FACTSHEET FOR PARTNERSHIP FIELD VALIDATION TEST

Partnership Name	Big Sky Regional Carbon Partnership
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Principal Investigator	Lee Spangler
Field Test Information: Field Test Name	Basalt Sequestration Pilot Test
Test Location	Near Wallula township in Eastern Washington State
Amount and Source of CO_2	Tons: 1000 Source: Refinery
Field Test Partners (Primary Sponsors)	Boise White Paper L.L.C., Shell Exploration and Production Company, Port of Walla Walla, Portland General Electric

Research Objectives:

The overall objectives of the Basalt Sequestration Pilot Test include:

1. Address the critical technical issues associated with the injection, fate and transport of supercritical CO_2 in one or more interflow zones in a deep basalt formation
2. Participate in public outreach activities as required or as requested by industry partners
3. Work with state regulators to ensure timely support of necessary permitting.

Site characterization activities support drilling, injection, and monitoring. These activities at the pilot test include: 1) installation of shallow soil gas monitoring probes and collection and analyses of gas samples from these probes to develop baseline profiles, 2) conducting a seismic swath survey near the site, 3) drilling and subsurface characterization including hydrologic tests, wireline logs, XRF and XRD analysis of cuttings samples, collection of rotary side-wall cores, hydrochemistry and isotopic sampling, and microbiological sampling.

Summary of Field Test Site and Operations:

The goal of the Basalt Sequestration Pilot Test is to prepare for and conduct a small scale CO_2 sequestration project in deep basalts of the Columbia River Basalt Group. The effort under Phase II consists of site characterization activities to be followed by injection of 1000 tons of CO_2, provided site characterization data demonstrate the feasibility and safety of doing so and a permit for the injection phase is approved by the Washington State Department of Ecology.

The field test location is 11 miles south of Pasco, Washington on private property owned by Boise White Paper L.L.C. in western Walla Walla County.

The Basalt Pilot well penetrated a total depth of 4110 ft in the Wapshilla Ridge member of the targeted Grande Ronde Formation (Table **1**). The as-built completion for the Wallula Pilot well is shown in Figure 1. The shallow 14-inch casing covers the Saddle Mountain and extends into the upper part of the Wanapum; The second casing string extends to the proposed injection zone. The wellbore below the injection zone is sealed with a cement plug.

Table 1. Geologic Formations in the Wallula Basalt Test Pilot Well.

Geologic Unit	Depth to Top of Unit, (ft below ground surface)
Surficial Sediment	0
Saddle Mountain Basalt Formation	44
Wanapum Basalt Formation	1,058
Grande Ronde Basalt Formation	1,594
Umtanum Member	2,418
Slack Canyon Member (SC)	2,590
SC Flow 1	2,590
SC Flow 2	2,730
SC Flow 3	2,808
Ortley Member (OM)	2,850
OM Flow 1	2,850
Wapshilla Ridge Member (WRM) (tentative ID)	3,810
WRM Flow 1	3,810
WRM Flow 2	4,068
Borehole – Total Depth	4,110.5

Figure 2 shows depth locations of 12 basalt hydrologic interflow zones selected for hydrologic tests. In addition, three low-permeability caprock intervals (Zones 9, 10A, and 10B) were tested above the candidate injection zone 8B (Figure 3). The candidate injection test zone is 2,716- 2,870 ft, with the majority of the transmissivity between 2,688 and 2,790 ft. Figure 3 shows a preliminary transmissivity versus depth profile of the 12 interflow zone tests.

