BELL CREEK TEST SITE – INJECTION EXPERIMENTAL DESIGN PACKAGE

Plains CO_2 Reduction (PCOR) Partnership Phase III
Task 5 – Deliverable D42

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EXECUTIVE SUMMARY

The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), is working with Denbury Resources Inc., to investigate the efficacy of incidental carbon dioxide (CO_2) storage associated with large-scale injection (>1 million tons a year) of CO_2 into a deep clastic reservoir during CO_2 enhanced oil recovery (EOR) at the Bell Creek oil field, which is operated by Denbury Onshore LLC (Denbury).

Denbury is carrying out the injection and production operations as part of a commercial EOR project, while the EERC is providing support for the site characterization, modeling and predictive simulation, assurance monitoring, and development of a monitoring, verification, and accounting (MVA) plan to study the interrelationship of CO_2 EOR and incidental CO_2 storage associated with EOR activities. The PCOR Partnership is using an iterative approach to evaluate the impacts of Denbury's injection and production scheme on reservoir performance and the array of MVA, site characterization, and modeling and simulation techniques used for the Bell Creek study.

Beginning in May 2013, the ongoing activities at Bell Creek are injecting approximately 1 million metric tons of CO_2 a year for a commercial CO_2 EOR operation. CO_2 is injected into an oil-bearing sandstone reservoir in the Lower Cretaceous Muddy (Newcastle) Formation at a depth of approximately 4500 feet (1372 meters). Produced water and CO_2 are being processed at a recycling facility, comingled with the incoming CO_2 stream, and reinjected into the formation as part of the CO_2 EOR project. Continuous CO_2 injection is expected to be followed by CO_2 water alternating gas (WAG) in Phase 1 at a target rate of 2 million cubic feet a day for each injector well.

The injection program being developed throughout the Bell Creek oil field, with current injection activities occurring in Phase 1, is dictated by the commercial EOR project. The injection-monitoring program at the Bell Creek oil field will capitalize on planned variances in the injection scheme to study (WAG cycle) flood conformance and incidental CO_2 storage specific to the Bell Creek CO_2 EOR activities, which in turn provide direct benefit to other carbon capture and storage sites throughout the PCOR Partnership region and beyond. Additionally, insights gained during EOR operations from injection pattern performance will allow enhancement of the other key Bell Creek study components (site characterization, MVA, and modeling and simulation) through the PCOR Partnership's iterative research philosophy.

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INTRODUCTION

The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), is working with Denbury Resources Inc. (Denbury), to study incidental carbon dioxide (CO_2) storage associated with large-scale injection (>1 million tons a year) of CO_2 into a deep clastic reservoir during CO_2 enhanced oil recovery (EOR) at the Bell Creek oil field, which is operated by Denbury Onshore LLC.

There is growing recognition that EOR operations utilizing CO_2 as the injectant can have additional value for the public and the environment by taking advantage of the normal situation that commonly takes place in any EOR operation utilizing an outside substance to increase oil production from a reservoir. The fluid being injected (including salt water), when utilized in an EOR project, ultimately occupies some of the pore space vacated by the produced oil. At the time of depletion and the closure of the enhanced recovery project, the injectant remains stored for eternity. This project is directed at taking advantage of the opportunity to monitor and account for this incidental storage of CO_2 that occurs during normal oilfield operations.

Denbury is carrying out the injection and production operations as part of the commercial CO_2 EOR project, while the EERC is providing support for the site characterization, modeling and predictive simulation, assurance monitoring, and development of a monitoring, verification, and accounting (MVA) plan to study the interrelationship of CO_2 EOR and incidental CO_2 storage associated with EOR activities. The PCOR Partnership is using an iterative approach to evaluate the impacts of Denbury's injection and production scheme on reservoir performance and the array of MVA, site characterization, and modeling and simulation techniques used for the Bell Creek study.

