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

BELL CREEK TEST SITE – TRANSPORTATION AND INJECTION OPERATIONS REPORT

Plains CO_2 Reduction Partnership Phase III
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BELL CREEK TEST SITE – TRANSPORTATION AND INJECTION OPERATIONS REPORT

ABSTRACT

The Plains CO_2 Reduction (PCOR) Partnership, which is led by the Energy & Environmental Research Center (EERC), is working with Denbury Onshore LLC (Denbury) to study CO_2 storage associated with a commercial enhanced oil recovery (EOR) project at the Denbury-operated Bell Creek oil field located in southeastern Montana. The CO_2 for the project is sourced from the ConocoPhillips Lost Cabin Gas Plant and the ExxonMobil Shute Creek gas-processing facility, both of which are in Wyoming. The Lost Cabin CO_2 is pressurized to a maximum pressure of 15.2 MPa (2200 psi) and transported through the 373-km (232-mi) Greencore pipeline to the Bell Creek field. The Shute Creek CO_2 enters the Greencore pipeline through the Anadarko pipeline tie-in to the Greencore line.

The Bell Creek EOR facility follows a scheme in which the water and CO_2 that are separated from the oil are reinjected. Water is disposed of in a deeper formation or is used to pressurize portions of the field prior to CO_2 injection, to continue water flood operations, or during WAG (water alternating gas) activities. Fluids from the individual wells are transported through flow lines and enter the header system of the production manifold in the manifold building. From the production manifold, the commingled stream flows to the process building for separation. The oil piped to oil storage and sales tanks. The water is piped to temporary water storage tanks prior to being pumped back to the field for reinjection. The CO_2 is piped to the compressor building. Following pressurization, the CO_2 discharges back to the manifold building where it is combined with the purchase CO_2 for reinjection into the oil reservoir. Water and CO_2 are distributed to the field through injection manifolds.

The methods used by Denbury to plan, construct, and operate the Greencore pipeline for EOR may also apply to CO_2 transport during a future carbon capture and storage (CCS) project. Likewise, many of the surface facilities associated with CO_2 EOR are similar to those that would be needed for storage of CO_2 within any secure geologic formation. While the Bell Creek project is an EOR project rather than a CCS project, the data being collected during all phases of this EOR project will be invaluable in helping to prove the usefulness of the CCS concept as a way to effectively decrease atmospheric CO_2 levels. It is anticipated that many of the lessons learned from this EOR operation will also apply to CCS projects in the future.

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NOMENCLATURE AND ABBREVIATIONS LIST

°C	degrees Celsius
°F	degrees Fahrenheit
ANSI	American National Standards Institute
ATWS	additional temporary work space
AWS	American Welding Society
bbl	barrel
BLM	Bureau of Land Management
BMP	best management practice
CCS	carbon capture and storage
cm	centimeter
CO_2	carbon dioxide
COS	carbonyl sulfide
d	day
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EERC	Energy & Environmental Research Center
EI	environmental inspector
EOR	enhanced oil recovery
ft	feet
H_2S	hydrogen sulfide
HDD	horizontal directional drilling
in.	inch
km	kilometer
m	meter
m^3	cubic meters
m^3/d	cubic meters per day
mi	mile
MLV	mainline valve
MMcf	million cubic feet
MMcfd	million cubic feet per day
MMscfd	million standard cubic feet per day (volume measured at 60°F and 1 atm)
MP	mile point
MPa	megapascal
OSHA	Occupational Safety and Health Administration
PCOR	Plains CO_2 Reduction (Partnership)
psi	pounds per square inch
psig	pounds per square inch, gauge
RCSPs	Regional Carbon Sequestration Partnerships
ROW	right-of-way
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SSV	surface safety valve
t	tonne (i.e., metric ton)
WAG	water alternating with gas

BELL CREEK TEST SITE – TRANSPORTATION AND INJECTION OPERATIONS REPORT

EXECUTIVE SUMMARY

The Plains CO_2 Reduction (PCOR) Partnership, which is led by the Energy & Environmental Research Center (EERC), is working with Denbury Onshore LLC (Denbury) to study CO_2 storage associated with 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 storage of CO_2 associated 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 maximize storage efficiency and effective storage capacity in clastic geologic formations. It is anticipated that many of the lessons learned from this EOR operation will also apply to carbon capture and storage (CCS) projects in the future.

The EERC prepared this report to summarize the CO_2 pipeline and the Bell Creek injection facilities. Because the EOR operation is a business activity and much of the information is considered to be business-sensitive, this report was compiled exclusively using information that has previously been publicly disclosed.

The CO_2 for the Bell Creek site is sourced from the ConocoPhillips Lost Cabin Gas Plant and the ExxonMobil Shute Creek gas-processing facility. A target rate of 1.4 million m^3/d (50 MMcfd) CO_2 that was previously vented from the Lost Cabin Gas Plant is now compressed and transported via pipeline to Bell Creek. The quantity of CO_2 that is contributed to the Bell Creek site by the Shute Creek Plant is not publicly available.

The CO_2 is transported to the Bell Creek site using Denbury's Greencore pipeline, which is approximately 373 km (232 mi) long. The pipeline was designed to transport as much as 20.5 million m^3/d or 38,150 t/d (725 MMcfd or 42,053 short tons/d) CO_2, although plans called for the Greencore pipeline to initially transport a target rate of 1.4 million m^3/d, equal to 2630 t/d (50 MMcfd or 2900 short tons/d) (Denbury Resources Inc., 2015). The pipeline right-of-way (ROW) runs through private (65%), federal (30%), and state (5%) land (Blincow, 2013). The pipeline is 20 in. in diameter and was designed for a maximum operating pressure of 15.2 MPa (2200 psi). Steps taken when constructing the pipeline were standard pipeline construction sequence steps and included survey and staking; clearing; front-end grading; ROW topsoil stripping; restaking the trench centerline; stringing pipe; lining-up and welding pipe; x-ray

inspection and weld repair (if necessary); coating of field welds; trenching; inspection and repair of coating; lowering pipe into the trench; padding, backfilling, and rough grading; hydrostatic testing and final tie-in; and replacement of topsoil, cleanup, and full restoration. Construction began in August 2011, and the pipeline was commissioned and started up in December 2012. The pipeline cost an estimated US$285 million (Blincow, 2013; Hallerman, 2013).

The Bell Creek EOR facility follows a scheme in which the water and CO_2 that are separated from the oil are reinjected. Fluids from the individual wells are transported through flow lines and enter the header system of the production manifold in the manifold building. From the production manifold, the commingled stream flows to the process building for separation (Walsh and others, 2013). The oil is piped to oil storage and sales tanks. The water is piped to temporary water storage tanks prior to being pumped back to the field for reinjection. The CO_2 is piped to the compressor building. Following pressurization, the CO_2 discharges back to the manifold building where it is combined with the purchase CO_2 for reinjection (Walsh and others, 2013). Water and CO_2 are distributed to the field through injection manifolds (Walsh and others, 2013).

The methods used by Denbury to plan, construct, and operate the Greencore pipeline for EOR may also apply to CO_2 transport during a future CCS project. Likewise, many of the surface facilities associated with CO_2 EOR are similar to those that would be needed for storage of CO_2 within any secure geologic formation. While the Bell Creek project is an EOR project rather than a CCS project, the data being collected during all phases of this EOR project will be invaluable in helping to prove the usefulness of the CCS concept as a way to effectively decrease atmospheric CO_2 levels.

