Plains CO_2 Reduction Partnership—Development Phase Large-Scale Field Projects

Background

The U.S. Department of Energy Regional Carbon Sequestration Partnership (RCSP) Initiative consists of seven partnerships. The purpose of these partnerships is to determine the best regional approaches for permanently storing carbon dioxide (CO_2) in geologic formations. Each RCSP includes stakeholders comprised of state and local agencies, private companies, electric utilities, universities, and nonprofit organizations. These partnerships are the core of a nationwide network helping to establish the most suitable technologies, regulations, and infrastructure needs for carbon storage. The partnerships include more than 400 distinct organizations, spanning 44 states and four Canadian provinces, and are developing the framework needed to validate geologic carbon storage technologies. The RCSPs are unique in that each one is determining which of the numerous geologic carbon storage approaches are best suited for their specific regions of the country and are also identifying regulatory and infrastructure requirements needed for future commercial deployment. The RCSP Initiative is being implemented in three phases, the Characterization Phase, Validation Phase, and Development Phase. In September 2003, the Characterization Phase (2003–2005) began with the seven partnerships characterizing geologic and terrestrial opportunities for carbon storage and identifying CO_2 stationary sources within the territories of the individual RCSPs. The Validation Phase (2005–2013) focused on evaluating promising CO_2 storage opportunities through a series of small-scale field projects. Finally, the Development Phase (2008-2018+) activities are proceeding and will continue evaluating how CO_2 capture, transportation, injection, and storage can be achieved safely, permanently, and economically at large scales. These field projects are providing tremendous insight regarding injectivity, capacity, and containment of CO_2 in the various geologic formations identified by the partnerships. Results and assessments from these efforts will assist commercialization efforts for future carbon storage projects in North America.

The Plains CO_2 Reduction (PCOR) Partnership, led by the University of North Dakota's Energy & Environmental Research Center (EERC), includes all or part of the states of Iowa, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, Wisconsin, and

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PARTNERS (2003 TO PRESENT)

Abengoa Bioenergy New Technology, Inc.

Air Products and Chemicals, Inc.

Alberta Department of Energy

Alberta Department of Environment

Alberta Innovates - Technology Futures

ALLETE

Ameren Corporation

American Coalition for Clean Coal Electricity

American Lignite Energy

Apache Canada Ltd.

Baker Hughes Incorporated

Basin Electric Power Cooperative

Bechtel Corporation

Biorecro AB

Blue Source, LLC

BNI Coal, Ltd.

British Columbia Ministry of Energy, Mines, and Petroleum Resources

British Columbia Oil and Gas Commission

C12 Energy, Inc.

Chicago Climate Exchange

Computer Modelling Group, Inc.

Dakota Gasification Company

Denbury Onshore LLC

Ducks Unlimited Canada

Ducks Unlimited, Inc.

Eagle Operating, Inc.

Eastern Iowa Community College District

Enbridge Inc.

Encore Acquisition Company

Energy & Environmental Research Center (University of North Dakota)

Energy Resources Conservation Board/ Alberta Geological Survey

Environment Canada

Excelsior Energy Inc.

Great Northern Project Development, LP

Great River Energy

Wyoming and the Canadian provinces of Alberta, British Columbia, Manitoba, and Saskatchewan. The PCOR Partnership has received support from more than 100 organizations. The nine states in the PCOR Partnership account for about 17 percent of total U.S. CO_2 emissions from stationary sources. Regional characterization activities conducted by the PCOR Partnership confirmed that while numerous large stationary CO_2 sources are present, the region also has tremendous potential for CO_2 storage. The varying natures of the sources and storage sites reflect the geographic and socioeconomic diversity across this nearly 1.4 million mi^2 area of central North America. The region offers significant potential for storage in deep saline formations (both carbonate and clastic formations), unmineable coal seams, and depleted oil and natural gas fields. Of particular interest to this region of the U.S. is the optimization of CO_2 for geologic storage in tandem with enhanced oil recovery (EOR).

Project Description

Project Summary

The PCOR Partnership is planning two large-scale CO_2 projects (Bell Creek site and Fort Nelson site) for the Development Phase, also known as Phase III (Figure 1).

