremental costs associated with the cleanout and reattempt to characterize the candidate injection well. No negative financial or technical implications are expected by the NCTE. Extending BP1 to January 31, 2022, will establish the timeline necessary to satisfy completion of M2 by integrating field data and determining the go/no-go decision point to progress into BP2.

Revised SOPO and PMP

In response to the February 2, 2021, NCTE, a revised SOPO and PMP were submitted to DOE on February 8, 2021, to reflect 1) no installation of an ICV system into one of the two offset production wells; 2) the acquisition, processing, and interpretation of a 3D seismic survey in lieu of the ICV system originally intended for the offset production well; 3) updated project timeline; 4) new end date for BP1 of January 31, 2022; 5) new start date for BP2 of February 1, 2022; and 6) new planned completion dates for M2 (December 31, 2021) and the go/no-go decision point (January 31, 2022). The revised PMP also included an updated organizational structure chart and bios for new task leads.

The revised SOPO and PMP are not anticipated to impact the overall performance period and budgets within the BPs of the project. The total project cost across all three BPs will not change, and there is no net effect to labor budgets within each task. The goals, objectives, and outcomes of the project will not be adversely impacted.

Baseline Cost Plan Variance

As shown in the Budgetary Information table and described in the October 2020 quarterly summary, there is currently a variance between the Baseline Cost Plan and the Actual Incurred Cost.

The following items currently impact the project spending plan:

- Field activities were delayed until later in 2020, which was a necessity to adjust budget and reallocate planned contractual field expenses from BP1 to BP2.

- The costs of the originally planned ICV system in the production well were reallocated to a baseline and repeat 3D seismic of the test pattern area.

- A portion of planned field activities (labor only) were deferred from BP1 to BP2.

- The Denbury subcontract was executed later than originally planned, by Q4 2020. With many field activities initiated and ongoing in Q4 2020, invoices have not yet been incurred from Denbury to the EERC. The EERC anticipates invoiced items to occur once 3D seismic activities are at or near completion, along with additional field and laboratory characterization activities closer to the end of BP1. Once actual expenses are invoiced, this will bring the actuals closer to the baseline spending plan.

The revised project timeline in the forthcoming PMP will adapt any variances to the Baseline Cost Plan accordingly. There are no changes to the currently approved scope of work or budget for BP2.

SPECIAL REPORTING REQUIREMENTS

Nothing to report.

PARTNERS AND FINANCIAL INFORMATION

This project is sponsored by the North Dakota Industrial Commission (NDIC), DOE, Computer Modelling Group, and Schlumberger. Table 3 shows the total budget of $9,997,024 for this project and expenses through the reporting period.

Table 3. Project-to-Date Financial Report at March 31, 2021

Funding Source	Budget	Current Reporting Period Expenses	Cumulative Expenses as of 12/31/20	Remaining Balance
DOE	$7,997,077	$705,335	$1,706,073	$6,291,004
NDIC	$500,000	$12,819	$83,775	$416,225
CMG – In Kind	$733,304	$0	$733,304	$0
Schlumberger – In Kind	$766,643	$0	$508,350	$258,293
Total	**$9,997,024**	**$718,154**	**$3,031,502**	**$6,965,522**