The field demonstration test conducted in the Bell Creek Field in Powder River County, Montana, is evaluating the field's potential for CO_2 EOR and incidental CO_2 storage. The CO_2 is obtained from ConocoPhillips' Lost Cabin gas-processing plant in Fremont County, Wyoming, and injected into a sandstone reservoir in the Lower Cretaceous Muddy (Newcastle) Formation at a depth of approximately 4500 feet (1372 meters). The Lost Cabin Gas Plant is operated by ConocoPhillips and supplies a targeted delivery rate of approximately 50 million cubic feet of CO_2 a day to the Bell Creek oil field (Figure 1), where it is separated from the process stream during refinement of natural gas. The activities at Bell Creek inject an estimated 1 million metric tons of CO_2 annually, much of which will be incidentally stored in association with the EOR project.

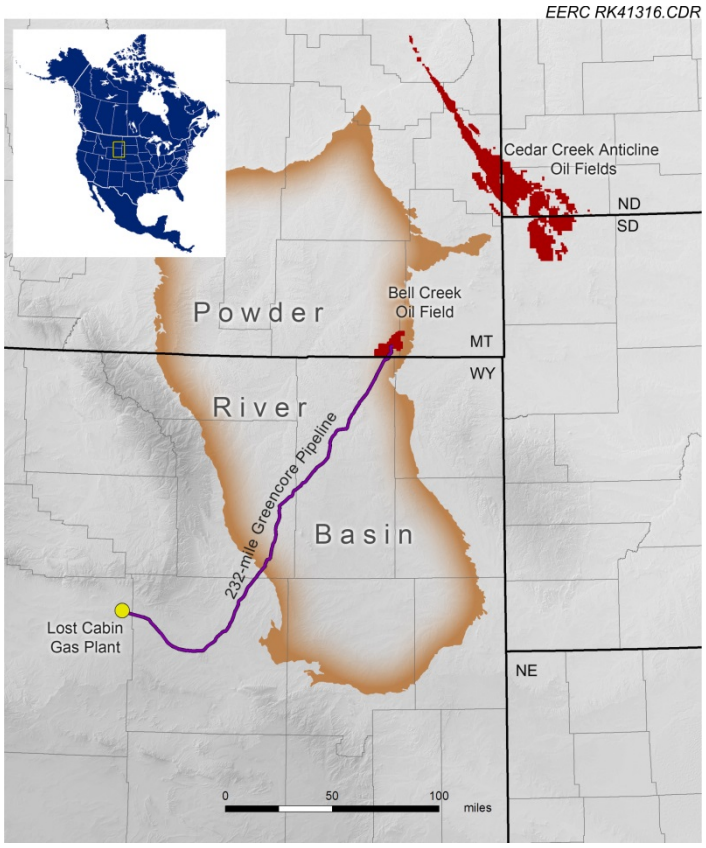

Figure 1. Location of the Lost Cabin Gas Plant and Bell Creek oil field in Wyoming and Montana (modified from Gorecki and others, 2012).

BACKGROUND

The U.S. Department of Energy's (DOE's) goals for carbon capture and storage (CCS) research revolve around developing geologic storage approaches and applying technologies to store significant quantities of CO_2 safely, permanently, and economically. Several methods for geological storage of CO_2 are available, including depleted oil and gas reservoirs, deep brine-saturated formations, CO_2 flood EOR operations, and enhanced coalbed methane recovery. DOE is pursuing a vigorous program for demonstration of CCS technology through its Regional Carbon Sequestration Partnership program.

Lessons learned from the PCOR Partnership's Phase III Bell Creek project will provide stakeholders with the real-world data necessary to move CCS technology deployment forward. These lessons include demonstrating the technical and economic viability of implementing cost-effective, risk-based monitoring strategies and methodologies for modeling reservoir performance under varying injection strategies.