BELL CREEK TEST SITE – TRANSPORTATION AND INJECTION OPERATIONS REPORT

1.0 INTRODUCTION

The Plains CO_2 Reduction (PCOR) Partnership is one of the U.S. Department of Energy's (DOE's) seven Regional Carbon Sequestration Partnerships. The DOE goal for each partnership is to inject at least 1 million tonnes of CO_2 into the subsurface during a field test in which the fate of the CO_2 will be studied. The PCOR Partnership, which is led by the Energy & Environmental Research Center (EERC), is working with Denbury Onshore LLC (Denbury) to study associated CO_2 storage at 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 storage of CO_2 associated 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 maximize storage efficiency and effective storage capacity in clastic geologic formations. It is anticipated that many of the lessons learned from this EOR operation will apply to carbon capture and storage (CCS) projects in the future.

The EERC prepared this report to summarize the CO_2 pipeline and the Bell Creek injection facilities. Because the EOR operation is a business activity and much of the information is considered to be business-sensitive, this report was compiled exclusively using information that has previously been made public.

2.0 CO_2 SOURCE

The CO_2 for the Bell Creek site is sourced from two gas processing plants: the ConocoPhillips Lost Cabin Gas Plant and ExxonMobil's Shute Creek Gas Processing Plant. The raw natural gas that is processed at the Lost Cabin Gas Plant comes from the Madden Field in the Wind River Basin of Wyoming. It contains approximately 67% methane, 20% CO_2, 12% H_2S, and 1% COS (Lohnes, 2007). The Shute Creek facility processes gas from the LaBarge Field in Wyoming's Green River Basin. The composition of the gas processed at the Shute Creek plant is approximately 65% CO_2, 21% methane, 7% nitrogen, 5% H_2S, and 0.6% helium (Massachusetts Institute of Technology, 2015). The Lost Cabin Gas Plant produces a target rate of 50 MMcfd of CO_2 that was previously vented from the processing system. The CO_2 is then compressed for transport to the Bell Creek Field for EOR and associated storage. The average composition of this

CO_2 stream is shown in Table 1. The quantity and composition of the CO_2 transported from the Shute Creek facility through the Anadarko line are not publicly available.

Table 1. Average Lost Cabin Vent Stack CO_2 Composition*

Component	Train 1	Train 2	Train 3	Average
CO_2, vol%	98.318	98.447	98.273	98.346
CH_4, vol%	1.472	1.389	1.550	1.470
C_2H_6, vol%	0.016	0.015	0.027	0.019
N_2, vol%	0.103	0.057	0.052	0.071
COS, vol%	0.091	0.092	0.098	0.094
H_2S, ppm	5.000	4.000	8.000	5.667

* From Lohnes, 2007.

3.0 PIPELINE TRANSPORT OF THE CO_2 TO THE BELL CREEK FIELD

3.1 Basic Information about the Greencore Pipeline

Purchased CO_2 is delivered to the Bell Creek Field from the Lost Cabin Gas Plant via the Denbury-operated Greencore pipeline and from the Shute Creek gas-processing facility via a tie-in of the Anadarko-operated Anadarko pipeline into the Greencore pipeline. The pipeline was constructed to move CO_2 from anthropogenic sources to petroleum reservoirs in the Rocky Mountain region (Denbury Resources Inc., 2015). Designed to ultimately transport as much as 20.5 million m^3/d, equal to 38,150 t/d (725 MMcfd or 42,053 short tons/d) CO_2, plans called for the Greencore pipeline to initially transport a target rate of 1.4 million m^3/d, equal to 2630 t/d (50 MMcfd or 2900 short tons/d) (Denbury Resources Inc., 2015). The pipeline cost an estimated $285 million (Blincow, 2013; Hallerman, 2013).

The Greencore pipeline is approximately 373 km (232 mi) long and follows the route shown in Figure 1. The pipeline right-of-way (ROW) runs through private (65%), federal (30%), and state (5%) land (Blincow, 2013). A pipeline spur is planned that will connect the Hartzog Draw Field in northeastern Wyoming with the Greencore line (Snyder, 2012). Denbury is also proposing an expansion of the pipeline system to incorporate CO_2 from Riley Ridge in the LaBarge Field in southwestern Wyoming (Snyder, 2012; Denbury Resources Inc., 2014) as well as an extension of the pipeline from Bell Creek northeastward to the Cedar Creek Anticline (Denbury Resources Inc., 2014).

The pipeline consists of 50.8 cm (20-in.)-diameter, Class 900# ANSI (American National Standards Institute) pipe and was designed to operate at a pressure of 15.17 MPa (2200 psig) and 37.8°C (100°F) (Denbury Resources Inc., 2010). The maximum design pressure for ANSI Class 900# carbon steel is 15.17 MPa (2200 psig) at 37.8°C (100°F) (Vize LLC, 2015). Maximum temperature and pressure of Class 900# Cr-Mo is 15.51 MPa (2250 psig) at 37.8°C (100°F) (Vize LLC, 2015). Denbury has not publicly disclosed the pipeline materials of construction.