Bell Creek Site

For the Bell Creek large-scale project, the PCOR Partnership is working with Denbury Onshore LLC (Denbury) to develop robust, practical, and targeted support programs to study incidental CO_2 storage associated with a commercial-scale EOR operation. These programs include modeling and simulation; monitoring, verification, accounting (MVA), and assessment;

Figure 1: Project locations for the two PCOR Partnership Development Phase Projects

and risk management programs of appropriate size for a commercial-scale injection of CO_2. The project is being conducted in the Bell Creek Oil Field in Powder River County in southeastern Montana, and will provide insight into the relationship between successful incidental CO_2 storage and tertiary recovery on oil production within a sandstone reservoir in the Cretaceous Muddy Formation. The Bell Creek project is a significant opportunity to develop a set of cost-effective MVA protocols for large-scale CO_2 storage associated with a commercial-scale EOR operation.

Fort Nelson Site

The Fort Nelson Carbon Capture and Storage (CCS) Feasibility Project is an international collaboration led by Spectra Energy that includes industry, government, universities, and technologists and would include a large application of deep saline geologic storage. If proven feasible, this project will provide permanent storage of up to 2 million metric tons of CO_2 per year from the Fort Nelson gas processing facility, the largest processing facility in the region and the largest of its type in North America. The concept of the project is to capture sour CO_2 (mixture of CO_2 and hydrogen sulfide [H_2S]) from one of the largest gas-processing plants in North America and inject it into a deep saline formation. The sour CO_2 will be compressed and transported approximately 9 miles (15 kilometers) in a supercritical state via pipeline to the target injection location. The target zone will be a carbonate rock (limestone and dolomite) formation in the Devonian-age Elk Point Group. The injection location will be in relatively close proximity to the gas plant at a depth greater than 7,200 feet.

Injection Site Description

Bell Creek Site

The specific host site for the injection wells for the Bell Creek demonstration is located in the Bell Creek Oil Field approximately 30 miles southeast of Broadus, Montana.

Figure 2: Drilling an exploratory well in the Ft. Nelson Area

PARTNERS (CONT.)

Halliburton

Hess Corporation

Huntsman Corporation

Husky Energy Inc.

Indian Land Tenure Foundation

Interstate Oil and Gas Compact Commission

Iowa Department of Natural Resources – Geological Survey

Kiewit Mining Group

Lignite Energy Council

Manitoba Geological Survey

Manitoba Hydro

Marathon Oil Company

MEG Energy Corporation

Melzer Consulting

Minnesota Pollution Control Agency

Minnesota Power

Minnkota Power Cooperative, Inc.

Missouri Department of Natural Resources

Missouri River Energy Services

Montana Department of Environmental Quality

Montana-Dakota Utilities Company

Montana Public Service Commission

Murex Corporation

National Commission on Energy Policy

Natural Resources Canada

Nebraska Public Power District

Nexant, Inc.

North American Coal Corporation

North Dakota Department of Commerce Division of Community Services

North Dakota Department of Health

North Dakota Geological Survey

North Dakota Industrial Commission Department of Mineral Resources, Oil and Gas Division

North Dakota Industrial Commission Lignite Research, Development and Marketing Program

North Dakota Industrial Commission Oil and Gas Research Council

PARTNERS (CONT.)

North Dakota Natural Resources Trust

North Dakota Petroleum Council

North Dakota Pipeline Authority

North Dakota State University

Otter Tail Power Company

Oxand Risk & Project Management Solutions

Petroleum Technology Research Centre

Petroleum Technology Transfer Council

Pinnacle, a Halliburton Service

Prairie Public Broadcasting

Pratt & Whitney Rocketdyne, Inc.

Praxair

Ramgen Power Systems, Inc.

RPS Energy Canada Ltd

Saskatchewan Ministry of Energy and Resources

SaskPower

Schlumberger Carbon Services

Shell Canada Energy

Spectra Energy

Strategic West Energy Ltd.

Suncor Energy Inc.

TAQA North Ltd.

Tesoro Refinery (Mandan)

TGS Geological Products and Services

U.S. Department of Energy

U.S. Geological Survey Northern Prairie Wildlife Research Center

University of Alberta

University of North Dakota

University of Regina

Weatherford Advanced Geotechnology

Western Governors' Association

Westmoreland Coal Company

WBI Energy, Inc.