PROJECT OBJECTIVES

From the CCS perspective, the primary project objectives are to demonstrate the following: 1) incidental CO_2 storage can be safely, permanently, and effectively achieved on a commercial scale in conjunction with a commercial EOR operation; 2) oil-bearing sandstone formations are viable sinks for CO_2; 3) MVA methods can be established to effectively monitor incidental CO_2 storage during a commercial EOR project and to provide the technical framework to account for CO_2 stored; 4) lessons learned and best practices employed will provide the data, information, and knowledge needed to develop similar MVA plans for CO_2 EOR storage projects across the region; and 5) the level of monitoring is needed to ensure safety, meet regulatory requirements, and provide insurance of project liability and/or identify areas of development needed to meet these goals. A thorough understanding of the injection characteristics of the Bell Creek oil field and its surrounding area is necessary to achieve these objectives.

PURPOSE

The PCOR Partnership has developed a programmatic philosophy that integrates site characterization, modeling and simulation, risk assessment, and MVA into an iterative process to produce meaningful results for large-scale incidental CO_2 storage projects (Figure 2). Elements of any of these activities are crucial for understanding or developing the other activities. For example, as new knowledge is gained from site characterization, it reduces a given amount of uncertainty in geologic reservoir properties. This reduced uncertainty can then propagate through modeling, risk assessment, and MVA efforts.

The PCOR Partnership Program is in a strong position to refine characterization, modeling, risk assessment, or MVA efforts based on the results of any of these activities as a result of this iterative approach (Gorecki and others, 2012). As applied to the injection program, various commercial injection scenarios utilized at Bell Creek, such as continuous CO_2 injection followed by water alternating gas (WAG), are coupled with MVA and simulation activities to help evaluate both reservoir and MVA performance with respect to incidental CO_2 storage. The study elements also work together and allow an understanding of optimal sweep and incidental CO_2 storage efficiency during injection as part of the EOR process. Lessons learned from these activities can be applied to enhance injection pattern performance for other CCS sites throughout the PCOR Partnership region and beyond.