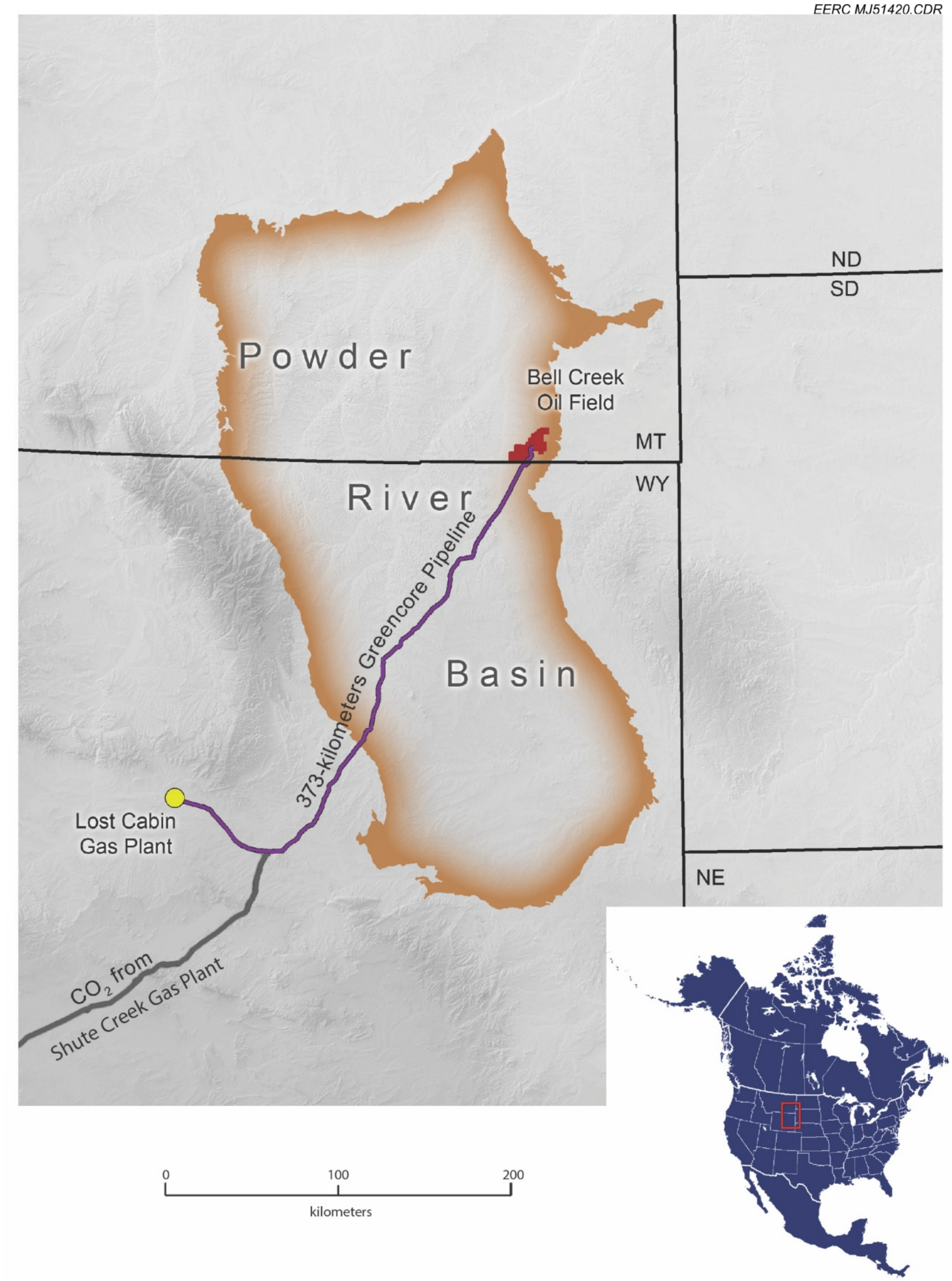

Figure 1. Denbury Greencore pipeline route.

Initial construction of the pipeline and mainline valves (MLVs) began on August 29, 2011, on two of four spreads (Denbury, 2011). Spread 2 contained approximately 85.3 km (53 mi) of pipe and four MLV installations. Spread 2's construction was completed on December 8, 2011. The pipeline was purged and packed with nitrogen to preserve it until the next year. Spread 3 comprised approximately 100 km (62 mi) of pipe and seven MLV installations. Following its completion on December 17, 2011, the line was again purged and packed with nitrogen. Spreads 1 and 4, as well as the remaining MLV installations and the metering stations at both Conoco's Lost Cabin Gas Plant and Denbury's Bell Creek Facilities station, were to be constructed in 2012 (Denbury, 2011). The pipeline was commissioned and started up in December 2012 (Blincow, 2013).

The *Greencore CO_2 Pipeline Project Plan of Development* (Greencore Pipeline Company LLC, 2011) contains considerable detail regarding the Greencore pipeline. Select information contained in the document is summarized in Sections 3.2 and 3.3 of this report. Interested readers are encouraged to download the Greencore document for further perusal.

According to the planning document (Greencore Pipeline Company LLC, 2011), the pipeline contains a launcher, meter run, and block valve at the receipt point at Lost Cabin Gas Plant, as well as a block valve, scraper receipt trap, tee, and meter run at the Bell Creek Field Unit C delivery point/terminus. The document lists an additional 15 block valves as well as scraper receipt traps/launcher traps and tee and block valves at four other locations. The planned valve operator/actuator types and their location along the pipeline are given in Table 2. Figure 2 shows the location of tees along the pipeline that allow tie-in to other pipelines.

Pump stations were planned for approximate locations along the pipeline of 63.6, 231.7, and 371.9 km (39.5, 1440, and 231.1 mi). When given in miles, these locations are known as mile points [MPs]). Branch tees at mainline block valves were to be installed to facilitate future tie-in of these pump stations. Plans called for construction of the pump stations when product volumes exceeded 4.2 million m^3/d at standard oil and gas conditions (150 MMscfd). Each pump station would include valve manifolds, pumps, pigging equipment, power distribution, and control buildings (Greencore Pipeline Company LLC, 2011).

Scraper traps (including block valves) were planned for installation at several locations. One would be located at Lost Cabin location 0.0 km (MP 0.0), two at the future Natrona Hub located at 63.6 km (MP 39.5), two at the future Interconnect Station at 140.3 km (MP 87.2), two at the future Midpoint Pump Station at 231.7 km (MP 144.0), two at 322.5 km (MP 200.4), and one at Bell Creek 371.9 km (MP 231.1). Block valves were planned for installation at approximate 24.1- to 32.1-km (15- to 20-mi) intervals along the length of the pipeline, with exceptions of additional block valves that would be installed at major interstate and state highways for emergency response purposes. Additional tees and valves were planned for installation at potential future delivery/receipt locations (Greencore Pipeline Company LLC, 2011).

Planning for the Bell Creek Delivery Facility included a 22.9-m-long × 10.7-m-wide × 7.3-m-high (75-ft-long × 35-ft-wide × 24-ft-high) meter building, receiving scraper trap, flow control valve, communications and satellite dish, CO_2 vent, and electric service pole with pad-mounted transformer. The plans call for the entire facility to be enclosed by a 1.8-m (72-in.)-high chain-link security fence (Greencore Pipeline Company LLC, 2011).

Table 2. Valves and Actuators on the Greencore Pipeline*

	Location along the Pipeline	
Type	**km**	**mi**
Lost Cabin – Meter Run and Block Valve	0.0	0.0
Block Valve	31.7	19.7
Block Valve	52.8	32.8
Natrona Hub – Scraper Receipt Trap/Launcher Trap, Tee Block	63.6	39.5
Block Valve	72.6	45.1
Block Valve	104.0	64.6
Block Valve	133.6	83.0
Future Interconnect Station – Scraper Receipt Trap/Launcher Trap, Tee and Block Valve	140.3	87.2
Block Valve	161.7	100.5
Block Valve	189.3	117.6
Block Valve	222.9	138.5
Future Midpoint Pump Station – Block Valve, Scraper Receipt Trap/ Launcher Trap, Tee Block Valve	231.7	144.0
Block Valve	239.1	148.6
Block Valve	240.2	149.3
Block Valve	255.1	158.5
Block Valve	287.1	178.4
Block Valve	287.9	178.9
Pigging Station – Block Valve, Scraper Receipt Trap/Launcher Trap, Tee	322.5	200.4
Block Valve	327.5	203.5
Block Valve	350.7	217.9
Belle Creek Unit C Delivery/Terminus Point – Block Valve, Scraper Receipt Trap, Tee and Meter Run	371.9	231.1

* As given in Greencore Pipeline Company LLC, 2011.

