BELL CREEK TEST SITE – MVA EQUIPMENT INSTALLATION AND BASELINE MVA ACTIVITIES COMPLETED

Plains CO_2 Reduction (PCOR) Partnership Phase III
Task 5 – Milestone M27

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TABLE OF CONTENTS

LIST OF FIGURES

BELL CREEK TEST SITE – MVA EQUIPMENT INSTALLATION AND BASELINE MVA ACTIVITIES COMPLETED

INTRODUCTION

The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), is working with Denbury Onshore, LLC (Denbury), to determine the effect of large-scale injection of carbon dioxide (CO_2) into a deep clastic reservoir for the purpose of simultaneous CO_2 enhanced oil recovery (EOR) with incidental CO_2 storage at the Bell Creek oil field, which is operated by Denbury. CO_2 will be obtained from the ConocoPhillips' Lost Cabin gas-processing plant in Fremont County, Wyoming, which will supply approximately 50 million cubic feet of CO_2 per day to the Bell Creek oil field. The CO_2 will be transported to the field via the 232-mile-long Greencore Pipeline and injected into an oil-bearing sandstone reservoir in the Lower Cretaceous Muddy Formation at a depth of approximately 4500 feet.

The Muddy Formation within the boundaries of the Bell Creek oil field are characterized by high permeability (150–1175 mD) and high porosity (25%–35%), with reservoir pressures and temperatures that will maintain injected CO_2 in a supercritical state and are near conditions required for miscibility of CO_2 in the oil. The overlying Upper Cretaceous Mowry Formation shale will provide the primary seal, preventing potential fluid migration to overlying aquifers and to the surface. On top of the Mowry Formation are several thousand feet of low-permeability shale formations, including the Belle Fourche, Greenhorn, Niobrara, and Pierre shales, which will provide redundant layers of protection in the unlikely event that the primary seal fails to prevent upward fluid migrations fieldwide.

Denbury will carry out the injection and production operations, while the PCOR Partnership will provide support for the site characterization, modeling and predictive simulation, and integrated risk assessment and will aid in the development of the monitoring, verification, and accounting (MVA) plan to address key technical challenges related to documenting CO_2 storage associated with EOR.

The activities at Bell Creek will inject an estimated 1.1 million tons of CO_2 annually, much of which will be permanently stored. The Bell Creek demonstration project is a unique opportunity to develop a set of cost-effective MVA protocols for large-scale (>1 million tons per year) combined CO_2 EOR and storage in a clastic formation. Developing cost-effective approaches to predict and determine the fate of the injected CO_2 is an important aspect of implementing large-scale carbon capture and storage (CCS) technology. Baseline

characterization and MVA activities are critical components of geological CCS projects for three key reasons: 1) to assure the safety and security of the CO_2 storage; 2) to facilitate accurate accounting of CO_2 injected and stored; and 3) to provide key data to optimize the site-specific injection program, assess effective storage capacity, and understand the ultimate fate of injected CO_2.

At the Bell Creek Field, the PCOR Partnership will establish baseline conditions through the use of integrated programs that combine robust geological, hydrogeological, geochemical, and geomechanical characterization and baseline MVA activities. A cost-effective MVA plan will then be developed and executed based upon the detailed data derived from these activities (Hamling and others, 2013). The baseline conditions will also provide a point of comparison to document the movement and fate of the injected gas stream and detect potential vertical and lateral migration from the storage unit.

Demonstrating the technical and economic viability of implementing cost-effective, risk-based MVA strategies at a large-scale (>1 million tons of CO_2 per year) commercial CO_2 EOR project will provide CCS stakeholders with the real-world data necessary to move CCS technology deployment forward. The results generated by the Bell Creek project will provide stakeholders, including policy makers, regulators, industry, financiers, and the public, with the knowledge necessary to make informed decisions regarding the real cost and effectiveness of CCS (through CO_2 EOR) as a carbon management strategy.

MONITORING SCHEME

The goal of the MVA program is to provide critical data to verify site security; evaluate reservoir behavior during the injection program; determine interactions between oil, water, and CO_2 within the reservoir; determine the ultimate fate of injected CO_2; and investigate mechanisms that affect CO_2 storage efficiency within the EOR process. The MVA program utilizes targeted time-lapse data acquisitions as part of a surface-, near-surface-, and deep subsurface-monitoring program guided by key subsurface technical risk, geologic characterization, and predictive simulation results. If the MVA program identifies a significant variance from anticipated performance, a targeted characterization effort could then be deployed to evaluate the impact and source of the event.