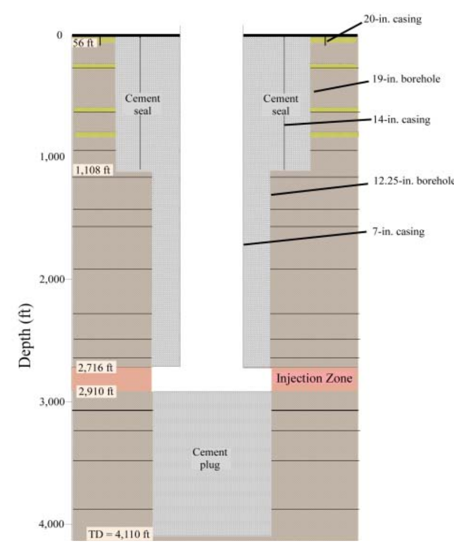

Figure 1. As-built completion for the Wallula Pilot Borehole

The basalt flow interior sections between the three candidate flow tops are thin; the194 ft open-hole section is considered as a single, hydraulically communicative, hydrogeologic unit (Figure 2). Transmissivity distribution is not uniform: ~90% of the composite T is in the upper 48-ft S.C. flow top #2, with an average hydraulic conductivity K = 0.184 to 0.371 ft/day (calculated average intrinsic permeability k = 75 - 150 mD). The lower two flow tops have a composite effective thickness of 43 ft, and an average K and k = 0.023 to 0.046 ft/day (9 to 19 mD, respectively). Preliminary average K estimates for the three caprock intervals are ~1.0E^{-12} to 1.0E^{-13} m/sec (~0.01 to ~0.1 micro-darcies).

Groundwater samples indicate that all six sampled test zones contain relatively dilute, sodium-bicarbonate chemical water-type. The proposed injection zone has a pH of 9.0 - 9.7, and relatively high fluoride concentrations (3.2 to 11.9 mg/L). Secondary and primary drinking water standards for fluoride are 2.0 and 4.0 mg/L, respectively.

All five intervals sampled for free-living microbial cells in groundwater contained microbes. Microbial communities found in the Wanapum and the upper Grande Ronde strata are somewhat similar to each other but distinct from microbes found in the lower Grande Ronde layers.

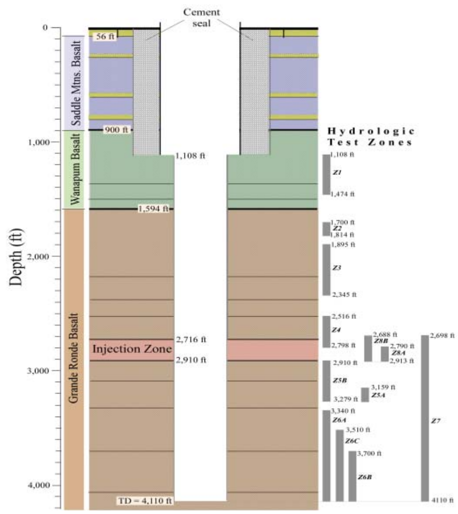

Figure 2. Depth location of Wallula Pilot Basalt interflow test zones

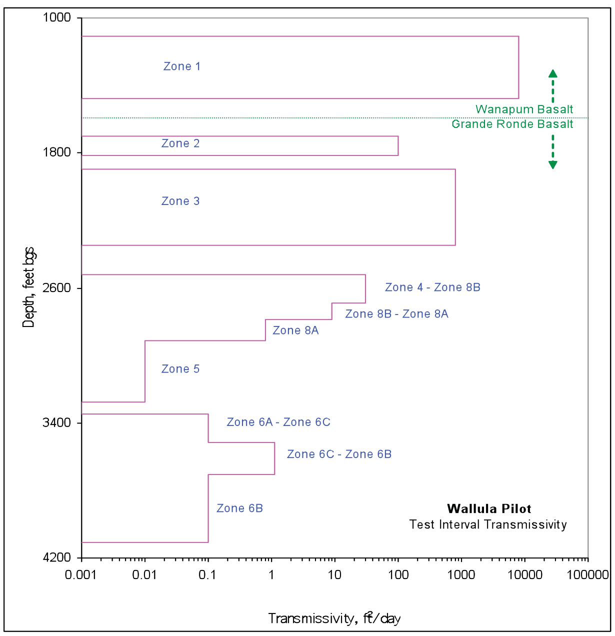

Figure 3. Wallula Pilot Basalt Interflow Transmissivity versus Borehole Depth

An extensive set of wireline logs was collected (some for the first time in basalts) that included: Platform Express with AIT, Elemental Capture Spectroscopy log (ECS), Sigma Saturation log, Flowmeter and fluid temperature log, Sonic Scan including SonicScanAdvancedAnswer, anisotropy analysis, P/S compression and shear with summary interpretation, FMI with summary fracture interpretation over 1,600 feet of interval, rotary sidewall cores. Detailed analysis of the full waveform sonic and the resistivity-based image wireline logs has been performed with regard to interpretation of geomechanical properties, earthstress tensors, and basalt lithofacies. This work provided collaborative support to the earlier geophysical log and wellbore hydrologic evaluation of caprock seals and injection reservoirs, as well as the determination of lack of faulting within the wellbore and low structural dip of basalt flows within the Wallula pilot borehole. The open-hole wireline logging suite provided data for developing log signatures for basalt interflow reservoirs and caprock seals (Figure 4).