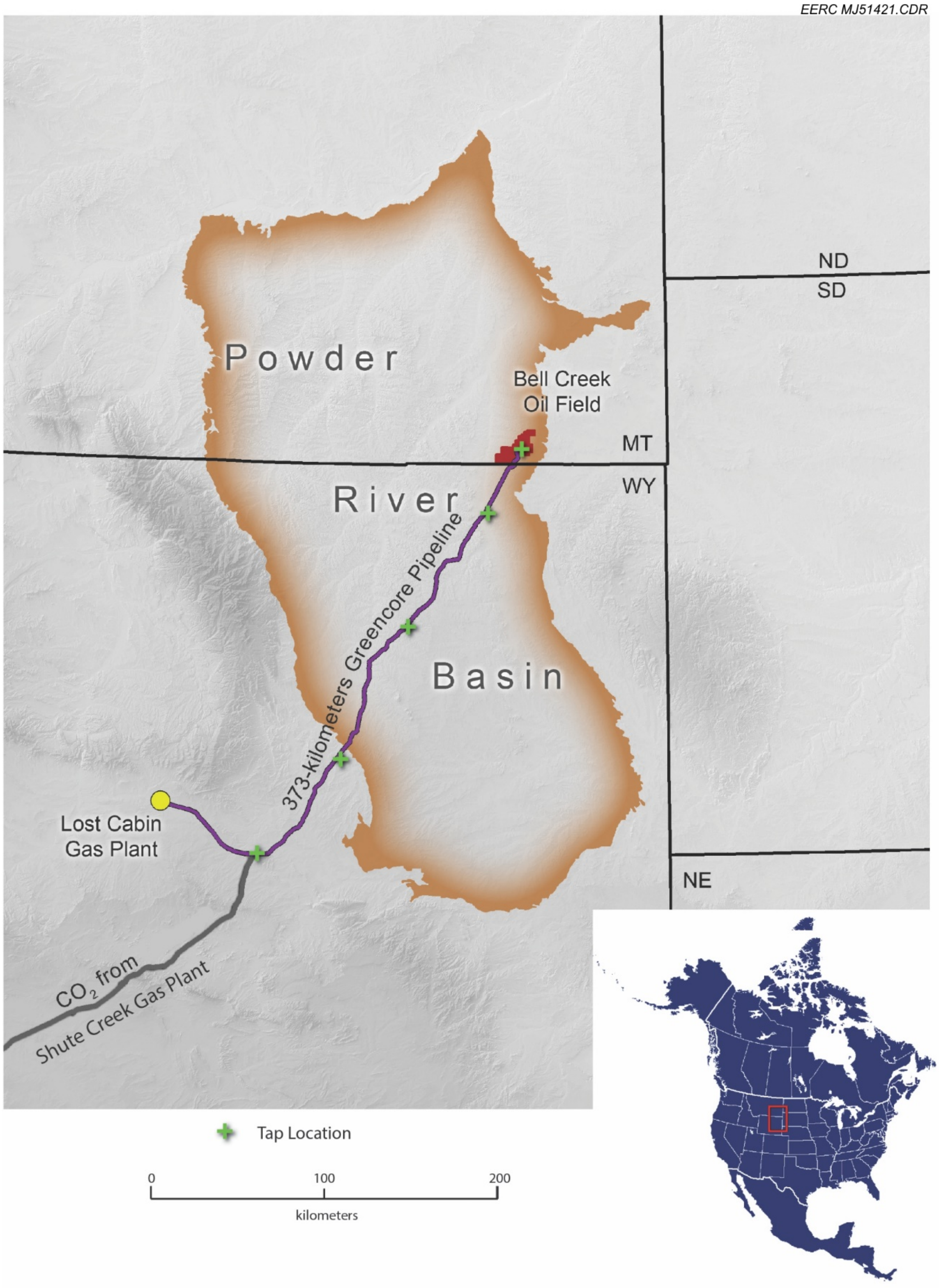

Figure 2. Location of tees along the pipeline.

3.2 Construction and Installation of the Greencore CO_2 Pipeline

Several phases are involved in the standard construction and installation of a CO_2 pipeline. Figure 3 graphically shows the steps involved in constructing and installing a CO_2 pipeline. The steps are described in detail in a Greencore Pipeline Company LLC (2011) document and are summarized in the following subsections. It is assumed that all of these steps were taken during construction of the Greencore pipeline, but that has not been confirmed.

3.2.1 Preconstruction (summarized from Greencore Pipeline Company LLC, 2011)

All biological and cultural impacts and permit stipulations will have been determined by the time the pipeline is constructed. Engineering surveys are used to identify the pipeline centerline as well as the boundaries of the areas in which the construction will be performed. The permanent

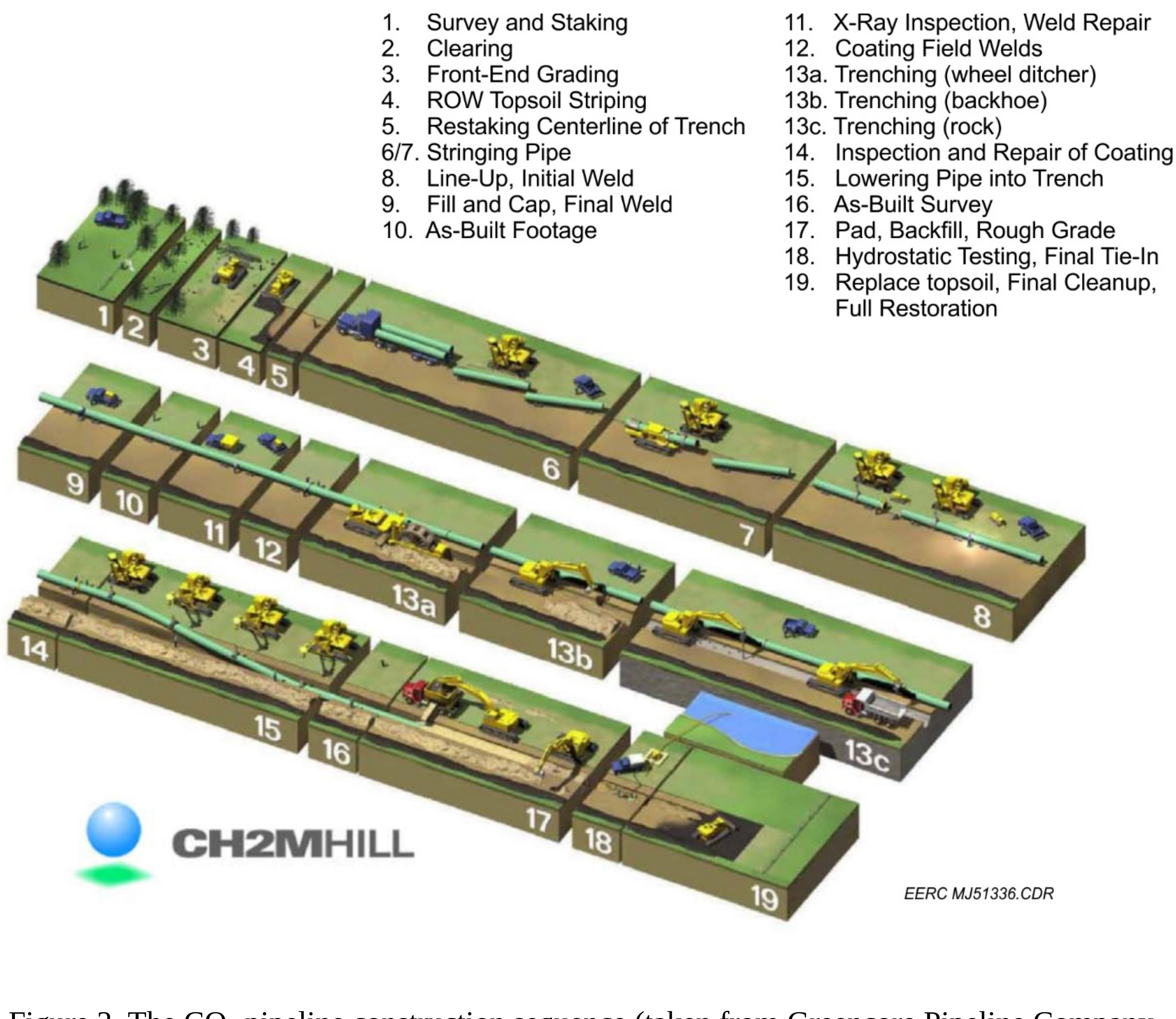

Figure 3. The CO_2 pipeline construction sequence (taken from Greencore Pipeline Company LLC, 2011).

