MONITORING FOR CO_2 STORAGE AND ENHANCED COALBED METHANE RECOVERY IN THE COAL SEAMS OF THE CENTRAL APPALACHIAN BASIN

MVA Introduction and Background

In 2012, the Virginia Center for Coal and Energy Research (VCCER) at Virginia Tech was awarded a grant from the US Department of Energy to store approximately 20,000 tons of Carbon Dioxide (CO_2) in thin, unmineable coal seams in Buchanan County, Virginia. This project was awarded on the basis of a previously successful project carried out by the VCCER and industrial partners, in which approximately 1,000 tons of CO_2 was injected into similar coal seams in Russell County, Virginia, and a DOE 'characterization' project that led to the study of various geological formations in southwestern Virginia, which demonstrated sufficient storage capacity to pursue future, larger scale projects such as the current one.

The purpose of this project is to learn more about the behavior of CO_2 as it bonds with the surface of the coal, and to determine long-term storage possibilities, as the CO_2 displaces the methane(CH_4) already in the coal, so that the methane can be recovered (enhanced coalbed methane recovery). The successful completion of such a project requires the atmosphere, surface, and subsurface of the region of the injection to be monitored to verify that the CO_2 remains underground, migrates where models predict that it will, and effectively displaces the methane. Such a monitoring project has come to be referred to as 'Monitoring, Verification and Accounting,' or MVA. The previous storage project in Russell County is considered successful because a well-designed MVA program verified those three things. An MVA program has been designed for the Buchanan County project as well.

The DOE, through its National Energy Technology Laboratory, sets forth the following goals for MVA in its guide document, Best Practices for: Monitoring, Verification and Accounting of CO_2 Stored in Deep Geological Formations (http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_document.pdf).

- Improve understanding of storage processes and confirm their effectiveness
- Evaluate the interactions of CO_2 with formation solids and fluids
- Assess environmental, safety, and health (ES&H) impacts in the event of any migration of CO_2 to the atmosphere
- Evaluate and monitor any required remediation efforts should migration occur
- Provide a technical basis to assist in legal issues resulting from any impact of sequestration technology.

MVA Application to Buchanan County Project

Every carbon storage project has a unique geological profile, with unique features and topography. Different features and topographies favor different MVA tests and strategies, requiring an MVA program designed specifically for that setting. This section describes the features found at the Buchanan County injection site and the subsequent design of the MVA program for the project.

This project has four phases, and it is important to understand an MVA program in terms of each of the four. The following is a description of what goes on in MVA during each of the phases.

1. **Pre-operation:** During the Pre-operation Phase, the MVA plan is designed, drawing on experience with the previous, similar but smaller, project in Russell County and the experience of other successful projects in the country. The topography of the region surrounding the injection is mapped, and the underground structures are determined through previous mapping and core sampling. Air, soil, and water samples are taken, setting "baselines" for CO_2 in the air, water, and soil, so it can be determined if those amounts change during the project.

MVA Application to Buchanan County Project (cont.)

2. **Operation:** The Operation Phase begins with the commencement of the injection of CO_2 into, in this case, a pre-existing well that has been used for recovery of methane from the pore spaces of the coal seams. It is most important to continue measurement in the air, soil, and underground reservoirs and coal seams to determine that no upward migration is occurring. In addition, monitoring in this phase helps determine where and how fast the injected CO_2 is migrating, which is called determining the "extent of the plume," since the CO_2 radiates out underground in the coal seam. Other surrounding wells, called offset wells, are sampled to discover the extent of the plume. This process continues until all the CO_2, in this case approximately 20,000 tons, has been injected.

3. **Closure:** During the Closure Phase, equipment begins to be removed from the site, including the removal of the large tanks that stored the CO_2 near the injection site. The wells used during the project are returned to their prior production status. The site is restored to its previous condition, but monitoring to determine if CO_2 migration occurs in the atmosphere, soil and water continues as before.

4. **Post-closure:** Since the wells involved in this project will have been returned to their pre-injection use, occasional monitoring will continue after the project closes.

