Plains CO_2 Reduction (PCOR) Partnership
Energy & Environmental Research Center (EERC)

BELL CREEK TEST SITE – INITIAL ANALYSIS FOR FIRST LARGE-SCALE REPEAT PULSED-NEUTRON LOGGING CAMPAIGN POST-SIGNIFICANT CO_2 INJECTION COMPLETED

Plains CO_2 Reduction (PCOR) Partnership Phase III
Task 9 – Milestone M51

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INTRODUCTION

The Plains CO_2 Reduction Partnership (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), is working with Denbury Onshore LLC (Denbury) to study associated carbon dioxide (CO_2) storage with regard to a commercial enhanced oil recovery (EOR) project at the Denbury-operated Bell Creek oil field located in southeastern Montana. Denbury is managing all injection, production, and recycle activities as part of its commercial CO_2 EOR operation. The EERC, through the PCOR Partnership, is studying the behavior of reservoir fluids and injected CO_2 to demonstrate safe and effective associated CO_2 storage with a commercial EOR project. The PCOR Partnership is developing practices and technologies that will allow future commercial-scale CO_2 storage projects to make informed decisions regarding site selection, injection programs, operations, and monitoring strategies that improve storage efficiency and effective storage capacity in clastic geologic formations.

A pulsed-neutron logging program was conducted at the Bell Creek oil field as a part of an overall MVA (monitoring, verification, and accounting) strategy to demonstrate and validate more technologies based on site-specific technical risks, to better understand sweep efficiency, effective storage capacity, and vertical and lateral flow boundaries in the Bell Creek Field. The logging program consisted of both baseline and time-lapse acquisitions to understand how fluid saturations were changing in the near wellbore environment during active injection. Sigma logs were collected and interpreted to monitor for gas saturation changes both within the reservoir and overlying strata. The sigma logs also provided enhanced subsurface site characterization through acquisition of high-resolution porosity and gamma ray in the generally less characterized overlying strata. Because of the low salinity of the injection target, inelastic capture (IC) logs were collected through the reservoir interval and interpreted in conjunction with the sigma logs to monitor changes in oil, water, and gas saturation. IC logs were needed to distinguish oil from low-salinity formation water, which have nearly identical sigma values, to better understand associated storage efficiency. Like the sigma log, the IC logs provided enhanced characterization through the reservoir interval by providing spectral lithology information.

INITIAL ANALYSIS FOR FIRST LARGE-SCALE REPEAT PULSED-NEUTRON LOGGING CAMPAIGN POST-SIGNIFICANT CO_2 INJECTION COMPLETED

The pulsed-neutron log (PNL) logging campaign has consisted of two parts: first, running a baseline set of logs and, second, running a series of repeat logs to compare against the baseline (Figure 1). The baseline logs were acquired from 33 wells from November 2012 to June 2013.