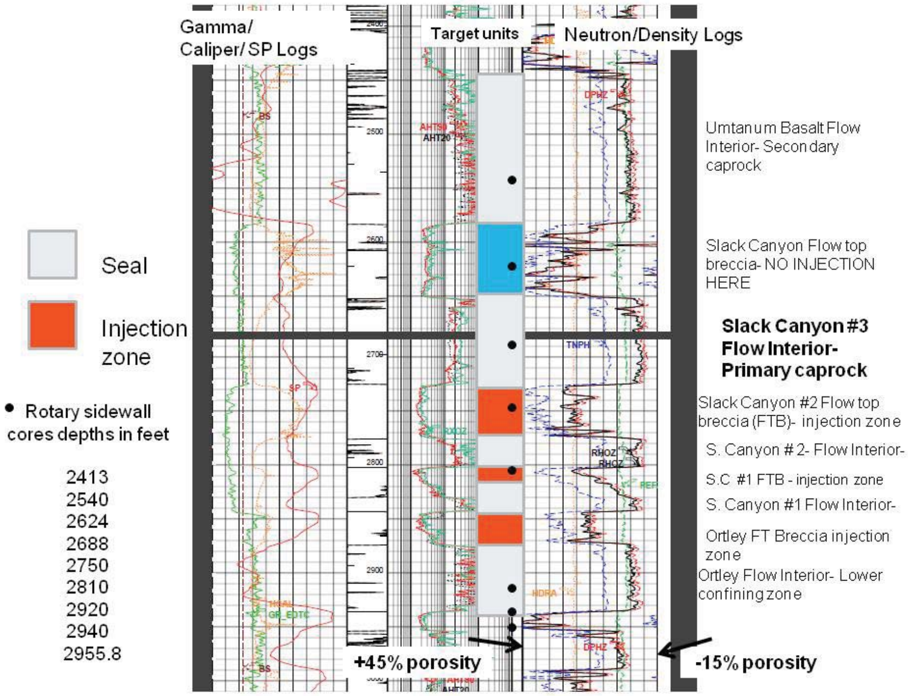

Figure 4. Schlumberger Platform Express Logs through the Proposed Injection Zone. Flow tops are easily identified by excursions to the left on the Neutron /density logs.

Summary of Modeling and MMV Efforts:

Based on results from the wireline logs and hydrologic testing, new simulations of CO_2 injection into the three proposed flow top reservoirs were conducted with the STOMP-H2O-CO2-NaCl simulator (White and Oostrom, 2006).

Measured horizontal hydraulic conductivities vary considerably. The hydraulic conductivity for the SCFT2 is highest (6.35×10^{-5} cm/sec); hydraulic conductivities for the SCFT1 and OFT are 8 times lower, at 8.2×10^{-6} cm/sec. Vertical hydraulic conductivities were assumed to be one order of magnitude lower than horizontal hydraulic conductivities. Flow tops were modeled at 10% porosity; flow interiors at 1% porosity

Two-dimensional simulations utilized a cylindrical coordinate grid, and a model domain from 2930.5 ft depth to 2442.5 ft (488 ft total), with a radial width of 1000 ft. Vertical grid spacing was 2 ft; radial grid spacing was 5 ft. Layers were assumed homogeneous. Simulations included only multiphase flow behavior and did not include chemical reactions with the basalts. Reactive transport simulations are in progress.

For open-borehole simulated injection of 1000 metric tons over 14 days into the OFT, SCFT and SCFT2, most of the injected CO_2 flows into the SCFT2 (Figure 5), due to its higher permeability. The density of the injected supercritical CO_2 is 66% of the formation fluid at the formation temperature and pressure. The supercritical CO_2 does not displace all of the formation water in the pore space and the average fluid density contrast is 75-100% of initial formation water. The radius of the injected supercritical CO_2 increases from 100 ft at two weeks after start of injection, to 180 ft at one year. Increase in pressure in the well bore is less than 110 psi. At one year, 18% of the injected CO_2 has dissolved into the aqueous phase. No CO_2 migration into the overlying Slack Canyon flow interior is predicted even after 1 year of simulation time. Based on the cumulative analyses completed to date, the Wallula basalt pilot borehole appears to be well suited to conduct the world's first supercritical CO_2 injection test into continental flood basalts.