There are a variety of methods, or techniques, for monitoring in an MVA program, and several areas that must be sampled on any CCUS project. The MVA Poster includes a list of available monitoring techniques, only some of which are applicable to this project. The MVA Poster divides techniques into three different types, based on the area to be sampled. First, there is sampling of the atmosphere. Second, near-surface methods apply to surface water and soils. In the final column, subsurface methods are methods that sample under the ground, in the reservoirs and coal seams that make up the geology of the Central Appalachian Basin.

In the Russell County test, all three areas were sampled. Atmospheric methods utilized included infrared gas analyzers (IRGAs) to measure CO_2 concentration. Near-surface methods included soil CO_2 flux, surface water sampling, and shallow tracer detection.

For the subsurface in Russell County, seven offset production wells were sampled for gas composition, including CO_2 concentration and tracer breakthrough. A harmless tracer gas that isn't ordinarily found in CO_2 is injected with the CO_2 so that it can be determined whether the CO_2 found at the offset wells is actually the CO_2 that was injected, and not some CO_2 that might have been present before the injection.

Two new monitoring wells were tested, including:

- Pressure/temperature logging
- Spinner surveys
- Gas composition
- Formation water sampling
- Tracer analysis

MVA Application to Buchanan County Project (cont.)

Results of sampling during the Russell County project included:

- No leakage was detected by any sampling, including IRGAs, soil CO_2 and tracer detectors, and water sampling
- There was a rapid spread of CO_2. The monitoring well, M1, reached over 95% CO_2 concentration within hours of injection, and M2 within 8 days, demonstrating the connectivity of the wells.
- The tracer was detected far from the point of the injection. Tracer samples were positive at all seven close offsets wells, and at three far offset wells.
- There was evidence of CO_2 adsorption; that is, that the CO_2 had bonded with the coal and displaced the methane. There was increased methane (CH_4) and nitrogen (N_2) in flowback streams of the injection well.
- Increased CH_4 production at two offset wells, with no CO_2 breakthrough, indicated that there was enhanced coalbed methane production.

In the Buchanan County project, the objective is to inject up to 20,000 tons of CO_2 over a one-year period using three converted coalbed methane wells in order to assess the properties and behavior of the CO_2 during injection and to assess both CO_2 storage potential and the potential for enhanced coalbed methane recovery. The reservoir that the CO_2 will be injected into is comprised of 15-20 individual coal seams, with a combined thickness of 15-20 feet.

Site Characteristics:

- Structurally quiet, on flank of anticline
- Depleted reservoir
- Low-traffic
- Single, agreeable mineral owner

Several tests that were conducted in Russell County will be repeated in the Buchanan County test, including:

- Atmospheric monitoring with IRGAs to measure CO_2 concentration
- Surface methods including soil CO_2 flux, surface water sampling, and shallow tracer detection
- Offset well testing for gas composition (CO_2 concentration, tracers, ECBM)

There are several new monitoring tests that will be performed at the Buchanan County site that were not part of the Russell County project. Three monitoring wells will be installed at the Buchanan County test site in order to measure formation data, including reservoir pressure and gas content (CO_2, methane, tracer). One of these wells will also be used to collect core samples from coal seams and other parts of the formation. The samples will be assessed in a lab in order to determine important rock properties that will improve understanding of the reservoir and update the reservoir model. Unique tracer gases will be injected into each of the three injection wells with the CO_2 stream in order to determine how the spread of gas may differ at each location. Furthermore, unique tracers may also be used in different sets of coal seams to determine whether the spread of gas varies depending upon the properties of a specific seam. The presence of CO_2 will cause the deep coals to swell, an effect which is harmless but has been successfully detected in other settings using highly sensitive surface-based instruments. This technique, called surface deformation measurement, is capable of measuring less than a millimeter of movement in the earth and will be used at the Buchanan County site as an additional method to confirm the storage of CO_2 in the coal reservoir. Finally, a cutting-edge technology called tomographic fracture imaging (TFI) will be used to record the very weak acoustic energy (sound) caused by fluid moving through the coal reservoir. This energy can be mapped to define an approximate boundary for the spread of CO_2.