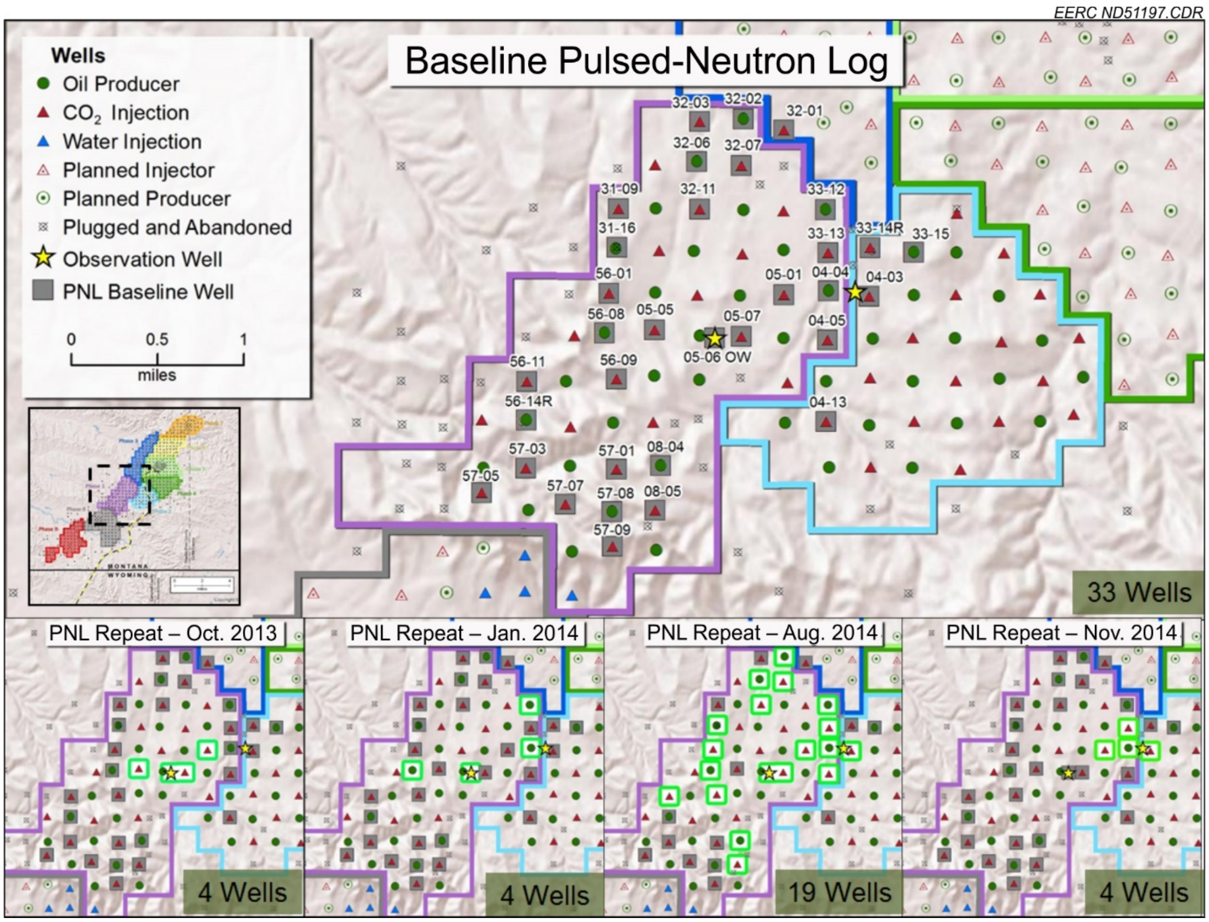

Figure 1. Map of the baseline and repeat PNL program throughout the Bell Creek oil field as of June 2015.

Two four-well PNL monitor tests were performed (during October 2013 and January 2014) in advance of a large-scale repeat. The monitor tests were conducted to demonstrate that PNLs had sufficient capability of resolving changes in water, oil, and gas saturation through the reservoir interval and to test their sensitivity to those changes. Based on the results of the monitor tests, the first large-scale PNL monitor campaign consisting of 19 wells occurred during August 2014. Following the full-scale repeat, a third PNL monitor test was performed during November 2014 on four wells to determine the short-term sensitivity of PNLs in relation to field injection and production rates in an established flood area and to provide a concurrent tie between near wellbore saturations from PNLs with a time-lapse seismic acquisition. An initial analysis of the repeat logs for the first large-scale repeat campaign has been completed. Key findings from this analysis include:

- IC logs interpreted in conjunction with sigma logs were capable of distinguishing between CO_2, oil, and water saturations in the low-salinity reservoir (<5000-ppm total dissolved solids) (Figure 2).

- CO_2 saturations of up to 40% were observed in the injection horizon.

