Energy & Environmental Research Center
15 North 23rd Street, Stop 9018 • Grand Forks, ND 58202-9018 • P. 701.777.5000 • F. 701.777.5181
www.undeerc.org

July 29, 2022

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 Report Entitled "Unitized Legacy Oil Fields: Prototypes for Revitalizing Conventional Oil Fields in North Dakota"; Contract No. G-045-086
EERC Fund 26645

Attached is a copy of the subject quarterly status report for the period of April 1 through June 30, 2022.

If you have any questions, please contact me by phone at (701) 777-5343 or by e-mail at tjiang@undeerc.org.

Sincerely,

DocuSigned by:
Tao Jiang
4E5F948EDBBF43C...

Todd Jiang
Principal Reservoir Engineer

TJ/ro

Attachment

UNITIZED LEGACY OIL FIELDS: PROTOTYPES FOR REVITALIZING CONVENTIONAL OIL FIELDS IN NORTH DAKOTA

Research Performance Progress Report (quarterly)

(for the period April 1 – June 30, 2022)

Prepared for:

Karlene Fine

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

Contract No. G-045-086

Prepared by:

Todd Jiang
Nejma Djabelkhir
Lu Jin
Stephen N. Guillot
Michael P. Warmack
Yang Yu
Charlotte D. Riter

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

July 2022

EERC DISCLAIMER

LEGAL NOTICE This research report was prepared by the Energy & Environmental Research Center (EERC), an agency of the University of North Dakota, as an account of work sponsored by the North Dakota Industrial Commission (NDIC). Because of the research nature of the work performed, neither the EERC nor any of its employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement or recommendation by the EERC.

NDIC DISCLAIMER

This report was prepared by the EERC pursuant to an agreement partially funded by the Industrial Commission of North Dakota, and neither the EERC nor any of its subcontractors nor the North Dakota Industrial Commission nor any person acting on behalf of either:

(A) Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the North Dakota Industrial Commission. The views and opinions of authors expressed herein do not necessarily state or reflect those of the North Dakota Industrial Commission.

TABLE OF CONTENTS

LIST OF TABLES

UNITIZED LEGACY OIL FIELDS: PROTOTYPES FOR REVITALIZING CONVENTIONAL OIL FIELDS IN NORTH DAKOTA
Quarterly Progress Report
April 1 – June 30, 2022

EXECUTIVE SUMMARY

The Energy & Environmental Research Center (EERC) was awarded a contract by the North Dakota Industrial Commission (NDIC) to pursue the Unitized Legacy Oil Fields: Prototypes for Revitalizing Conventional Oil Fields in North Dakota project. The goal of this research program is to enable revitalization of unitized conventional oil fields in North Dakota, ultimately resulting in increased daily oil production and prolonging the operational lifetime of those fields. The three major objectives to meet this goal are to 1) evaluate waterflood optimization and CO_2 enhanced oil recovery (EOR) potential and implementation approaches specific to Madison producing field(s) or other legacy conventional fields producing from suitable horizons; 2) explore operational strategies that address key technical challenges, optimize current facilities, and systematically consider necessary new facilities; and 3) frame project results and experience as a prototype for revitalizing analogous conventional oil fields in North Dakota in anticipation of CO_2 EOR. These objectives are being executed through two corresponding tasks:

- Task 1.0 – Assessing the Potential of a Unitized Legacy Oil Field
- Task 2.0 – Developing a Prototype to Revitalize a Unitized Legacy Oil Field

To maintain the operational timeline of project partner, Eagle Energy Partners Tundra (EEP Tundra), the following accomplishments were achieved during the preceding calendar quarter: Deliverable [D] 2 – Data Needs Analysis – Priorities for Revitalization and D5 – Technology Transfer and Progress Update. D2 – Data Needs Analysis – Priorities for Revitalization was completed using a list of required/preferred geologic and operational data to characterize a reservoir for waterflood and CO_2 EOR. Using this compilation, a gap analysis was performed to ascertain data needs required to revitalize the study field using CO_2 EOR. The needs were prioritized based on intended use, scarcity, cost, and benefits. The D2 report describes the process that can be applied by operators seeking to revitalize similar oil fields in North Dakota. A PowerPoint presentation was created for D5, outlining progress reported to NDIC at the completion of Year 1. EEP Tundra and the EERC will also work with the Oil and Gas Research Council (OGRC) and the North Dakota Petroleum Council to identify and implement opportunities for EOR education in North Dakota.