ROW is 15.2 m (50 ft) wide. An additional temporary workspace (ATWS) of 15.2 m (50 ft) width is located parallel and adjacent to the ROW. Best management practices (BMPs) are used to limit erosion and transport of sediment. BMPs are usually site-specific and depend upon weather and site conditions. Therefore, there will be many BMPs for the length of the pipeline, and they may require adjustment during construction. A Stormwater Pollution Prevention Plan will also be prepared to ensure proper control of sediment and erosion as well as to document reporting procedures should they be needed.

3.2.2 Construction (summarized from Greencore Pipeline Company LLC, 2011)

3.2.2.1 Clearing, Grading, and Topsoiling

Clearing, grading, and topsoiling are the first steps that are undertaken during pipeline construction. Clearing involves windrowing or piling tree limbs and brush for use during reclamation. Stumps are typically left in place except directly over the trench line or when it is necessary to remove them in order to create a safe and level workspace. When removal is required, disposal of the stumps will be performed in coordination with the landowner or appropriate agency.

Grading will not be performed over ATWS, drainages, wetlands, or historic trails. Ground disturbance and construction are limited to areas approved for such activities. When possible, grading is limited so as to preserve vegetation and reduce environmental impact. This might occur in a level field or pasture, where topsoil would be removed only over the trench line. When the terrain is mountainous or hilly and contains slopes that cross the ROW, a level work area must be cut out of the hillside. These areas will be reclaimed to the natural contours to the extent possible. Figure 4 shows a hilly area that was reclaimed. Topsoil is stockpiled separately and used only as the final layer of soil during reclamation. It will not be used to pad the trench or construct trench breakers. When the pipeline traverses wetlands, the topsoil is only removed above the trench line. It is placed on the banks of drainage such as wetlands, floodplains, dry drainages, or washes so that natural flows are not blocked and the topsoil is not washed away.

3.2.2.2 Survey Monuments

It is understood that survey monuments such as General land Office and Bureau of Land Management (BLM) Cadastral Survey Corners, reference corners, witness points, U.S. Coastal and Geodetic benchmarks and triangulation stations, military control monuments, and recognizable civil (both public and private) survey monuments will not be disturbed or obliterated.

3.2.2.3 Trenching

Construction methods for excavating a pipeline trench vary depending on soil, rock, terrain, and other related factors. Excavated subsoil is stored separately from the topsoil and, as is the case with topsoil, is not stored where water bodies, dry drainages, or washes cross the ROW. Gaps are left in the subsoil piles to avoid ponding and impact to natural runoff during storm events. Crossing and access is provided for private landowners and tenants to be able to move livestock, vehicles, or equipment across the ditch. Livestock are not prevented from being able to reach water sources.

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Figure 4. Photograph of Greencore pipeline route through a hilly area taken postreclamation (taken from Blincow, 2013).

The width and depth of the trench depend on pipe diameter and soil types. A typical ditch is excavated approximately 0.9–1.2 m (3–4 ft) wide at the base with the sides sloped to Occupational Safety and Health Administration (OSHA) specifications, which would be approximately 2.4 m (8 ft) wide. The standard depth of a trench ranges from 0.8 to 1.5 m (30 to 60 in.), being deeper at water, drainage, and road crossings and on agricultural lands and shallower elsewhere. If an existing pipeline were encountered in the ROW, machine excavation would not be performed within 1.5 m (5 ft). Prior notification is to be given to the operator of underground utilities/existing pipelines.

3.2.2.4 Blasting

Mechanical rippers or rock trenching equipment may be used during the excavation when rock is encountered. Should these not be sufficient or practical because of site conditions, blasting may be used, although only when necessary. Blasting work is conducted by a fully licensed operator in compliance with federal, state, and local laws and regulations.

3.2.2.5 Railroad and Road Crossings

Boring or open-cut techniques may be used at road crossings depending on regulations, traffic, equipment availability, and cost. The open-cut technique is typically used for crossings at two-track or gravel roads, while the slick bore or small directional drill bore methods are used for county roads and state highways. Road crossings are not cased.

3.2.2.6 Water Body Crossings

Crossing water or wetlands requires special permitting to be in place. A Nationwide Permit must be obtained from the Army Corps of Engineers if jurisdictional waters will be crossed. In these cases, ROW clearing is limited to 22.9 m (75 ft). BMPs are used to protect water resources, and ATWS will be designated to provide additional work space.

In wetlands and waterbodies, equipment is limited to that required for ROW clearing, trench excavation, pipe fabrication and installation, and backfilling. The boundaries of wetlands are flagged or staked prior to construction, and clearing of the ROW is kept to the minimum necessary for safe construction of the pipeline. Any trees or shrubs that interfere with travel lane (for the equipment) installation will be cut at grade level so that the root systems are left intact. If the trench fills with water, it could be dewatered and the water disposed of in accordance with Wyoming Department of Environmental Quality or Montana Department of Environmental Quality regulations. An on-site environmental inspector (EI) will work with the contractor to make sure that all BMPs are followed correctly, thereby ensuring permit compliance. Water quality is protected by reclaiming water and wetland crossings as soon as practical. Accumulated material will be removed and, to the extent possible, drainages returned to preconstruction form. Seed for wetlands will be obtained from the wetland topsoil that was segregated for reclamation, although stream banks that contain upland vegetation will be reseeded. Wetlands that are temporarily dry can be mulched with certified weed-free mulch. Stream banks and slopes that lead directly to streams and wetlands will be reseeded and natural ground matting installed in order to limit erosion and promote germination of the seeds.

Horizontal directional drilling (HDD) was planned for water body and road crossings because the technique minimizes surface impact except at the equipment entry and exit sites. Table 3 shows the location of these crossings and their length. In fact, there is no surface ground disturbance between the entry and exit drill path locations. The typical minimum depth of the drill

Table 3. Proposed Horizontal Directionally Drilled Crossings on the Greencore CO_2 Pipeline*

Name	MP	Length
Lost Cabin Rd/CR 158	0.2	36.6 m (120 ft)
Diagonal HDD Crossing of Foreign Line, Arminto Road/ CR 104 and Foreign Line	25.2	237.7 m (780 ft)
Highway 20/26	33.1	167.6 m (550 ft)
I-25 Service Rd, I-25 North- and Southbound Lanes	86.9	239.2 m (785 ft)
I-90	149.8	527.9 m (1732 ft)
Wild Horse Creek–Extended Wetland	160.0	426.7 m (1400 ft)
BNSF Railroad	165.9	137.2 m (450 ft)
Horse Creek	199.5	396.2 m (1300 ft)
Little Powder River	203.1	30.5 m (100 ft)
Donner Reservoir	218.3	91.4 m (300 ft)

* From Greencore Pipeline Company LLC, 2011.

under a stream is either 7.6 m (25 ft) or 1.8 m (6 ft) below the stream bed, whichever provides the higher margin of safety. A heavy-wall line pipe with an abrasive coating will be utilized to ensure pipeline integrity at the crossing. The HDD method eliminates future disturbance of the ground surface that might occur during annual maintenance typically required with an open-ditch crossing.

