BELL CREEK TEST SITE – GEOLOGICAL CHARACTERIZATION DATA COLLECTION COMPLETED

Plains CO_2 Reduction (PCOR) Partnership Phase III
Task 4 – Milestone M14

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BELL CREEK TEST SITE – GEOLOGICAL CHARACTERIZATION DATA COLLECTION COMPLETED

INTRODUCTION

The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center, is working with Denbury Resources Inc. (Denbury) to determine the effect of a large-scale injection of carbon dioxide (CO_2) into a deep clastic reservoir for the purpose of simultaneous CO_2 enhanced oil recovery (EOR) and CO_2 storage at the Bell Creek oil field, which is owned and operated by Denbury.

The Bell Creek oil field in southeastern Montana is a significant hydrocarbon accumulation that lies near the northeast corner of the Powder River Basin (Figure 1). Exploration and production activities for mineral and energy resources in the area over the last 55 years have yielded a significant amount of information about the geology of southeastern Montana and the northern portion of the Powder River Basin. Decades of oil and gas production through primary and secondary recovery (waterflood and polymer flood pilot tests) has resulted in approximately 38% recovery of the original oil in place and has left behind millions of barrels of oil, which is the target of a CO_2 injection-based tertiary oil recovery project. Denbury plans to initially inject fifty MMscf of CO_2 into the field that will be transported to the site via the Greencore pipeline from ConocoPhillips' Lost Cabin gas plant (Figure 1).

CO_2 will be injected into an oil-bearing sandstone reservoir in the Lower Cretaceous Muddy Formation at a depth of approximately 4500 feet (1372 meters) (Figure 2). CO_2 injection will occur in a staged approach (nine planned CO_2 development phases, namely Phases 1 to 9) across the field (Figure 3). It is expected that a miscible flood will be implemented at the Bell Creek Field with approximately 30 million barrels of incremental recovery. The activities at the Bell Creek oil field will inject an estimated 1.1 million tons of CO_2 annually, much of which will be permanently stored at the end of the EOR project.

Geological Characterization Data Collection

Geological characterization data collection for the Bell Creek project has been completed. Because of the extensive hydrocarbon production in the Bell Creek Field, existing data—including well logs (Figure 4), 2-D seismic data, and laboratory core testing—were available. In December 2011, a monitoring and characterization well (05-06 OW) was drilled in the Phase 1 area of the Bell Creek Field. Although this well will be used for the purpose of monitoring the CO_2 flood of the Muddy Formation (target injection formation) as part of the overall monitoring, verification, and accounting (MVA) program for the Bell Creek project, it also allowed the

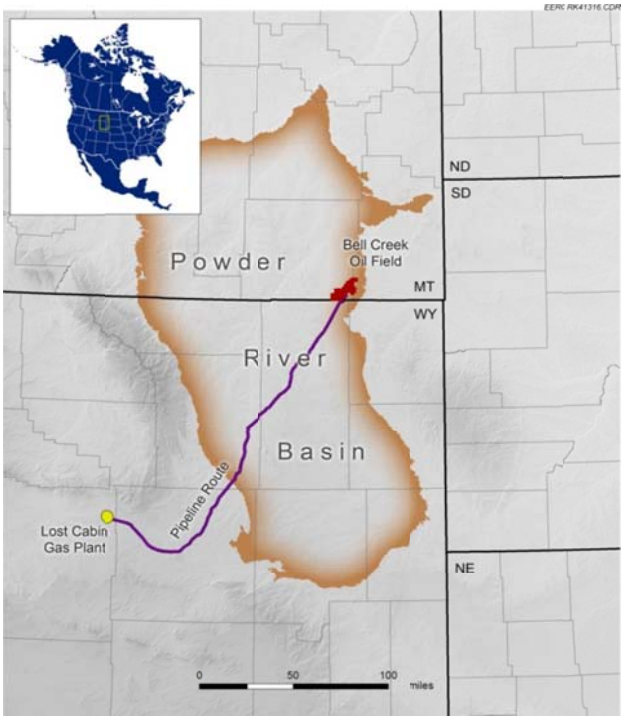

Figure 1. Map depicting the location of the Bell Creek oil field in relation to the Powder River Basin and the pipeline route to the site from the Lost Cabin gas plant (figure from Gorecki and others, 2012).