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

UNITIZED LEGACY OIL FIELDS: PROTOTYPES FOR REVITALIZING CONVENTIONAL OIL FIELDS IN NORTH DAKOTA
Quarterly Progress Report
April 1 – June 30, 2022

INTRODUCTION

The Energy & Environmental Research Center (EERC) will conduct this North Dakota Industrial Commission-funded project in close collaboration with project partner, Eagle Energy Partners Tundra (EEP Tundra). Information generated by this project will positively affect ultimate recovery from North Dakota's conventional oil pools and will lead to additional projects, processes, ideas, and activities to facilitate implementation of oil exploration and production technologies presently not used in the state. The potential to revitalize conventional oil fields and increase ultimate recovery will bring new investment to North Dakota, resulting in the growth of oil and gas jobs, wealth, and tax revenues. The goal of this 3-year research program is to enable the revitalization of unitized conventional oil fields in North Dakota, ultimately resulting in increased daily oil production and prolonging the operational lifetime of those fields.

Major objectives to be accomplished to meet the stated goal are to 1) evaluate waterflood optimization and CO_2 enhanced oil recovery (EOR) potential and implementation approaches specific to the Madison or other suitable production horizons; 2) develop cost-effective operational strategies that address key technical challenges, optimize current facilities, and systematically consider necessary new facilities; and 3) frame the results from this project as a prototype for revitalizing analogous conventional oil fields in North Dakota in anticipation of tertiary CO_2 EOR. The first objective will be achieved by using new and existing geologic and reservoir engineering characterization data (e.g., core analyses, well logs, oil analyses) and modeling/simulation to optimize waterflood operations in preparation for near-term CO_2-based EOR operations. To achieve the second objective, results of new characterization and geologic assessments will be combined with refined performance forecasts to conduct CO_2 EOR scenario analysis. The results will be used to develop strategies for the design and operation of prudent EOR schemes that will be applicable to other unitized fields producing from similar pools. The third objective will be achieved through the synthesis of project results into a guidance document for producers and investors looking to revitalize analogous conventional unitized fields in North Dakota with CO_2-based EOR.

Project activities are organized within two tasks: 1) assessing the potential of a unitized legacy oil field and 2) developing a prototype to revitalize a unitized legacy oil field.

ACCOMPLISHMENTS

Task 1.0 – Assessing the Potential of a Unitized Legacy Oil Field

The goal of Task 1.0 will be to gather, assess, and construct much of the data needed to complete the overall goal of the proposed project.

Subtask 1.1 – Data Reconnaissance and Conditioning

Subtask 1.1 focuses on compiling, organizing, managing, screening, vetting, digitizing, and interpreting the various types of data for integration into Subtasks 1.2 and 1.3 and reporting. Much of the data needed are available through either publicly available sources (e.g., NDIC database, scholarly studies) or available from EEP Tundra. A gap analysis process will identify missing key data and guide new data acquisition. Existing data (e.g., well logs, well files, core data, fluid and rock properties) are anticipated to be in a variety of formats and will require conditioning prior to use.

Significant accomplishments for Subtask 1.1 during the reporting period include the following:

- Available data were formatted and spliced into necessary formats for loading into applicable software packages. Coverage was evaluated based on geological heterogeneity and spacing of the production/injection wells.

- Quality control (QC) and cross-referencing were performed with operator well files and NDIC and Enverus databases.