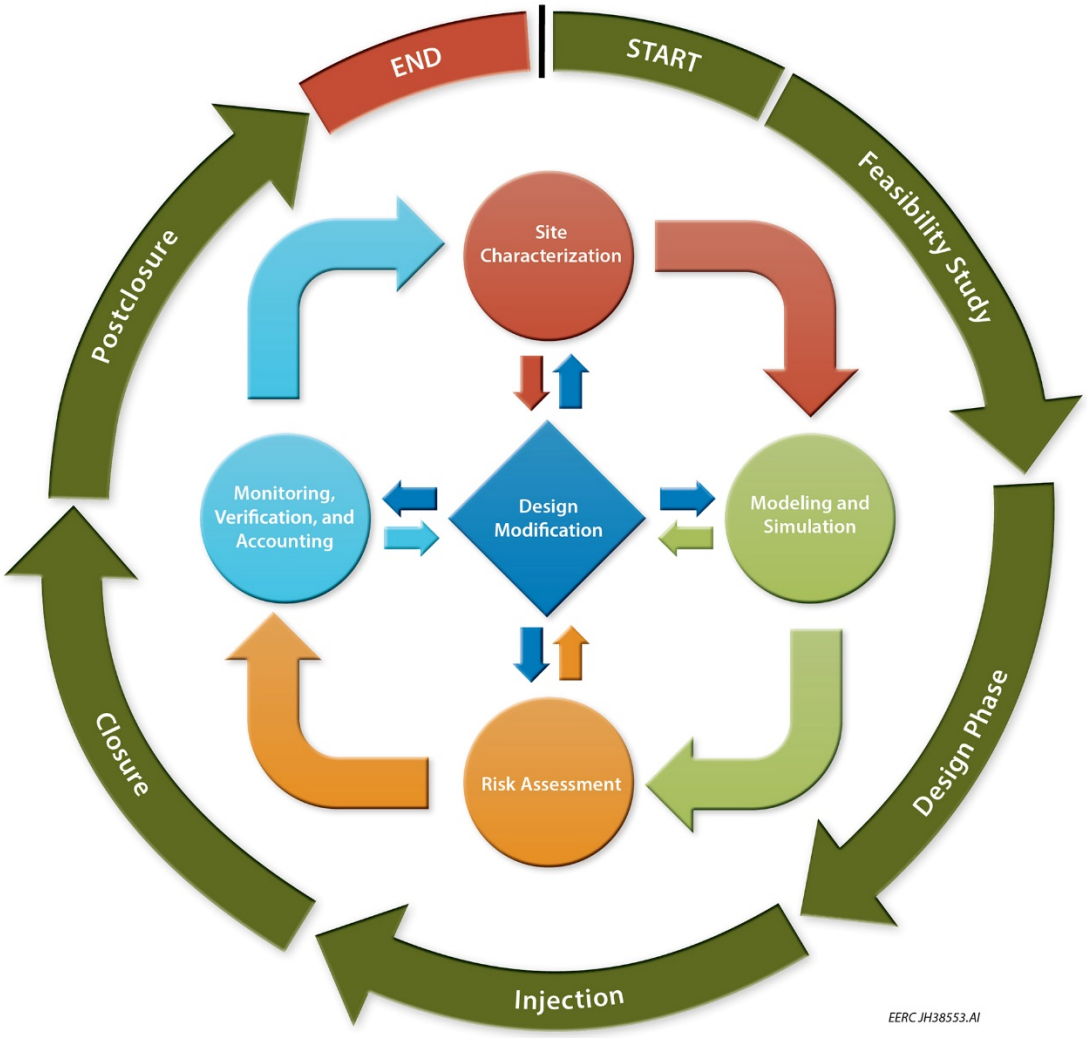

Figure 2. Project elements of the Bell Creek study. Each of these elements feeds into another, iteratively improving results and efficiency of evaluation (Hamling and others, 2012).

INJECTION SCHEME

The Bell Creek oil field has produced over 133 MMbbl of oil through both primary production and continuous waterflood over the past 40 years. Beginning in May 2013, the current and ongoing activities at Bell Creek are injecting approximately 1 million metric tons of CO_2 a year as part of a commercial EOR operation. CO_2 is injected into the oil-bearing sandstone reservoir in the Lower Cretaceous Muddy (Newcastle) Formation at a depth of approximately 4500 feet (1372 meters). The overlying Lower Cretaceous Mowry Formation shale will provide the primary seal, preventing 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 (Figure 3).