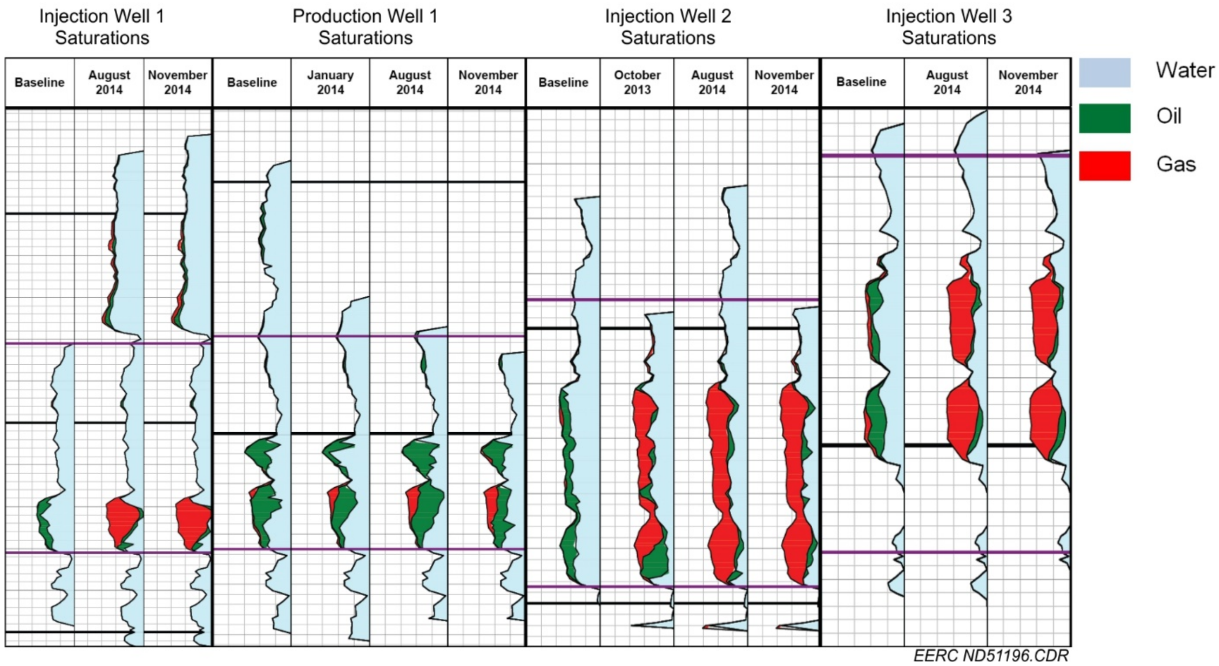

Figure 2. Changes in fluid saturations between baseline and repeat campaigns for four selected wells. Purple lines represent the top and bottom of the target injection interval.

- CO_2 is contained within the target injection horizon, demonstrating effective confining layers.

- Time-lapse changes in saturation are providing enhanced insight into associated storage performance.

- Time-lapse PNLs have demonstrated a continually evolving saturation profile over the first 18 months of active injection (see Figure 2).

In addition to the analysis of saturation changes, the PNL results are being used in a variety of ways to support the characterization, modeling and simulation, and risk assessment activities being performed to study associated CO_2 storage at Bell Creek. Workflows are being developed to use near wellbore saturation data from baseline PNLs to better understand uncertainty in existing simulation models and guide where additional characterization is needed to improve reservoir simulations. PNLs are also being used to provide a more accurate understanding of the geologic formations in the field by updating formation tops and thicknesses, creating a structural model above the reservoir, and updating rock properties in the geologic model. Data from the PNLs have helped to characterize potential above-zone monitoring intervals. Additionally, near-wellbore gas saturation data from PNLs were used in conjunction with dynamic simulation results to successfully determine if CO_2 saturations in the reservoir were sufficient to image using seismic techniques prior to deploying a repeat 3-D seismic survey. Finally, the PNLs are undergoing statistical analyses to help reduce error in comparing baseline and repeat logs to assist in monitoring for CO_2's presence above the reservoir.