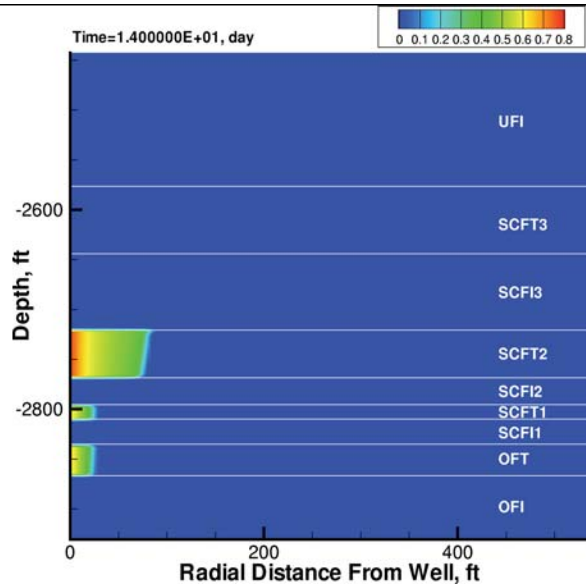

Figure 5. CO_2 Saturation in the Ortley, Slack Canyon #1 and Slack Canyon #2 Flow Tops, immediately after 1000 MT Supercritical CO_2 Injection.

MMV Summary

To date, the MMV activities undertaken are shallow soil gas monitoring and a seismic survey. Both compositional analysis and isotope fraction mass spectrometry have been conducted on the gas samples and show no anomalous chemical or isotopic properties.

Surface seismic swath data acquired near Wallula, Washington in December, 2007 employed 3-component VectorSeis sensors so that ground-roll noise, P-P reflection signal, and P-SV (converted-S) data could be analyzed in 3-component (3-C) data space. The final migrated P wave data indicate that about 8,000 feet of basalt are present; no faults disrupt the deep basalt interval, and thus no major deep-seated breaks are likely to penetrate the shallower basalt section. These data are now being analyzed by a Radon Reflection Extraction technology to isolate seismic models that propagate with specific velocities. This processing is expected to better image details in the shallow section.

This survey represents the first known success of surface seismic imaging of on-shore, thinly covered continental flood basalts, and represents a critical milestone for future subsurface characterization and monitoring of sequestration of CO_2 in basalts.

Accomplishments to Date:

- A five line, four-mile long 3C seismic swath survey acquired in December 2007 and processed in 2008 resulted in successful imaging of the deep basalt strata at the field site.
- A revised Field Activity Plan for the field pilot study issued in September 2008:
- Two shallow soil gas probes installed near the field site in 2007; gas samples collected on a monthly basis provide baseline data for CO_2 and other gases well ahead of injection.
- Approval of a Class V Well Registration package by the WADOE
- Initiation of the Wallula Pilot Well January 13, 2009; completed April 2009.

- Extensive subsurface characterization and identification of a candidate injection zone in the Grande Ronde. Simulation of a 14 day injection of 1000 metric tons indicates the radius of the injected supercritical CO_2 will reach180 ft one year after the start of injection; maximum pressure increase in the well bore is less than 110 psi. At one year, 18% of the injected CO_2 has dissolved into the aqueous phase.
- Extensive stakeholder and public involvement activities include interviews and small meetings/focus groups with stakeholders, open house, and tours. Geology classes from a local college toured CCS laboratories and the drilling site.
- Three undergraduate interns from Washington universities and colleges conducted outcrop and geophysical studies from June-September, 2009. These projects resulted in publication of abstracts and poster presentations at the 2009 GSA Annual meeting.

Summarize Target Sink Storage Opportunities and Benefits to the Region:

Within the BSCSP region, there are several major geological provinces with high potential for geologic sequestration. One of these is the Columbia Plateau Volcanic Province, which represents the dominant regional geologic feature occupying much of Idaho, Oregon, and Washington states. The CO_2 storage potential of the Columbia River Basalt Group (CRBG) within this volcanic province has been estimated at between 10 to 50 $GtCO_{2,}$ making it one of the most significant potential deep geological storage formations in the region. The ultimate goal of the Basalt Sequestration Pilot Test is to demonstrate and validate the safe, permanent storage of CO_2 in reactive mafic formations that underlie this site and surrounding region.