The PCOR Partnership strives for the development of sustainable MVA strategies that are compatible with commercial operations and practices (i.e., demonstrate value to commercial operations while integrating EOR operational data into the MVA program with minimal impact for commercial EOR operators) while also being site-specific, cost-effective, and technically viable. No single technology exists that is capable of effectively monitoring the lateral and vertical extent of CO_2 throughout the stratigraphic column in both the near-wellbore and interwellbore environment for all storage sites. For this reason, the PCOR Partnership has designed a monitoring program specific to the needs of the Bell Creek Field which monitors a variety of physical phenomena within the field utilizing a variety of commercially viable technologies and techniques (Figure 1).

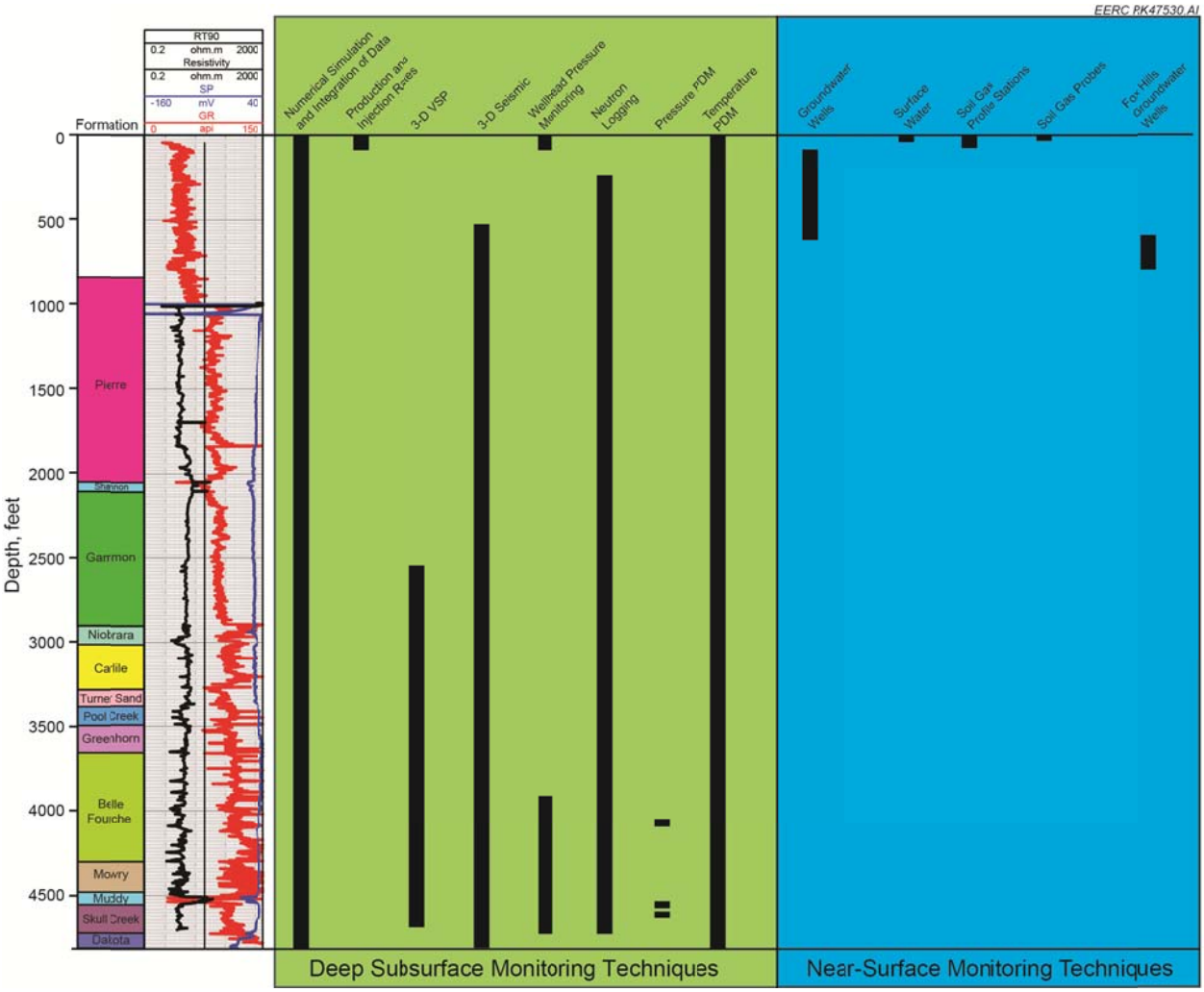

Figure 1. Current and ongoing surface-, near-surface-, and deep subsurface-monitoring techniques employed throughout the Bell Creek oil field and their effective monitoring range as deployed for Bell Creek.

The specific technologies selected are also designed to operate in a complementary manner where an anomalous signal from one monitoring technique can be investigated and characterized through the use of one or more of the remaining techniques. Additionally, the PCOR Partnership is also evaluating the scientific validity and cost-effectiveness of each of these monitoring technologies in order to provide DOE and the CCS community with recommendations and lessons learned that can be used to guide MVA programs at other CO_2 storage sites in the future.

To facilitate the accomplishment of these goals, baseline MVA data were collected at the Bell Creek oil field to be utilized as a point of comparison for time-lapse data.

MVA EQUIPMENT INSTALLATION AND MVA BASELINE ACTIVITIES COMPLETE INTEGRITY DATA COLLECTION COMPLETED

Collection of relevant baseline MVA data to aid in evaluating site security, accounting, and location of the lateral and vertical extent of CO_2 in the Bell Creek oil field and surrounding area was completed in May 2013.

These activities included the following:

- Baseline soil gas monitoring
  - Fieldwide soil gas concentrations measured over six baseline sampling events (November 2011, April 2012, June 2012, August 2012, November 2012, and April 2013)
    - 124 active wells
    - 52 plugged and abandoned wells
    - Ten interspaced wells