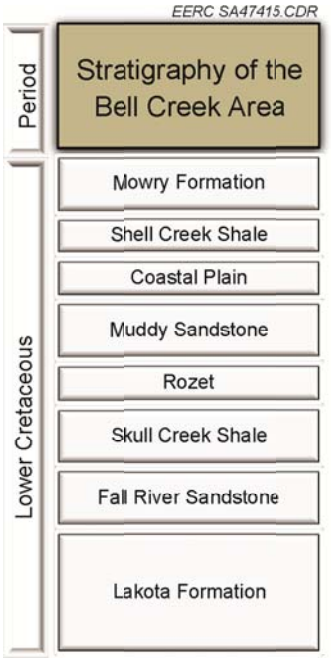

Figure 2. Stratigraphic column of the Lower Cretaceous period in the Bell Creek Field (figure modified from Saini and others, 2012).

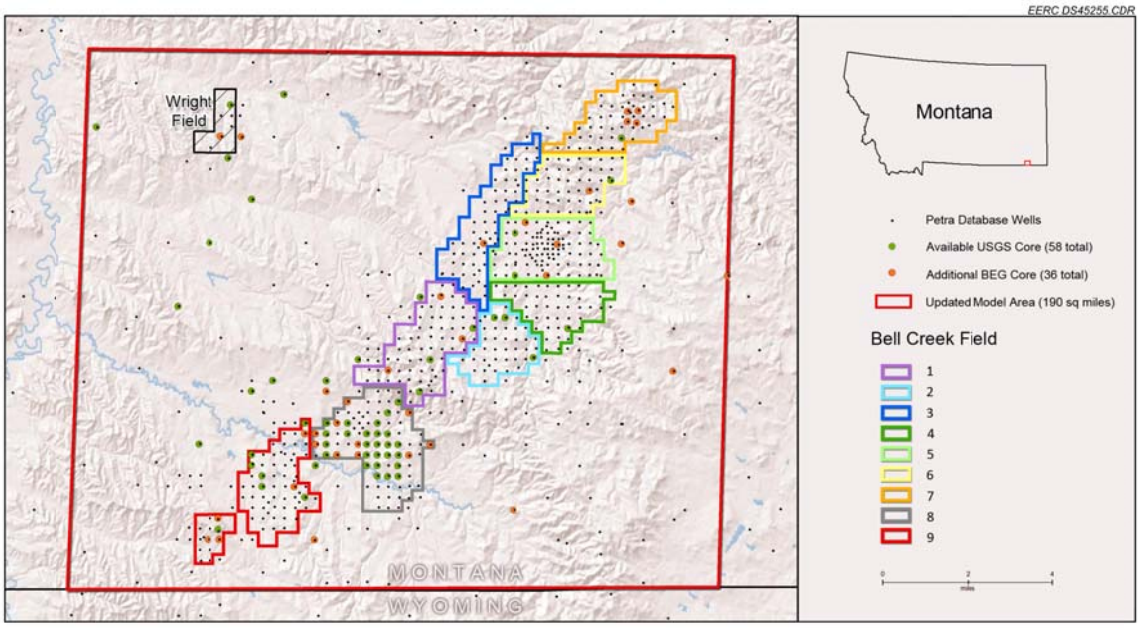

Figure 3. Bell Creek project development Phases 1–9 (USGS stands for U.S. Geological Survey; BEG stands for Bureau of Economic Geology at the University of Texas at Austin) (figure from Saini and others, 2012).