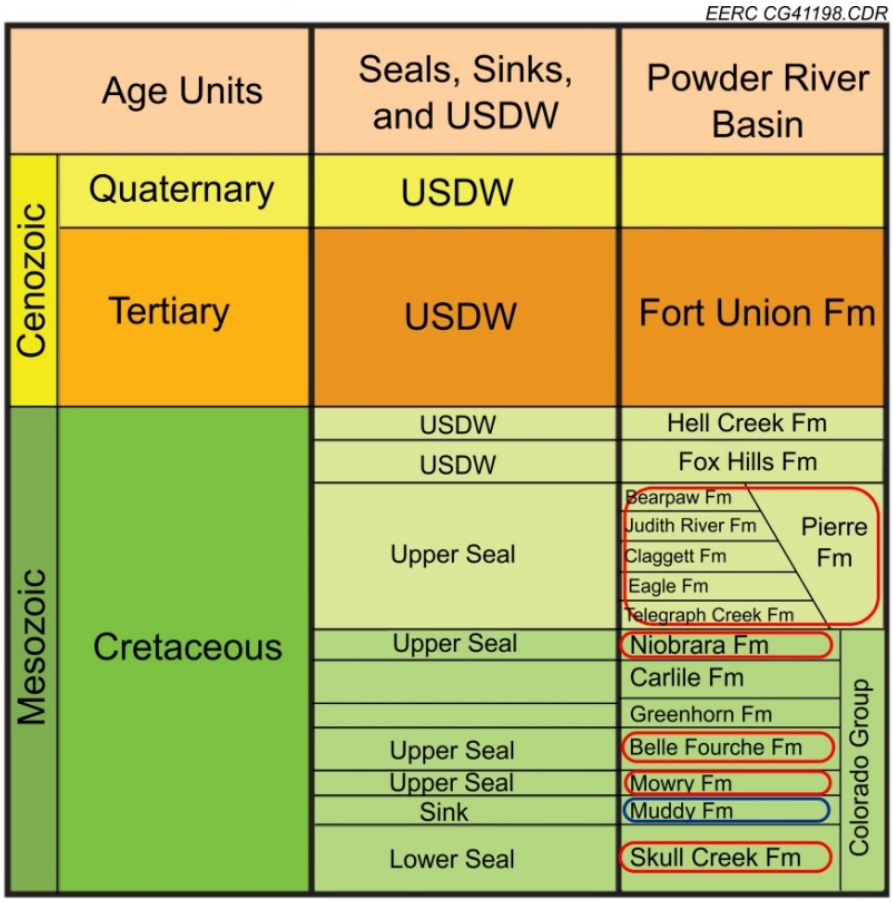

Figure 3. Late Cretaceous to Quaternary stratigraphic column of the Powder River Basin. Sealing formations are circled in red, and the primary oil-producing and sink formation is circled in blue. Formations bearing underground sources of drinking water (USDW) are also identified (Gorecki and others, 2012).

CO_2 injection will occur in a staged approach (nine planned CO_2 development phases, designated as Phases 1 to 9) across the field (Figure 4). It is expected that the reservoir will be suitable for miscible flooding conditions with an incremental oil production target of approximately 30 million barrels as part of the commercial tertiary CO_2 EOR process.

The injection program was initiated with the continuous injection of CO_2 into the 27 injection wells located within Phase 1 (Figure 5). Once suitable reservoir conditions are reached, the remaining 27 producer wells will be brought online. Production will continue until certain recovery minimum targets are reached, at which point a planned CO_2 WAG process will be initiated. All of the Phase 1 wells will eventually be part of the CO_2 WAG injection scheme.