Wisconsin Department of Agriculture, Trade, and Consumer Protection

Wyoming Office of State Lands and Investments

Xcel Energy

Fort Nelson Site

The specific host site for the injection wells for the Fort Nelson demonstration will be located in northeastern British Columbia, approximately 9 miles west of the Fort Nelson gas plant (Figure 2).

Description of Geology

Bell Creek Site

Carbon Dioxide is being injected into the oil-bearing sandstone reservoir in the Lower Cretaceous Muddy (Newcastle) Formation at a depth of approximately 4,500 feet. Within the Bell Creek oil field, the Muddy Formation is dominated by high-porosity (25%–35%), high-permeability (150–1,175 millidarcies) sandstones deposited in a nearshore marine environment. The initial reservoir pressure was approximately 1,200 psi, which is significantly lower than the regional hydrostatic pressure regime (2,100 psi at 4,500 ft) which provides evidence of effective seals above and below the reservoir. The oil field is located structurally on a shallow monocline with a 1°–2° dip to the northwest and with an axis trending southwest to northeast for a distance of approximately 20 miles. Stratigraphically, the Muddy Formation in the Bell Creek oil field features an updip sand facies pinchout into shale facies serving as a trap. The barrier bar sand bodies of the Muddy Formation strike southwest to northeast and lie on a regional structural high, which represents a local paleodrainage deposition. A deltaic siltstone overlaps the sandstone on an erosional barrier bar surface and, finally, is partially dissected and somewhat compartmentalized by intersecting shale-filled incisive erosional channels. The overlying Lower Cretaceous Mowry Shale provides the primary seal, preventing fluid migration to overlying aquifers and to the surface. On top of the Mowry Shale are several thousand feet of low-permeability 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 migration field-wide.

Fort Nelson Site

The target zone for the Fort Nelson injection is a carbonate rock formation, known as the Elk Point Group, located at a depth of greater than 7,200 feet. The Elk Point Group is composed of carbonate rocks with average porosities ranging from 8% to 12%, with permeability in the tens to hundreds of millidarcies range. These rocks were deposited in a series of reef-building events and have undergone extensive post-depositional alteration, resulting in a highly heterogeneous mixture of dolomites and limestones. Although highly variable in geology, formations within the Elk Point Group have held large natural gas fields locally and regionally, demonstrating their ability to hold large quantities of gas for geologic time periods. Thick, competent, laterally continuous shales of the Devonian Fort Simpson and Muskwa Formations act as the primary confining zone holding this gas in place and will also act as the primary confining zone for CO_2 storage. These shales range in thickness between 1,310 and 1,970 feet in the Fort Nelson area and are characterized by low permeability and high geomechanical strength, and should make excellent seals for CO_2 storage. Secondary confinement also exists above the Fort Simpson Formation, the most competent and massive being the Banff Formation, which is predominantly shale and is not less than 100 feet thick in the Fort Nelson area.

Source of CO_2

Bell Creek Site

Carbon dioxide for the Bell Creek demonstration is being sourced from ConocoPhillips' Lost Cabin Gas Plant, a gas-processing facility located in Fremont County, Wyoming. The Lost Cabin Gas Plant currently supplies approximately 50 million cubic feet of CO_2 per day to the Bell Creek oil field. Denbury and Conoco Phillips have entered into a CO_2 purchase-and-sale agreement, and compression facilities adjacent to the Lost Cabin Gas Plant pressurize the CO_2 from approximately 50 to 2,200 psi, for transportation to the project site at a near-injection-ready pressure. This infrastructure includes a 232-mile pipeline (known as the Greencore Pipeline) that was completed in 2012 that is bringing CO_2 to the injection site at a rate of approximately 1 million metric tons per year (Figure 3). Denbury commercial activities are estimated to recover approximately 30 million barrels of incremental oil over the operation's 20- to 25-year life, but these commercial activities are outside the scope of the PCOR Partnership project.

Fort Nelson Site

The Fort Nelson demonstration will utilize sour CO_2 from the Spectra Energy Fort Nelson Natural Gas-Processing Plant in northwestern British Columbia, Canada. The sour CO_2 will be captured using an existing amine-based acid gas removal system, dried, compressed, and transported by pipeline as a supercritical fluid to a nearby injection site. Its composition will be approximately 95 percent CO_2 and 5 percent H_2S.