- Quick interpretations/maps were made and data quality-checked, with data conditioned further when necessary.

Subtask 1.2 – Reservoir Modeling and Engineering

Subtask 1.2 activities include geologic and engineering characterization of the study field. Geologic and simulation models representative of the geology and physical performance of the producing horizon will be constructed, history-matched, and calibrated. The geologic and simulation models will be assessed based on sensitivity and uncertainty in performance to define and prioritize data needs.

Significant accomplishments for Subtask 1.2 during the reporting period include the following:

- A variety of reservoir engineering analyses and calculations were performed based on the scope of work for the project as well as the request of EEP Tundra. The key items are listed below:

  - Water injection and oil production performance were analyzed for the injector well and producer wells. The pressure response showed that water injectivity can be established.

  - Preliminary waterflooding simulation was performed using the eight-well simulation model; results and findings provided feedback to the geomodeling team for updating the geologic model.

  - Oil, water, and gas production performance was analyzed for 23 producing wells owned by EEP Tundra. A set of maps were made to identify the sweet spots in the Foreman Butte Field.

  - Detailed decline curve analysis was performed well by well, and original oil in place (OOIP) was estimated based on production performance using decline curve analysis results and other fundamental reservoir engineering calculations.

- The EERC discussed the preliminary findings internally on whether the waterflood could apply to the current model and/or simulation. The information effort included water injectivity and best- and worst-case scenario estimates for the existing well pattern.

- The model was tested by preliminary simulation, and the understanding has been incorporated into the updated model.
  - Property distribution was satisfactory and will continue to improve the Sw distribution.

  - Reservoir zone from 25' above Flat Lake to the base of Alexander, is modeled with more layers (thinner) to ensure resolution close to log data.

Additional wells were incorporated and have been utilized for petrophysical property distribution. More control points were utilized for mapping.

- Petrophysics and reservoir quality:
  - Porosity and permeability were both modeled in 3D to preserve the log-based relationship.

  - Rock types were derived from core samples and used to calibrate the 3D model.

  - The model was updated with rock typing based on flow and storage properties, e.g., RQI and FZI.

- Special core analyses and thin-section analyses were integrated to perform the rock typing and reservoir characterization.

- Water saturation has been modeled by resistivity log-based estimation. Further attempts for core analysis to estimate Sw are underway: Archie parameter measurements and oil–water capillary pressure measurements.

Subtask 1.3 – Operability Assessment

Existing facilities, infrastructure, and data monitoring used in the Foreman Butte oil field will be assessed with the development strategies and operating scenarios investigated in Subtask 1.2. Data collection, management, and a facility upgrade plan for the fields will be developed.

Significant accomplishments for Subtask 1.3 during the reporting period include the following:

- Monitoring the rates and pressures of water injection into the Foreman Butte Field continued, along with the effects on offsetting wells.

- Well bottomhole pressure (BHP) measurements were reviewed within the Foreman Butte Field.

- The EERC team supported EEP Tundra on well workover and cleanout activities by providing recommendations on data gathering during workover operations, sample analysis on recovered material, and review of potential logging opportunities, treatment options, etc.

Subtask 1.4 – Strategic Characterization

Based on the results of Subtasks 1.2 and 1.3, new data will be collected, analyzed, and interpreted (e.g., well logs, pressure testing, production profiles, core testing) to support the research program. The data from this subtask will be used to calibrate and improve geologic and simulation model performance (Subtask 1.2) and evaluate operating scenarios and inform development strategies to revitalize the selected field (Subtask 1.3).

Significant accomplishments for Subtask 1.4 during the reporting period include the following:

- A data reconnaissance and conditioning task was performed to compile publicly available data from the NDIC and Enverus databases, scholarly studies, and other operational data from EEP Tundra, including mud logs from Sunburst and operator well reports.