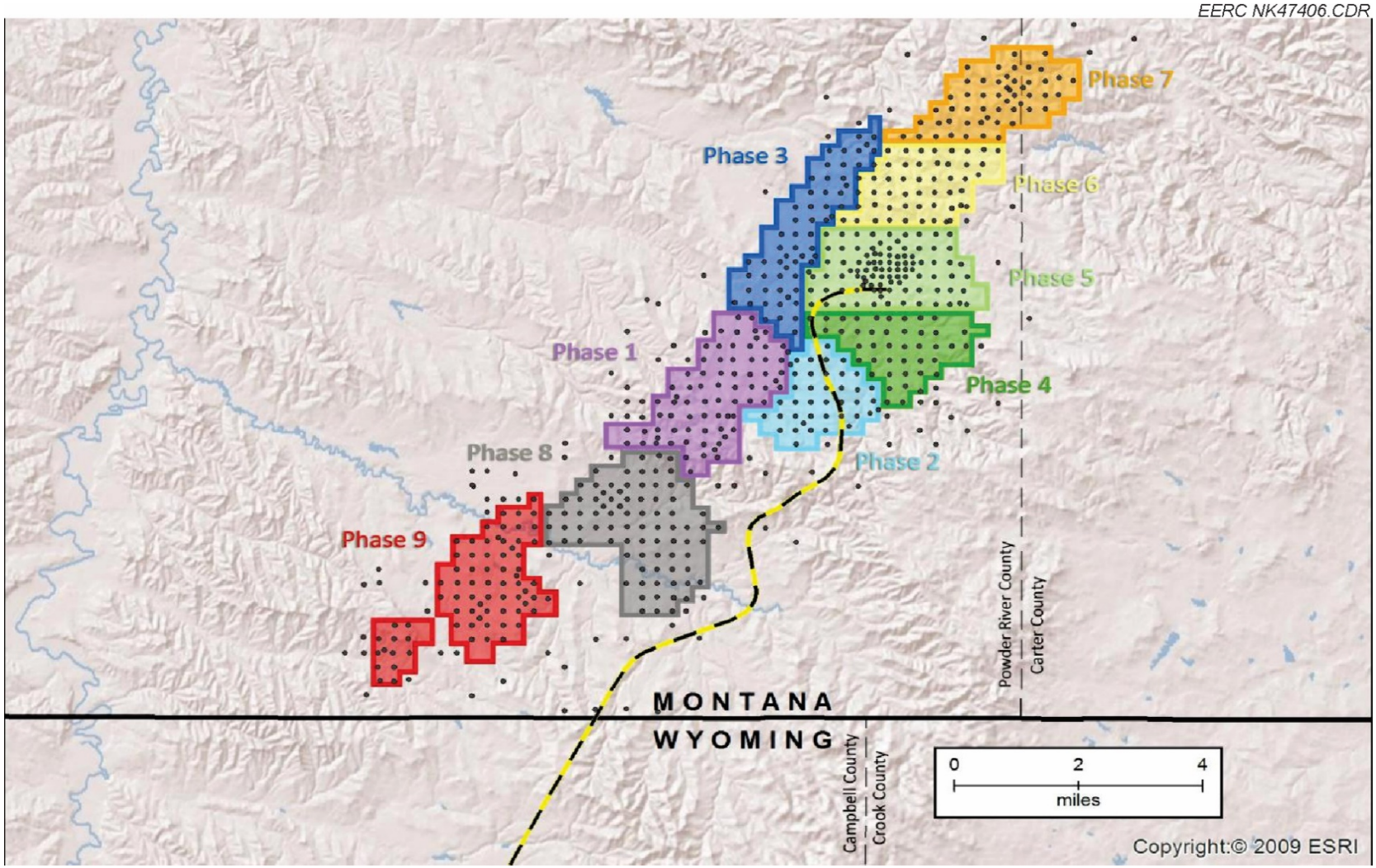

Figure 4. Bell Creek CO_2 EOR development phases.