The flume and trench method will be used in most situations where flowing water is present. The contractor determines the proper size and number of flumes needed to handle the expected volumes of water. The flumes are placed in the drainage with sandbags or wing walls placed around the inlet and outlet of the flume to direct flow into the pipes and to reduce backflow into the working area. During flume placement, disturbance of the banks and channel should be minimized. The pipeline trench is dug beneath the flumes. When the trench is backfilled, care is taken so that foreign material is not added to the stream channel. The channel is recontoured to its original condition as nearly as is possible.

When dry swales, arroyos, and minor drainages that are not carrying water are crossed, the open-cut method is used. The trench spoils are placed in an upland area, and the channel is not blocked in case a storm results in flowing water. No foreign material is added to the channel when the trench is backfilled. The channel is recontoured to the original condition as nearly as possible. Reclamation takes place as soon as possible in order to protect water quality.

3.2.2.7 Areas with Special Conditions

The pipeline has been routed to avoid impact to environmental and cultural resources to the extent possible, although some areas cannot be avoided entirely. In order for construction to continue through these areas while protecting them, timing restrictions and construction stipulations have been established. The pipeline route does not cross any Wilderness Study Areas or Areas of Critical Environmental Concern, although it does cross the Historic Texas Trail and the Historic Bozeman Trail. Historic trails would not be graded, and trail crossings would be trenched. An archaeological monitor would be present during construction at these sites as well as at any areas having potential archaeological resources.

Active faults that may be present along the pipeline ROW would be studied during the detailed engineering phase of the project. A design would be developed that would mitigate the effects of fault movement.

The pipeline route crosses various types of terrain, each having different erosion potentials. The EI will identify or modify BMPs for highly erodible areas to increase their stability. Water body crossings will be reviewed during the design phase to ensure that all potential bank erosion issues are addressed.

The pipeline is collocated with existing utilities for about 90% of the pipeline route. In the areas in which the Greencore pipeline must be within 6.1 m (20 ft) of the utility, added precautions will be taken to support pipeline construction. A representative of the utility will be notified prior to initiation of pipeline construction and activity would be limited over the adjacent utility.

3.2.3 Pipe Installation (summarized from Greencore Pipeline Company LLC, 2011)

Pipe installation includes stringing, bending pipe for angles in the alignment, welding the segments together, inspecting the pipeline, applying corrosion-prevention coating, lowering the pipe into the ditch, and padding the ditch.

3.2.3.1 Stringing

Stringing consists of placing individual joints of pipe parallel to the ditch in a continuous line. Pipe that will cross roads or waterbodies is stockpiled at temporary use areas nearby. Gaps are left at access points across the ditch in order to allow crossing of the ROW. Stringing operations are coordinated with trenching and installation activities so that construction time on a particular tract of land can be better managed.

3.2.3.2 Bending

Once the pipe joints are strung along the ditch, individual joints are bent to accommodate vertical or horizontal changes in direction. Bending can be accomplished in the field using hydraulically operated bending machines. If larger bends are required, factory bends are installed.

3.2.3.3 Welding

The bent pipe joints are placed end-to-end and clamped into position. The pipeline joints are welded together in conformance with applicable regulations.

3.2.3.4 Welding Inspection

Welds are visually inspected by a certified American Welding Society (AWS) inspector who is on the construction management staff. Nondestructive radiographic inspection methods are conducted in accordance with U.S. Department of Transportation (DOT) requirements. When radiographic inspection is conducted, it will be performed by a specialized contractor who is AWS-certified. Defects that are found are repaired or cut out as required under the applicable regulations and standards. Documents that verify the pipeline's integrity are kept on file by Greencore for inspection by the DOT Office of Pipeline Safety.

3.2.3.5 Coating

Prior to delivery, the pipe was externally coated with fusion-bonded epoxy coating. The welded field joints are coated with a tape wrap, shrinkable sleeve wrap, or field-applied fusion-bond epoxy. This is not a necessary step for pressure-fitted pipe. The pipeline coating is visually inspected and tested with an electronic detector. Any faults or scratches are repaired.

3.2.3.6 Cathodic Protection

Test sites are installed at accessible locations at least every 2 mi. These sites measure the pipe-to-soil potential for the establishment and maintenance of an effective cathodic protection system.

3.2.3.7 Lowering In and Padding

Prior to lowering a pipe section into the ditch, an inspection is performed to verify that the pipe is properly fitted, that minimum cover is provided, and that the trench bottom is free of rocks or other debris that could damage the external pipe coating. Side-boom tractors simultaneously lift the pipe section, position it over the ditch, and lower it in place. Soil files may be sifted from the excavated subsoils in order to provide rock-free pipeline padding and bedding for the pipe. Sandbags can also be used to pad the bottom of the ditch, either alone or in concert with padding with the fines. Padding material or a rock shield is used to protect the pipe in rocky areas. Topsoil is **never** used as padding material. Figure 5 shows the lowering in of a section of the Greencore pipeline, while Figure 6 shows pipe in the trench.

3.2.4 Backfilling (summarized from Greencore Pipeline Company LLC, 2011)

After a section of pipe has been placed in the ditch, the trench is checked to ascertain that there are no wildlife or livestock present. Backfilling is conducted using suitable equipment such as a bulldozer or rotary auger backfiller. Subsoil previously excavated from the trench is generally used as backfill. Rocky areas may need imported fill material.

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Figure 5. Greencore pipeline construction (taken from Snyder, 2012).

EERC MJ51521.PSD

Figure 6. Greencore pipeline construction with pipe in trench (taken from Blincow, 2013).

The backfill is graded and compacted to the extent that the trench does not contain any voids. In irrigated agricultural areas, the soil is compacted to the same density as the adjacent undisturbed soil. A 0.2-m (0.5-ft) mound generally will be placed over the trench to account for subsidence.

3.2.5 Pressure Testing and Water Use (summarized from Greencore Pipeline Company LLC, 2011)

Each pipeline is tested in compliance with DOT regulations. Each section of pipeline is cleaned by passing reinforced poly pigs through the pipeline interior. The entire pipeline would then be hydrostatically tested to at least 125% of maximum operating pressure. Test water would be obtained from a permitted source through a water use agreement.

Directional drilling and dust abatement would require that water be consumed. The water would be obtained from permitted sources for both uses.

3.2.6 Cleanup and Reclamation (summarized from Greencore Pipeline Company LLC, 2011)

All construction debris and miscellaneous items were removed from the construction site and disposed of properly. Fences and roads were replaced/rebuilt as negotiated with the landowner(s). Disturbed areas were returned to preconstruction grades and contours as nearly as possible. Original drainage patterns were reestablished. Topsoil was replaced over the ROW at the approximate area from which it was stripped. All disturbed areas will be seeded and mulched, with reseeding and mulching generally completed as soon as possible. Land that has been disturbed by pipeline construction activities is reclaimed in accordance with applicable regulations and permit requirements. Figure 7 shows a photograph taken after the Greencore pipeline was constructed and the trench reclaimed.