PROJECT DURATION

Start Date
10/01/2007

End Date
09/30/2017

COST

Total Project Value
$123,097, 534

DOE/Non-DOE Share
$79,000,893/ $44,096,641

PROJECT NUMBER

FC26-05NT42592

Injection Operations

Bell Creek Site

The injection strategy for Bell Creek was developed by Denbury, for the purposes of commercial CO_2 EOR. Note that Denbury's commercial CO_2 EOR operations are independent from the PCOR research project. Under PCOR, the EERC is conducting site characterization, modeling and predictive simulation, and MVA to study the interrelationship of commercial CO_2 EOR and incidental CO_2 storage and to evaluate how various EOR injection strategies affect reservoir response, storage efficiencies, and storage capacities. Injection in the Bell Creek oil field began in May 2013. Since the Bell Creek Oil Field has undergone secondary recovery, much of the infrastructure necessary for a combined CO_2 EOR and CO_2 storage project was already in place. In addition, Denbury has the Greencore Pipeline which is delivering CO_2 from the ConocoPhillips Lost Cabin gas-processing plant to the Bell Creek Oil Field. Surface facilities and support infrastructure were constructed, and were commissioned in August 2013, which allow for CO_2 separation from produced hydrocarbons and subsequent reinjection into the Muddy Formation.

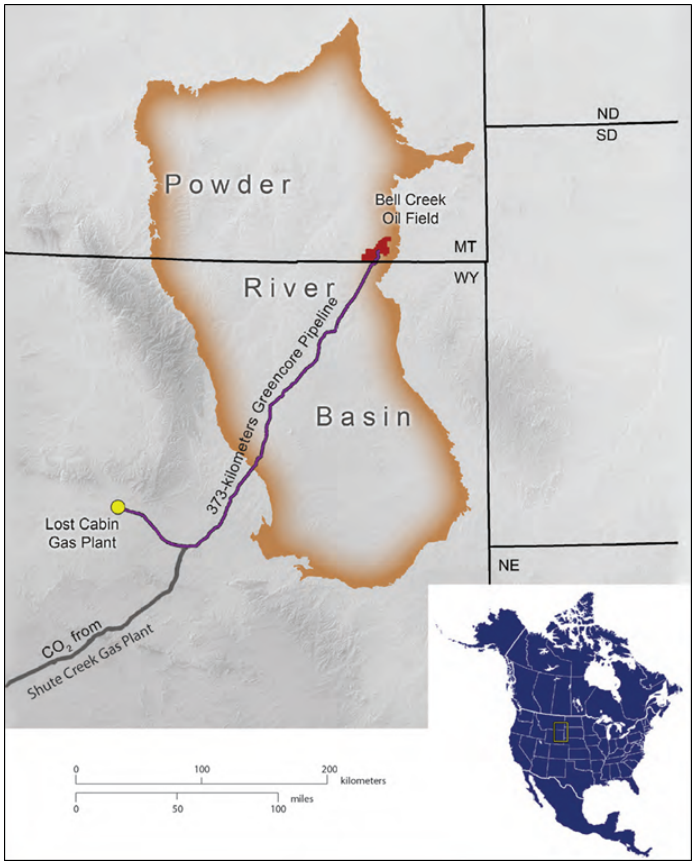

Figure 3: Location of the Lost Cabin Gas Plant and Greencore Pipeline.

As of August 2015, over 2,301,000 cumulative metric tons were stored, thereby surpassing a major RCSP Phase III metric of injection of 1 million metric tons of CO_2 per project. Currently planned operations consist of a continuous CO_2 flood followed by a water alternating gas (WAG) cycle utilizing both recycled CO_2 from the processing facilities and incoming CO_2 from the Greencore Pipeline.

Fort Nelson Site

For the Fort Nelson demonstration, if proven feasible, Spectra Energy will install significant infrastructure to transport the supercritical sour CO_2 to the injection site, including construction of compressors, a dehydration system, a pipeline for the sour CO_2 gas stream, and a pump. The target injection formation is at a depth of greater than 7,200 feet. Formations in this depth range will be at temperatures and pressures that ensure the injected sour CO_2 remains in a supercritical state.