Cost:

Total Field Project Cost: $8,787,594

DOE Share: $8,787,594
Non-Doe Share: $735,731

Field Project Key Dates:

Baseline Completed: 06/30/2009
Drilling Operations Completed: April 2009
Injection Operations Begin: Spring 2010
MMV Events: Soil gas baseline monitoring completed, seismic survey completed and processed

Field Test Schedule and Milestones (Gantt Chart):

Task 16.0	Q1-06	Q2	Q3	Q4	Q1-07	Q2	Q3	Q4	Q1-08	Q2	Q3	Q4	Q1-09	Q2	Q3	Q4	Q1-10	Q2
Task 16.1 Planning and Permitting																		
Public Outreach and Regulatory Briefings								Gm31										
Submit NEPA EQ									Gm32									
Submit Class V UIC Application																Gm33		
Submit SEPA Application										Gm34								
Task 16.2 Characterization Options and Reservoir Simulations																		
Transport and Reactive Process Modeling Simulations								Gm35								Gm35		
Task 16.3 Site Characterization Activities																		
Install Soil Gas Monitoring Probes								Gm36										
Obtain land access permission from adjoining landowners								Gm37										
Complete Seismic Survey								Gm38										
Task 16.4 - Pre-Injection Characterization and Drilling																		
Drill and Complete Well														Gm39				
Complete Pre-Injection Sampling and Testing															Gm40			
Task 16.5 - CO2 Procurement																		
Complete CO2 Injection Facilities																		Gm41
Task 16.6 - Injection																		
Complete Injection and Evaluate Pressure Responses																		Gm42
Task 16.7 - Site Monitoring and Verification																		
Conduct Atmospheric & Soil, Geochemical, and Microbiological Monitoring																		Gm43
Task 16.8 - Pre-Closure Characterization																		
Assess in-situ geochemical reactions																		Gm44
Task 16.9 Site Closure and Restoration																		
Continued Use Determination or Plug and Abandon Well																		Gm45

Measurement Technologies Employed at Field Test Site *(Please Modify to Reflect Actual)*

Measurement technique	Measurement parameters	Application
Introduced and natural tracers	Travel time Partitioning of CO_2 into brine or oil Identification sources of CO_2	Tracing movement of CO_2 in the storage formation Quantifying solubility trapping Tracing leakage
Water composition	CO_2, HCO_3, CO_3^{2-} Major ions Trace elements Salinity	Quantifying solubility and mineral trapping Quantifying CO_2-water-rock interactions Detecting leakage into shallow groundwater aquifers
Subsurface pressure	Formation pressure Annulus pressure Groundwater aquifer pressure	Control of formation pressure below fracture gradient Wellbore and injection tubing condition Leakage out of the storage formation
Well logs	Brine salinity Sonic velocity CO_2 saturation	Tracking CO_2 movement in and above storage formation Tracking migration of brine into shallow aquifers Calibrating seismic velocities for 3D seismic surveys
Time-lapse 3D seismic imaging	P and S wave velocity Reflection horizons Seismic amplitude attenuation	Tracking CO_2 movement in and above storage formation
Vertical seismic profiling and crosswell seismic imaging	P and S wave velocity Reflection horizons Seismic amplitude attenuation	Detecting detailed distribution of CO_2 in the storage formation Detection leakage through faults and fractures
Passive seismic monitoring	Location, magnitude and source characteristics of seismic events	Development of microfractures in formation or caprock CO_2 migration pathways
Electrical and electromagnetic techniques	Formation conductivity Electromagnetic induction	Tracking movement of CO_2 in and above the storage formation Detecting migration of brine into shallow aquifers
Time-lapse gravity techniques	Density changes caused by fluid displacement	Detect CO_2 movement in or above storage formation CO_2 mass balance in the subsurface
Land surface deformation	Tilt Vertical and horizontal displacement using interferometry and GPS	Detect geomechanical effects on storage formation and caprock Locate CO_2 migration pathways
Visible and infrared imaging from satellite or planes	Hyperspectral imaging of land surface	Detect vegetative stress
CO_2 land surface flux monitoring using flux chambers or eddycovariance	CO_2 fluxes between the land surface and atmosphere atmosphere	Detect, locate and quantify CO_2 releases
Soil gas sampling	Soil gas composition Isotopic analysis of CO_2	Detect elevated levels of CO_2 Identify source of elevated soil gas CO_2 Evaluate ecosystem impacts

Source: IPCC Special Report on Carbon dioxide Capture and Storage