



July 26, 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 April 1 through June 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,

A handwritten signature in blue ink that reads "Nicholas A. Azzolina".

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 April 1, 2021, through June 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. G-050-97

Prepared by:

Nicholas A. Azzolina
Nicholas W. Bosshart
Lonny L. Jacobson
John A. Hamling
Nicholas S. Kalenze

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

July 2021

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

Quarterly Progress Report

April 1 – June 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 (CO₂) enhanced oil recovery (EOR). The CO₂ 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 contract modification submitted in the previous quarter was executed on June 1, 2021, which extends Budget Period (BP) 1 and the project performance date by 1 year. 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 1.0: Project Management, Planning, and Reporting; Task 2.0: ICV Pilot Systems Design; Task 3.0: Operation and Monitoring; Task 4.0: Active Control System Development; and Task 5.0: Business Case Development. Task 4.0 and 5.0 activities do not start until BP2; therefore, this quarterly summary describes accomplishments achieved within Tasks 1.0, 2.0, and 3.0 over the preceding calendar quarter and reports the status of project milestones or deliverables in accordance with the project management plan (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, interpreted, and have begun initial integration into the test pattern geologic model; and 2) the project team continued 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.

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 (CO₂) enhanced oil recovery (EOR). The CO₂ 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 (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 1.0 – Project Management, Planning, and Reporting
- Task 2.0 – ICV Pilot Systems Design
- Task 3.0 – Operation and Monitoring
- Task 4.0 – Active Control System Development
- Task 5.0 – Business Case Development

Tasks 4.0 and 5.0 activities do not start until BP2; therefore, this quarterly summary describes accomplishments achieved within Tasks 1.0, 2.0, and 3.0 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.
- On June 1, 2021, the EERC received a formal modification from DOE accepting the no-cost time extension (NCTE) 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

* Project manager.

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	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

* National Energy Technology Laboratory.

** 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 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 prestack time migration (PSTM) and converted wave (PS) processing and registration were completed.

Interpretation of the processed PP and PS 3D seismic deliverables are in progress. This initial interpretation includes extraction of attributes resulting in detailed 3D structural characterization of the study area around the CHSU-43-18NH-15 (API 3301101001) including those areas connected to offset producers (i.e., "test pattern"). The PP data set is sensitive to vertical compressibility variations related to rock strength and fluid saturation changes. The sensitivity of the compressibility response will be further investigated and ground-truthed once the logging of the injection well is completed. The PP seismic response is less sensitive to fluid saturation variability in the low porosities present in the Red River dolomitic matrix. However, the fluid saturations within densely fractured high porosity (relative to the matrix porosity) can be further integrated with wellbore data (i.e., proposed log suite, quad combo, and FMI) in the test pattern areas characterizing connectivity between the injection and producing wellbores. The PS seismic response is sensitive to lithologic variability and strain variations. The PS data are lower resolution and will continue to be evaluated once the logging is complete.

Full-stack geometric attributes have been calculated with IHS Kingdom Geophysics and OpendTect and extracted from the PP and PS 3D seismic volumes along the Red River Formation. The PP azimuthal attributes have been derived from multiple 3D volumes and interpreted along the Red River Formation. These azimuthal attributes are sensitive to formation characteristics that have dominant orientations at a scale that the seismic frequency can detect. These azimuthal attributes give a measure of anisotropy that can be cross-checked with core and log measurements.

Next steps: The full-stack geometric attributes (i.e., dip azimuth, curvature, similarity, semblance) illuminate features in the test pattern area that will be further integrated with an "ant tracking" module in Petrel, and this fracture characterization will be incorporated into the updated geomodel of test pattern area. The azimuthal attributes and derived anisotropy attributes will be investigated to complement the full-stack geometric attribute interpretation and can potentially improve characterization of these fractures when filled with contrasting cementation, fluids, and or pressure. An important step in this data integration is to investigate the correlation of these various data types and scales when the matrix and fracture characteristics are characterized. The scale of core, log, and seismic are orders of magnitude apart but can be complementary and add confidence to data integration and modeling outcomes.

Subtask 2.3 – Baseline Modeling

Baseline Geomodel

The full-field 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/CO₂ 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 Ltd. (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).

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 2⁷/₈-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 CO₂ 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 CO₂ 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

Nothing to report.

No-Cost Time Extension

On June 1, 2021, the EERC received a formal modification from DOE accepting the NCTE 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 CO₂ 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 CO₂ 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

The revised statement of project objectives (SOPO) and PMP submitted to DOE in the previous quarter 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) an updated project timeline; 4) a new end date for BP1 of January 31, 2022; 5) a new start date for BP2 of February 1, 2022; and 5) 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 biographies 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

The current budgetary information supplied below is based on the recent contract modification executed on June 1, 2021. Previously, there was a variance (described in October 2020 quarterly). However, based on the revised forecast in remaining project activities, consistent with the revised SOPO and PMP submitted in previous quarter, the cost plan variance is minimal.

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 reporting period.

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	\$7,997,077	\$0	\$7,997,077	\$1,793,329
NDIC	\$500,000	\$0	\$500,000	\$86,694
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	\$3,121,677