Simulation and Monitoring of CO_2

In the Development Phase, an emphasis has been placed on developing practical, site-specific, cost-effective, and risk-based MVA plans. This philosophy begins with a thorough site characterization, which is used to develop geologic models and perform injection simulations to predict the long-term fate of the injected CO_2. Both the site characterization and the modeling and simulation then feed into a detailed and iterative risk assessment process which is used to identify potential leakage and migration risks, from which a detailed, site-specific, risk-based MVA plan is developed. This integrated approach will be repeated throughout the course of the project, and the cycle can be repeated and at any point if more data are required.

A wide variety of modeling activities have been conducted at the Bell Creek site, including geologic models at multiple scales, predictive multiphase fluid flow simulations, geomechanical modeling, and geochemical simulation. These models and simulations are used to interpret and analyze the geologic, reservoir, and fluid data and to conduct predictive multiphase flow, geomechanical, and geochemical simulations. These efforts identify data gaps and guide the MVA program to better predict and address challenges with long-term associated CO_2 storage. The goal of the MVA program is to provide critical data to verify site security, evaluate reservoir behavior during injection, determine the fate of injected CO_2, and investigate mechanisms that affect CO_2 storage efficiency within the EOR process, all while operating in a manner compatible with the commercial CO_2-EOR operation. The MVA program at the Bell Creek Site uses time-lapse data acquisitions as part of a surface-, shallow-subsurface-, and deep-subsurface-monitoring effort (Figure 4) guided by the PCOR Partnership's adaptive management approach.

Goals and Objectives

The primary objective of the DOE's Storage Program is to develop technologies to safely and permanently store CO_2 and reduce greenhouse gas emissions without adversely affecting energy use or hindering economic growth. The programmatic goals of Storage research are to (1) develop and validate technologies to ensure 99 percent storage permanence; (2) develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness; (3) support industry's ability to predict CO_2 storage capacity in geologic formations to within 30 percent; and (4) develop Best Practices Manuals (BPMs) for monitoring, verification, accounting, and assessment; site screening, selection, and initial characterization; public outreach, well management activities, and risk analysis and simulation.

The PCOR Partnership's overall goal is to validate the information and technology developed under the Characterization and Validation Phases relative to research and field activities, public outreach efforts, and regional characterization. Specific objectives include the following:

- Conduct a successful Bell Creek large-scale injection to verify and validate the concept of utilizing the region's many oil fields for large-scale injection of anthropogenic CO_2, resulting safe long-term storage of CO_2 while producing incremental oil volumes.
- Conduct a successful Fort Nelson large-scale feasibility study and to ultimately provide risk management and MVA support for the injection to verify and validate the concept of utilizing the region's carbonate saline formations for large-scale injection and storage of anthropogenic CO_2.
- Demonstrate that oil-bearing formations are viable for CO_2 storage with significant storage capacity to help meet near-term CO_2 storage objectives.
- Establish MVA methods to safely and effectively monitor commercial-scale simultaneous CO_2-EOR and CO_2 storage projects.
- Utilize the commercial practices as the backbone of the MVA strategy and augment with additional cost-effective techniques.
- Share lessons learned for the benefit of similar projects across the region.
- Establish the relationship between the CO_2-EOR process and long-term storage of CO_2.

Accomplishments to Date

Bell Creek

- Injection of CO_2 began in May 2013. As of August 2015, over 2,301,000 cumulative metrics tons of CO_2 have been stored.
- A pulsed-neutron logging campaign was completed at the project site. This survey was conducted as a part of an overall MVA 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.
    - Inelastic capture logs were combined with sigma logs (logging types that focus on oil, gas, and water saturation) were capable of distinguishing between CO_2, oil and water in a low-salinity reservoir (<5,000 ppm total dissolved solids)
    - CO_2 saturations of up to 40% were observed, and the CO_2 was contained within the target injection horizon.