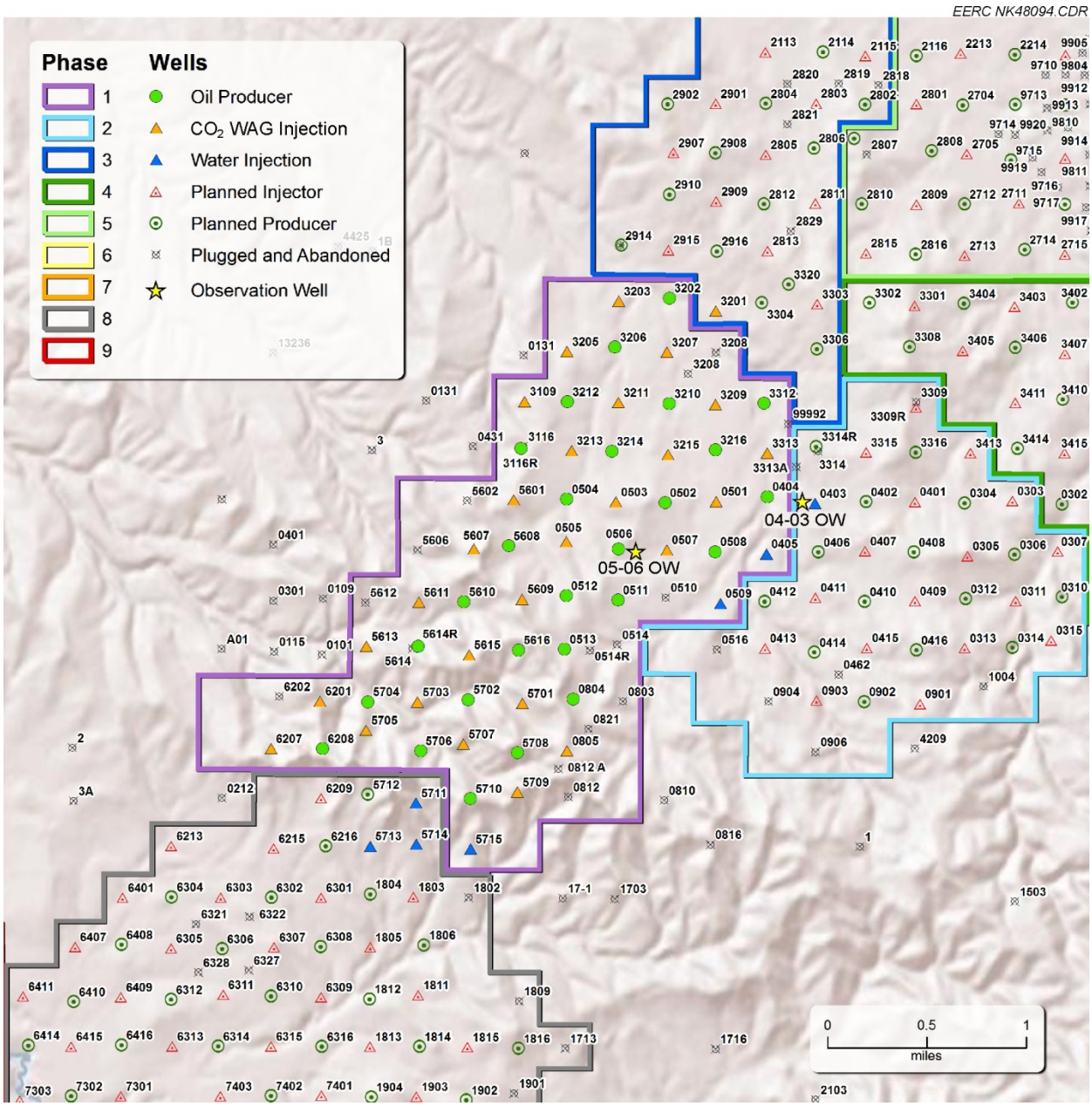

Figure 5. Injector well types as focused within Phase 1.

Injection/production will occur via a typical five-spot pattern of 40-acre spacing. The average rate of CO_2 WAG injection is expected to be ~2 million cubic feet/day for each Phase 1 CO_2 injection well. As with typical EOR procedures, recovered oil, CO_2, and water will be separated at the process/recycle facilities located on-site, and the CO_2 and water will be recycled into the WAG operation.

As this is a historic oil field, a number of wells were rejuvenated and an additional five wells were redrilled prior to the start of injection in additional to a dedicated monitoring well. This was

done to ensure both that the maximum benefit could be derived from the existing infrastructure (wellbores, well pads, etc.) and that the utilized infrastructure was within required engineering specifications.

The PCOR Partnerships's MVA program includes monitoring of all injection and production activities, including utilization of commercial project data such as injection and production pressures and flow data at Phase 1 wellheads, injection manifolds, and production test sites. The MVA program also includes indirect measurements such as periodic 3-D seismic, vertical seismic profiling, and downhole logging programs. These indirect methods will allow the movement of CO_2 to be closely studied as the CO_2 WAG process is initiated and matures.

All of the MVA program data will be used to continually evaluate the performance of the injection program. This will allow both Denbury and the PCOR Partnership to evaluate the effect of variances in the injection program (i.e., injection/production rates, pressures, five-spot design implementation, etc.) and their impact on reservoir performance to derive the maximum benefit to both partners. The PCOR Partnership's Bell Creek injection/production program is part of a commercial EOR project, and as such, some specifics related to injection/production program design are dictated by the commercial operator and/or are proprietary in nature. As a result, only program generalities have been presented in this document.

CONCLUSION

The injection program being developed throughout the Bell Creek oil field, with current injection activities occurring in Phase 1, is dictated by the commercial EOR project. The injection-monitoring program at the Bell Creek oil field studies flood conformance and incidental CO_2 storage specific to the Bell Creek CO_2 EOR activities, which in turn provide direct benefit to other CCS sites throughout the PCOR Partnership region and beyond. Additionally, insights gained during EOR operations from injection pattern performance will allow enhancement of the other key Bell Creek study components (site characterization, MVA, and modeling and simulation) through the PCOR Partnership's iterative research philosophy.

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