3.3 Pipeline Operation and Monitoring (summarized from Greencore Pipeline Company LLC, 2011)

An existing Denbury pipeline supervisory control and data acquisition (SCADA) control center is being utilized. SCADA is an industrial automation control system that provides control of remote equipment. Field SCADA equipment is located at the Lost Cabin supply station, mainline valve sites, and Bell Creek meter stations. Future pump stations will also have unit control centers that communicate status back to the Denbury SCADA control center. The main center will continuously monitor pipeline pressure and flow conditions at all supply and delivery points. It is programmed to alarm whenever a deviation in pressure or flow indicates an abnormal condition within the pipeline system. The pipeline will be operated and maintained in accordance with industry standards and regulations.

Denbury's pipeline management plans to promote safe, reliable operation include 24-hr monitoring of pipeline operations, aerial and ground surveillance, regular testing of pipelines, an integrity management program, and installation of pipeline marker signs at varying intervals and on both sides of road crossings. Denbury will also work closely with communities along the pipeline route to provide them with current information on emergency response procedures. The quarterly "Denbury Aware" newsletters provide interested parties with timely information

Figure 7. Photograph of the Greencore pipeline route taken postreclamation (taken from Blincow, 2013).

regarding pipeline transport of CO_2. The newsletters can be accessed from the Denbury Web site at the Web address www.denbury.com/responsibility/public-awareness/Denbury-Aware/ default.aspx.

4.0 CO_2 INJECTION AT THE BELL CREEK FIELD

4.1 Surface Facilities

The Bell Creek EOR facility follows a scheme in which the water and CO_2 that are separated from the oil are reinjected. Fluids from the individual wells are transported through flow lines and enter the header system of the production manifold in the manifold building. From the production manifold, the commingled stream flows to the process building for separation (Walsh and others, 2013). The oil is piped to oil storage and sales tanks. The water is piped to temporary water storage tanks prior to being pumped back to the field for reinjection. The CO_2 is piped to the compressor building. Following pressurization, the CO_2 discharges back to the manifold building where it is combined with the purchase CO_2 for reinjection (Walsh and others, 2013). Water and CO_2 are distributed to the field through injection manifolds (Walsh and others, 2013). The surface facilities associated with these activities at Bell Creek are shown in Figure 8, and some are discussed in more detail in the following paragraphs.

A production manifold is an arrangement of piping and valves that routes fluid flowing from individual wells to a specific test or separation process (Jarrell and others, 2002). Production manifolds usually are of modular construction and make use of flange connections to enable the system to be expanded or reduced as needed over time during the CO_2 flood (Jarrell and others, 2002). The fluids from each Bell Creek well flow into the low-pressure or high-pressure production system, depending upon the well pressure (Walsh and others, 2013). Each well is individually tested at least once each month to determine its oil, gas, and water volumes, which are then used to allocate total field production. A surface jet pump system is used to reduce the flow line pressure of a well that produces little or no fluid as this should allow the well to begin flowing (Walsh and others, 2013). The jet pump works as follows. Power fluid at a high pressure (but low velocity) is converted to a low pressure, high-velocity jet by the jet pump nozzle. The pressure at the entrance of the throat drops as the power fluid rate is increased. Because the pressure is lower, fluid is drawn from the wellbore (Walsh and others, 2013). A portion of the test site production manifold is shown in Figure 9.

After it is separated from the oil and water, the CO_2 is piped to the compressor building, where there are currently two compressors: one low pressure having a 1.7-MPa (250-psi) suction and the other a high-pressure compressor with a 4.1–5.5-MPa (600–800-psi) suction (Walsh and others, 2013). The interior of the compressor building is shown in Figure 10. The Bell Creek site currently has the capacity to recycle 2.3 million–2.8 million m^3/d at oil and gas standard conditions (80–100 MMscfd) of CO_2, although long-term plans aim to increase the recycle capacity to 8.5 million m^3/d at oil and gas standard conditions (300 MMscfd) through the addition of additional compressor trains as the field development continues (Walsh and others, 2013). Wells are initially put into the low-pressure system that feeds the low-pressure compressor. Once a well's

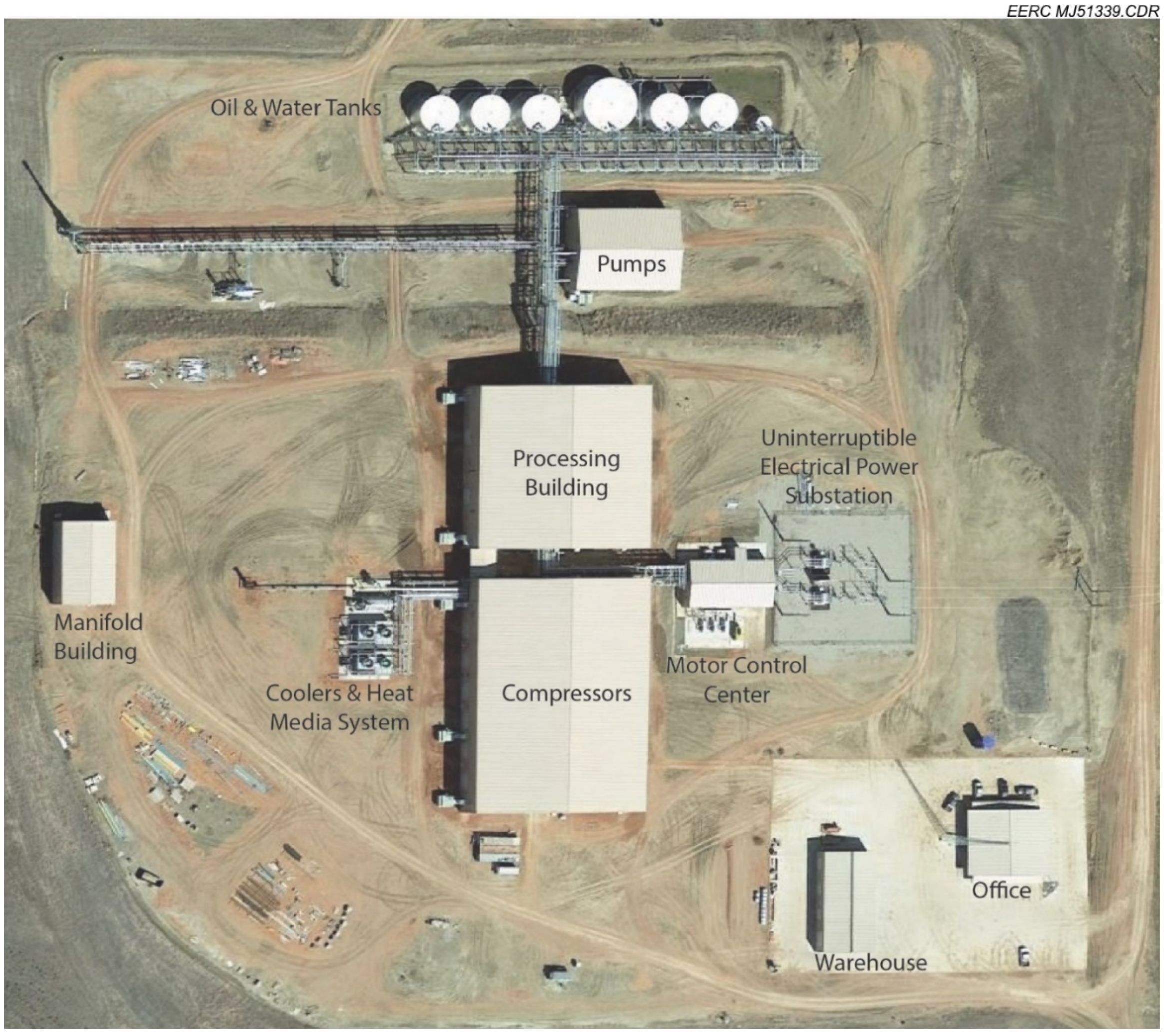

Figure 8. Bell Creek surface facilities (provided by Denbury, 2015).