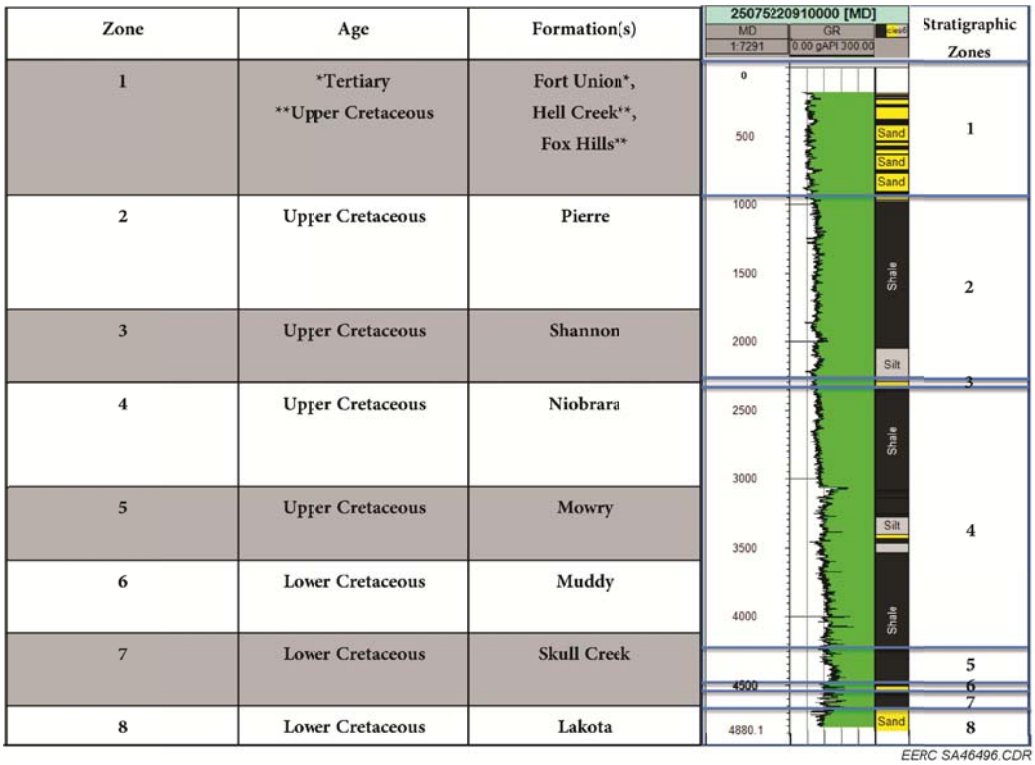

Figure 4. Gamma ray log from Well 25075220910000 in the Phase 1 area. Eight stratigraphic zones are denoted in descending order (figure from Ge and others, 2013).

collection of additional characterization data. Both field- and laboratory-based activities were performed to supplement existing data. Field-based activities included running a full log suite, including an analysis of in situ stress orientation and magnitude. Laboratory-based activities included subjecting core plug samples to compression tests to determine rock strength, static and dynamic elastic properties, compressibility, and stress-dependent permeability. In addition to existing data and the data collected from the monitoring well, a 3-D seismic survey was conducted at the Bell Creek Field covering an area of 45 mi^2 (Figure 5). Table 1 shows an overview of geologic characterization activities performed for the Bell Creek project.