- A data gap analysis was conducted to identify key data for successful geologic modeling and simulation, and key missing data were identified to guide data acquisition for the Foreman Butte Field. Criteria that were a focus included:
  - Good well control over the area for mapping to capture the structure. This data control is usually much denser than what is needed for petrophysical analysis.

  - Good-quality logs for petrophysics; good data distribution over the area based on geological heterogeneity and spacing of producing wells.

  - Core data for calibration of petrophysical properties: core gamma, porosity, permeability, and x-ray diffraction (XRD) data.

  - Special core analysis data for appropriate rock characterization and dynamic flow simulation: high-pressure mercury injection (or mercury injection capillary pressure [MICP]), relative permeability, etc.

  - For an accurate estimate of water saturation, Archie saturation exponents, oil–water capillary pressure measurements of core samples, etc.

- Lab tests supporting geomodeling update and engineering evaluation:
  - Interfacial tension (IFT) and contact angle: eight samples were selected to assist in determining EOR performance and relative permeability.

  - High-pressure mercury injection (HPMI): eight samples were selected to characterize pore size, pore throat, entry pressures (A/Hg, brine/oil systems) and relative permeability, rock quality, and flow properties using porosity and Swanson permeability.

  - Waterflooding experimental work to support simulation model development.

Task 2.0 – Prototype to Revitalize a Unitized Legacy Oil Field

Task 2.0 will synthesize Task 1.0 activities and results (e.g., performance response derived from scenario analysis) to assess potential development strategies for CO_2 EOR that can be applied to revitalize analogue legacy oil fields in North Dakota. This information will be incorporated into a guidance document and included as part of the final report (Deliverable [D] 6).

Significant accomplishments for Task 2.0 during the reporting period include the following:

- The process continued to identify legacy oil fields producing from the Madison Group (and other suitable producing horizons) for potential as CO_2 EOR candidates.

- A detailed geologic characterization, modeling, and simulation approach was used to evaluate the field's historical performance so that a potential operational plan can be developed as guidance to revitalize a similar conventional reservoir.

FINANCIAL INFORMATION

This project is sponsored by NDIC, with in-kind cost-share support from EEP Tundra. At the time of this reporting, EEP Tundra has provided certification of $2,189,240 of in-kind expenditures toward its committed cost-share amount. The in-kind contribution certification letter was received by the EERC on July 7, 2022, which listed documented costs incurred by EEP Tundra through June 30, 2022, that are associated with this project. Table 1 shows the budget of $3,000,000 over 3 years for this project and expenses through June 30, 2022.

Table 1. Project Cost

Funding Source	Cash	Expended	Balance
NDIC	$3,000,000	$744,141	$2,255,859
EEP Tundra – In-Kind	$3,000,000	$2,189,240	$810,760
Total	$6,000,000	$2,933,381	$3,066,619

FUTURE ACTIVITIES

The planned activities for the next quarter are detailed as follows:

- Discuss the OOIP and waterflooding evaluation with EEP Tundra.
- Discuss geologic properties and the geologic model of the reservoir with the prior prospect geologist and EEP Tundra.
- Complete the geologic model update with additional data from laboratory measurements.
- Update the simulation model with the updated property distributions received from the geologic modeling team.
- Collect incremental oil recovery (IOR)/EOR data from literature to develop an IOR/EOR database, which can be used to screen suitable IOR/EOR methods for different reservoirs in North Dakota.
- Based on the results from the modeling review, develop plans for instituting IOR/EOR activities as recommended.
- Conduct further coreflooding tests using different samples and fluids to evaluate recovery performance based on necessity.
- EERC staff, including members of the project team, will be participating in a multiday event during the week of July 25–29. This in-person-only event will occur at the EERC

facility in Grand Forks, North Dakota, and will comprise training on EERC functions related to research management and execution, team meetings, and team building.

PROGRAM MANAGEMENT AND REPORTING

Continuation of project progress and assembling deliverables to carry through with timely quarterlies and final reports.