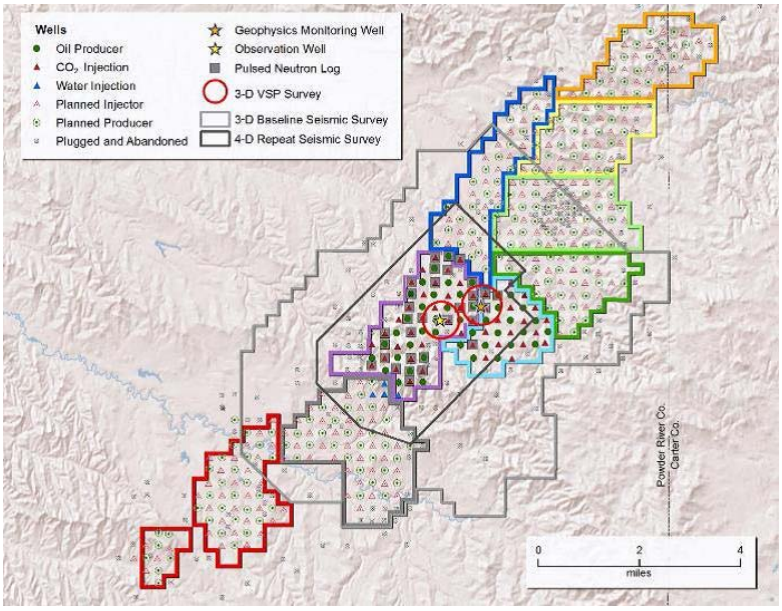

Figure 4: Subsurface MVA program for the Bell Creek Site.

- Two years of near surface monitoring has been completed at the Bell Creek site. The purpose of the near-surface monitoring program is to establish baseline conditions and variability of surface water, soil, and shallow groundwater aquifer chemistries in the vicinity of geologic CO_2 injection that can be used in conjunction with continued assurance monitoring to 1) provide a scientifically defensible source of data to show that near-surface environments remain unaffected by fluid or gas migration and 2) identify and evaluate anomalies that could be indicative of an out-of-zone migration event should they occur during assurance monitoring.
    - The monitoring program has been sufficient to detect, characterize, and attribute multiple anomalies to naturally occurring processes and has successfully demonstrated no impact to near-surface environments.
- A 75-mi^2 light detection and ranging (LIDAR) survey collected over the field in July 2011 was used to verify and correct well location and elevation data throughout the field, improving structural interpretations of the reservoir.
- A 40-mi^2, 3-D seismic survey was collected in August 2012 to aid in structural interpretation and to provide a baseline data set for future time-lapse CO_2 monitoring. A repeat 3-D seismic survey was collected in 2014.
- Two 3-D vertical seismic profile seismic surveys were conducted in the spring of 2013, which included the installation of a permanent geophone array. These surveys and the geophone array allow for time-lapse data acquisitions for CO_2 monitoring and passive seismic monitoring during injection. Repeat acquisitions occurred in 2014.
- Completed update of geocellular model and associated history matching and predictive simulations utilizing newly collected data from characterization and baseline MVA activities.

Fort Nelson

- Completed drilling, coring, and logging of the stratigraphic well at the Fort Nelson site.
- Acquired existing 2-D and 3-D seismic data in the area of the Fort Nelson site.
- Completed two rounds of modeling and risk assessments for the Fort Nelson site.
- Developed an MVA plan based on site characterization, modeling, and simulation activities.
- Completed a best practices manual based on site characterization and modeling and simulation activities.

Benefits

The PCOR Partnership region, which covers over 1.4 million square miles, emits approximately 522 million metric tons of CO_2 yearly from large stationary sources in the region. Research through the PCOR Partnership Development Phase projects can be used to ensure that geologic storage is not just an option for the distant future, but can be implemented on a large scale for both environmental and commercial reasons. Overall, based on the current geological formations characterized, the PCOR Partnership region has the storage resource of 583 billion metric tons of CO_2 in saline formations, 4 billion metric tons in depleted oil fields, and 7 billion metric tons in unmineable coal seams, which is over four times the anticipated regional emissions over the next 100 years, assuming a static emission profile.

The integrated approach at the Bell Creek Oil Field helps meet the common sense safety expectations of local landowners and communities. Further, by storing anthropogenic CO_2 at the Bell Creek Oil Field, Denbury benefits the environment by offsetting the carbon footprint of its regional oil field operation. The results of the Bell Creek project will help future projects effectively implement a proven CO_2 MVA system as part of a comprehensive approach to subsurface CO_2 management, utilizing it for regional EOR operations.

While providing a substantial reduction in CO_2 emissions, the Fort Nelson project will also facilitate the development of significant shale gas reserves in the Horn River Basin to provide North American markets with clean natural gas. Research aspects of the effort are being designed to provide proof of concept for geologic CO_2 storage in deep saline formations, particularly for co-storage with sour gas, and serve as a model for follow-on CCS projects using geologic CO_2 management at other gas-processing facilities in the region and around the world.