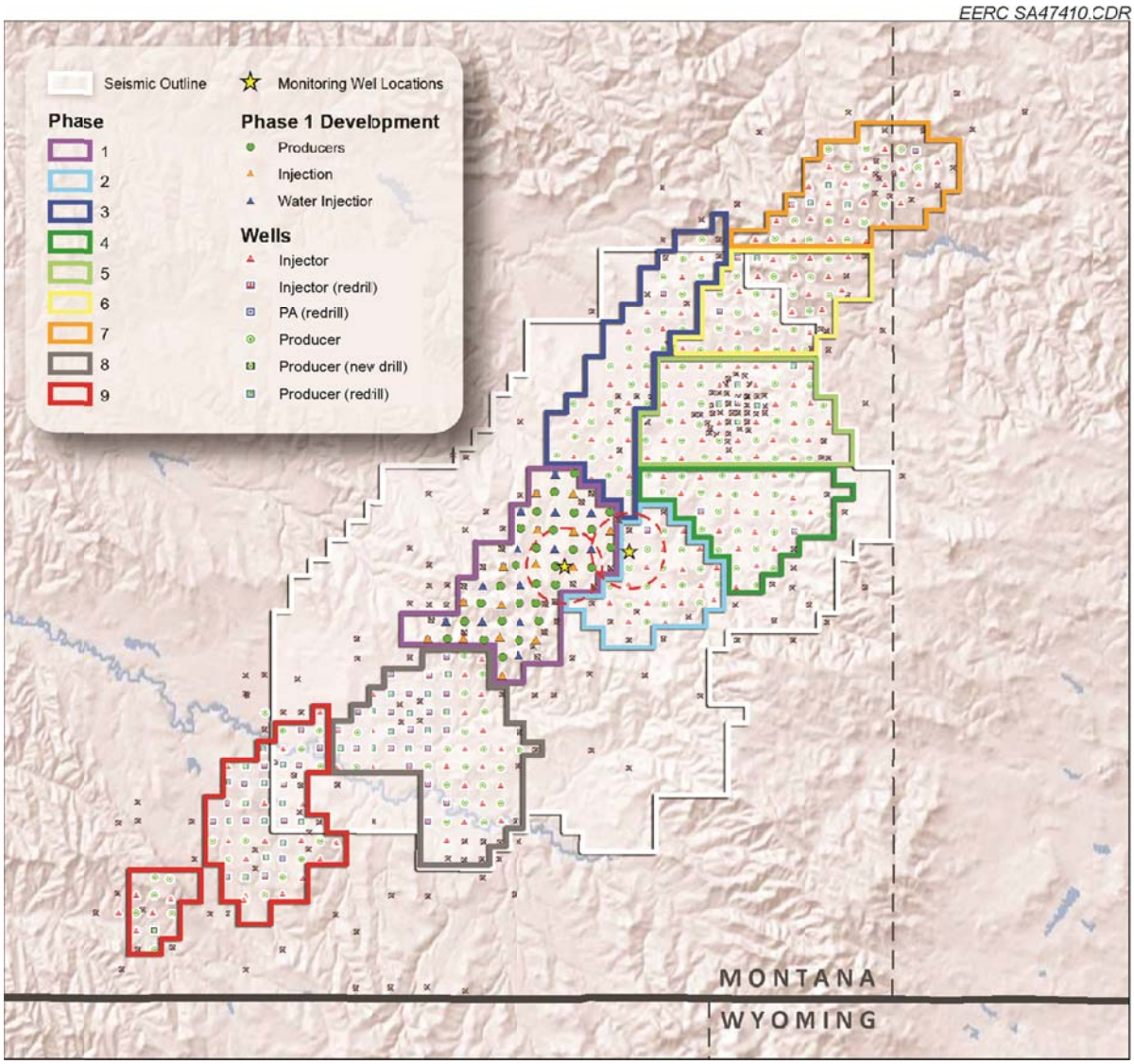

Figure 5. Area covered by the 2012 3-D seismic survey (white outline) and 3-D VSPs (red, dashed circles) (figure modified from Hamling and others, 2012).

Table 1. Overview of Geologic Characterization Activities

Characterization Activity	Description
Well File Review	674 total files; historic core analysis, compilations information, operations data
Bottomhole Pressure (BHP) Survey	143 BHP surveys from 2009–2013 analyzed
Core Examination	• Examined 60 existing cores, both U.S. Geological Survey and Bureau of Economic Geology core • Over 200 ft of new full-diameter core from 05-06 OW, 56-14R, and 33-14R wells • 62 sidewall cores from 05-06 OW and 56-14R wells
LIDAR	79 mi^2 survey over entire Bell Creek Field and perimeter
Log Suite (05-06 OW, 56-14R, 33-14R)	Some or all of the following were performed: gamma ray (GR), neutron and density porosity, bulk density, spontaneous potential, dipole sonic compression/shear loss with mechanical rock properties, capture spectroscopy, resistivity micro imaging, magnetic resonance, spectral GR, pulsed neutron
Laboratory-Based Core Analyses-Monitoring Well (05-06 OW)	Porosity, permeability, fluid saturation, mineralogy, relative permeability, threshold entry pressure, formation water resistivity, compressibility, triaxial testing
Pressure Testing	• Data for various formations from permanent downhole pressure sensors installed in the monitoring well (05-06 OW) • Pressure tests performed during openhole logging at 24 intervals within the Muddy Formation and overlying zones
3-D Vertical Seismic Profile	Two surveys; 0.82 mi^2 area of illumination at reservoir depth; covers over 17 active wells; over 1049 source locations; deployment: • 05-06 OW – 50-level retrievable geophone array with 50-ft spacing • 04-03 OW – 50-level permanently installed array with 50-ft spacing • 27 total wells
Pulsed Neutron Log	• Sigma logged from total depth to 200 ft below surface – gives porosity and GR data; over 116,000 ft logged • Carbon Oxygen Inelastic Scattering – 50-ft interval over reservoir; over 1300 total feet logged
3-D Surface Seismic Survey	45 mi^2; over 5499 source and receiver locations
Geocellular Modeling	Model covers over 200 mi^2; includes over 748 well logs and core data from over 25 wells

The PCOR Partnership has developed an integrated approach of site-characterization, modeling and simulation, risk management, and MVA (Figure 6), which is being implemented at the Bell Creek project. The baseline geological characterization data are being used to create and update a geologic model of the site, which will be used to perform predictive simulations. These simulations will provide an understanding of the behavior of the injected CO_2 into the reservoir and insight into retention and storage efficiency ratios. This in turn will help guide the development of the MVA plan for the project. As a result of this iterative approach and the dynamic nature of CO_2 EOR and storage projects, the geologic characterization of the Bell Creek Field will be updated throughout the life of the project as new data become available.