flow pressure is high enough, it is fed into the high-pressure system that feeds the high-pressure compressor (Walsh and others, 2013). This is advantageous in terms of power savings. Both compressors have a discharge pressure of slightly less than 13.8 MPa (2000 psi) (Walsh and others, 2013). Therefore, power is saved when the high-pressure compressor can be utilized because the difference between the suction and discharge pressures is not as great as it is for the low-pressure compressor.

The CO_2 returns to the manifold building, the interior of which is shown in Figure 11. As the figure shows, there are two production lines (high-pressure and low-pressure) coming from the field and two lines (recycle CO_2 and produced water) that are returned to the field. The recycle CO_2 is combined with purchase CO_2 then fed to individual wells through the header of the injection manifold (Walsh and others, 2013).

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Figure 9. The Bell Creek test site production manifold (taken from Rawson, 2014).

EERC MJ51341.CDR

Figure 10. Interior of the Bell Creek compressor building (taken from Walsh and others, 2013).

EERC MJ51342.CDR

Figure 11. Interior of the Bell Creek manifold building (taken from Rawson, 2014).

The injection manifold is shown in Figure 12. The bulk CO_2 and water injection lines feed wells through the header. Sweep efficiency and CO_2 utilization rates can be improved within the reservoir by alternating the injection of water and CO_2, a process called WAG (water alternating gas). The injection pressure for both water and CO_2 is slightly less than 13.8 MPa (2000 psi) (Walsh and others, 2013). Each well can inject either CO_2 or water by the opening or closing of valves attached to the bulk line. Rates and pressures are monitored at the test site or in the control center in the operations building. Rates are adjusted at the test site (Walsh and others, 2013).

As of September 2013, 26,822 m (88,000 ft) of bulk lines that are 15.2, 20.3, and 25.4 cm (6, 8, and 10 in.) in diameter; 58,522 m (192,000 ft) of 7.6-cm (3-in.) diameter injection line; and 55,169 m (181,000 ft) of 7.6-cm (3-in.) diameter production line had been installed (Walsh and others, 2013). Figure 13 shows the bulk lines coming to the surface facility from Test Site 1 during their construction.

This is the first Denbury project where the process is totally enclosed, which is necessary because of the cold winters. A heat media system (shown in Figure 14 during its construction) was built to reduce or eliminate the expense of stand-alone heating systems. Radiator fluid is pumped in a closed-loop system, capturing heat from the process operations such as the compressors. This is used to heat the storage tanks, vessels, and all buildings (Walsh and others, 2013).

EERC MJ51343.CDR

Figure 12. An injection manifold at Bell Creek (taken from Rawson, 2014).

EERC MJ51344.CDR

Figure 13. Bulk lines coming into the Bell Creek surface facility from Test Site 1 (taken from Walsh and others, 2013).

EERC MJ51345.CDR

Figure 14. The Bell Creek heat media system during its construction (taken from Walsh and others, 2013).

4.2 Wells

The Bell Creek Field includes both producer and injector CO_2 wellhead configurations. The two wellhead configurations are shown in Figures 15 and 16. Each of these is equipped with remote terminal units (RTUs) to send wellhead data back to the SCADA system (Walsh and others, 2013). The pressure on tubing and all casing strings is monitored continuously, with any abnormal casing pressure flagged for attention (Walsh and others, 2013). Each well has a surface safety valve (SSV) that will shut in the well should a flow line leak (exhibited by low pressure) or a plugged flow line (exhibited by high pressure) be detected. Wells also can be shut in remotely should it be necessary (Walsh and others, 2013). Capillary strings are incorporated into the producer wells, allowing chemical treatment of the production stream near the perforations (Walsh and others, 2013).

EERC MJ51346.CDR

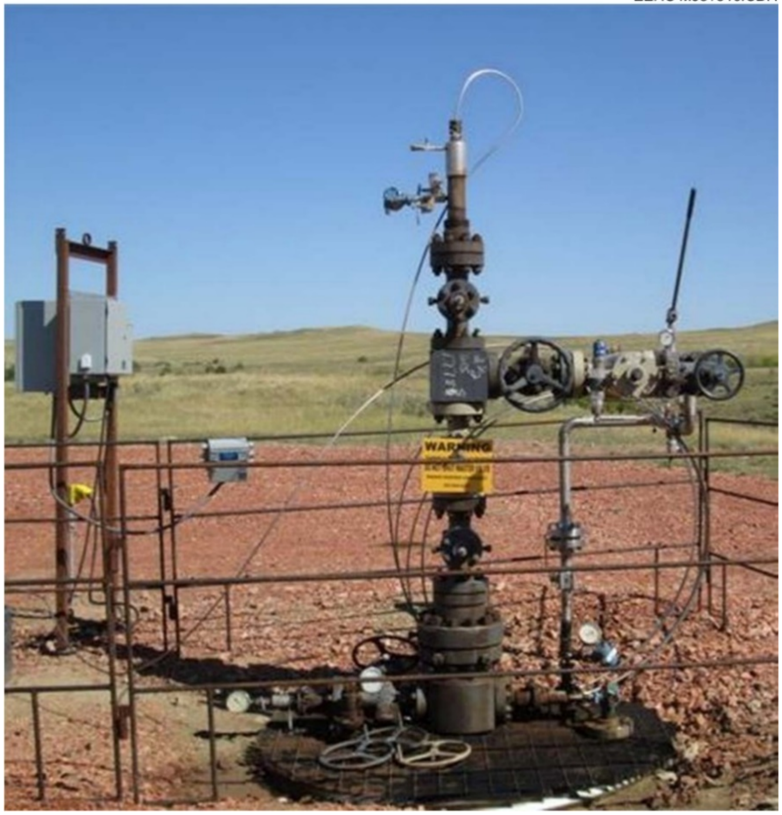

Figure 15. Producer well with capillary string (taken from Rawson, 2014).

5.0 CONCLUSIONS

The methods used by Denbury to plan, construct, and operate the Greencore pipeline for EOR may also apply to CO_2 transport during a future CCS project. Likewise, many of the surface facilities associated with CO_2 EOR are similar to those that would be needed for storage of CO_2 within any secure geologic formation. While the Bell Creek project is an EOR project rather than a CCS project, the data being collected during all phases of this EOR project will be invaluable in helping to prove the usefulness of the CCS concept as a way to effectively decrease atmospheric CO_2 levels.

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Figure 16. CO_2 or water injector wellhead (taken from Rawson, 2014).

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