  - Near-monthly monitoring of ten soil gas profile stations (SGPSs) sampled at depths of 3.5, 9.0, and 14 feet beginning in October 2012

- Groundwater monitoring
  - Fieldwide water chemistry analysis measured over six baseline sampling events (November 2011, April 2012, June 2012, August 2012, November 2012, and April 2013)
    - Seven stock wells
    - Seven residential wells
    - Nine surface waters
  - Near-monthly monitoring of two Fox Hills groundwater-monitoring wells (deepest regional underground source of drinking water) beginning in April 2013
    - 05-04 FH
    - 33-12 FH

- Reservoir and subsurface monitoring
  - Pulsed-neutron well logs (27 wells)
    - Liquid–gas saturation from reservoir depth up to 200 ft of surface
    - Water, oil, and CO_2 saturation over the Muddy Formation (storage reservoir)
    - Baseline pulsed-neutron logs may be run on an additional three to six wells if they become available prior to injection.

- Three casing-conveyed downhole pressure and temperature gauges (05-06 OW)
  - Near-continuous since April 2012 (5-minute intervals)
    - Lower facies of the Muddy Sandstone
    - Upper facies of the Muddy Sandstone
    - Niobrara (thin sand lense within the primary seal)

- Fiber optic distributed-temperature system (05-06 OW)
  - Near-continuous since April 2012 (4-hour intervals)

  - 1-meter intervals from ~4700 ft to surface

- 40-square-mile baseline 3-D surface seismic survey centered on the Phase 1 area

- Two 50-level 3-D vertical seismic profiling seismic surveys
  – 05-06 OW
  – 04-03 OW

- Bottomhole pressure surveys supplied by the commercial EOR project
  – 156 total

- Injection and production data for all wells supplied by the commercial EOR project.

While the primary baseline MVA activities are completed, the evolving and iterative approach to site characterization, modeling, predictive simulation, MVA, and risk assessment allow for continued integration of data throughout the lifespan of the project to better guide future monitoring efforts and increase the accuracy of CO_2 accounting practices.

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Hamling, J.A., Kalenze N.S., Klapperich, R.J., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2013, Bell Creek test site – monitoring experimental design package: Plains CO_2 Reduction (PCOR) Partnership Phase III Task 5 Deliverable D43 for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-05NT42592, Grand Forks, North Dakota, Energy & Environmental Research Center, in review.