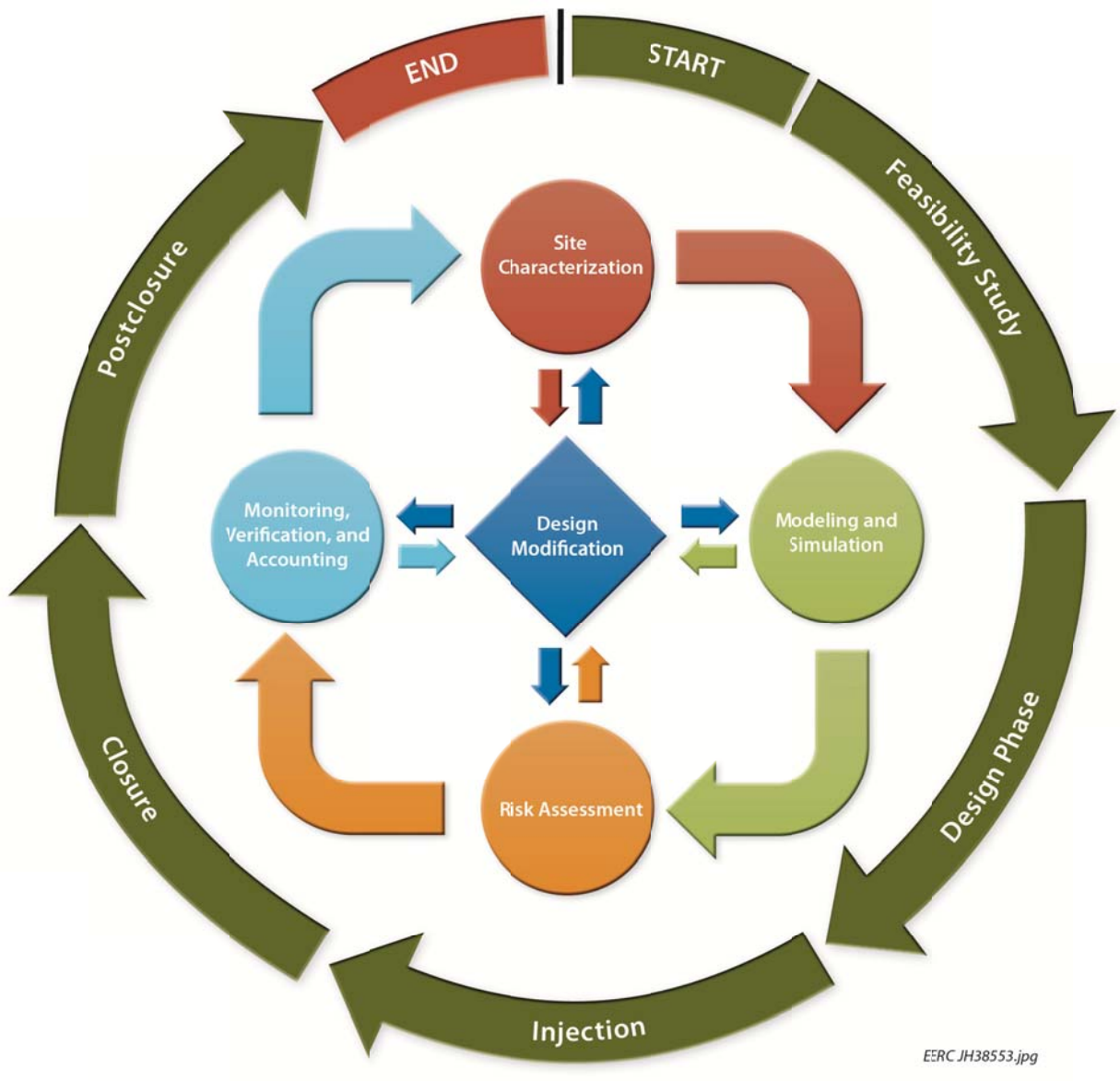

Figure 6. Integrated site-characterization, modeling and simulation, risk management, and MVA approach for the Bell Creek project (figure from Gorecki and others, 2012).

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