Virginia City Hybrid Energy Center
Response to Data Request
Bruce Buckheit, Member, Virginia Air Pollution Control Board

Question (Page No. 26):

Part I
The record is not nearly as complete with respect to CO2 separation and sequestration. AES Shady Point (a coal fired CFB egu) has employed CO2 stripping technology to produce dry ice. As with most other technology issues, the issue is not whether it can be done, but whether it can be done at a sustainable price. Dry ice costs over a dollar per pound at retail and, while concentrated, the CO2 is not sequestered. Many are optimistic that CO2 separation and sequestration can be accomplished on a national utility scale, others are not. http://www.nrdc.org/globalWarming/coal/mit.pdf; http://web.mit.edu/coal/; http://www.netl.doe.gov/technologies/carbon_seq/index.html. I assume the commenters may have submitted or be willing to submit literature on this point. I request that staff prepare a two page memorandum summarizing the views on either side so the Board may consider this issue in evaluating the collateral benefits of IGCC technology.

Part II
In addition, it has been represented that the VCHEC is "carbon friendly" because it is located near future potential sequestration sites. If true, however, this fact might argue in favor of constructing an IGCC plant in that infrastructure issues that might http://www.co2captureandstorage.info/project_specific.php?project_id=22.25 constrain CO2 sequestration elsewhere might be less of a challenge for a plant in Wise County. I understand that this issue is being evaluated by researchers at Virginia Tech. Please review the literature and request a assessment from the Virginia Tech researchers on this issue. Review area geology and identify sites in the area of Virginia City that are considered potential sequestration sites. See, http://dpor.virginia.gov/dporweb/geo_2007_2008Newsletter.pdf; http://energy.er.usgs.gov/health_environment/co2_sequestration/co2_illustrations.html.

Please also prepare short summary of potential greenhouse gas options for CFB boilers, see e.g.; http://www.fwc.com/publications/tech_papers/files/TP_CCS_07_02.pdf

Response:

Carbon Capture Technology – Part I

The U.S. Department of Energy (DOE) makes the following points on the issue of CO_2 capture (http://www.fossil.energy.gov/programs/sequestration/capture/): "Before carbon dioxide (CO2) gas can be sequestered from power plants and other point sources, it must be captured as a relatively pure gas. On a mass basis, CO2 is the 19th largest commodity chemical in the United States, and CO2 is routinely separated and captured as a by-product from industrial processes such as synthetic ammonia production, H2 production, and limestone calcination." The DOE also clearly notes on the same site that: "Existing capture technologies, however, are not cost-effective when considered in the context of sequestering CO2 from power plants. Most power plants and other large point sources use air-fired combustors, a process that exhausts CO2 diluted with nitrogen. Flue gas from coal-fired power plants contains 10-12 percent CO2 by volume and for effective carbon sequestration, the CO2 in these exhaust gases must be separated and concentrated."

As a result, the DOE, as well as the global community engaged on this topic, is pursuing research programs on three types of capture technologies with equal commitment and vigor (http://www.fossil.energy.gov/news/techlines/2006/06061-Sequestration_Research_Grants.html):

- "Pre-combustion, in which fuel is gasified to form a mixture of hydrogen and CO2, called synthesis gas or "syngas," and CO2 is captured from the syngas before it is combusted.
- Post-combustion, which involves capturing CO2 from flue gas after fuel has been combusted in air, which would be the case for CFB technology.
- Oxycombustion, in which fuel is combusted in pure or nearly pure oxygen rather than air, producing an exhaust mixture of CO2 and water that can easily be processed to produce pure CO2."

Some of the issues and challenges on these technologies were summarized in a presentation by AEP (Attachment 1, Figure 1).[1]

The rate of research progress on capture R&D, as well as on storage, is summarized in Attachment 1, Figure 2. This information was compiled for the 2005 special report of the Intergovernmental Panel on Climate Change entitled "Carbon Dioxide Capture and Storage."

The report and similar studies by a number of other agencies and organizations have concluded that Pre- and Post-combustion capture methods for generation facilities are

[1] B. Braine (a), AEP and Climate Legislation, Presentation at Sanford C. Bernstein 2007 Carbon Symposium, October 9, 2007.

progressing with similar pace. The table also addresses, amongst other parameters, the state of development of CO_2 storage options. Sequestration in coal seams, with Enhanced Coal Bed Methane Recovery, which is the method currently pursued by the Virginia Center for Coal and Energy Research is given a "Demonstration Phase" maturity.

The process of post-combustion capture using chilled ammonia as the solvent, funded amongst others by EPRI, Alstom , Statoil and DOE, will be demonstrated at two AEP facilities, the Mountaineer Plant in West Virginia and the Northeastern Plant in Oklahoma as cited in Attachment 1, Figure 3. [1] According the presentation, "the first carbon capture project, at the Mountaineer plant in West Virginia is expected to complete its product validation phase in 2009" and "the second, at the Northeastern plant in Oklahoma, will begin commercial operations in 2012."

According to the developers and AEP, this method of post combustion has the potential to be deployed with a power reduction to the generation facility (parasitic load) of 10% with an associate coast of electricity of about 25% to achieve CO2 capture.[2] Finally, the same article projects that pre- and post combustion capture will be fairly competitive in 15-20 years, and fuel specific issues are likely to drive the choice.

Post-combustion capture, a method proposed for the CFB Dominion Facility in Wise County, offers excellent promise. As indicated above, a number of post-combustion technologies are under development. Post-combustion capture using chilled ammonia as the solvent, has now moved to the demonstration stage, and is an excellent candidate for carbon capture. Economic and technical criteria (including parasitic load requirements) for this particular method are encouraging, and the commercialization validation is within reach, by 2012.

In addition to post-combustion capture using chilled ammonia, another greenhouse gas mitigation option for CFBs is carbon capture utilizing oxycombsution. As stated in Foster Wheeler's report "Oxyfuel CFB Boiler as a Route to Zero Emission Coal Firing", adapting an existing CFB boiler for oxycombustion appears technically feasible and does not require major changes in the boiler structures and heat surfaces." [3] While there are specific features of oxycombustion that need to be developed further, including the behavior of limestone in the process, it appears that the CFB design offers some degree of flexibility, especially in retrofit applications.

The National Association of Regulatory Commissioners: "Clean Coal Generation Technologies Review for New Power Plants Assessment," March 2008, reported that between technologies "numerous elements may affect these costs, and over the long term there is no clear leader in the technologies [PC,SCPC,CFB,IGCC] considered here." "Different technologies may have cost advantages depending on factors such as the impact of coal rank on projected cost and efficiency, the recent escalation in actual

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[2] *The Challenge of Carbon Capture*, EPRI Journal, Spring 2007
[3] http://www.fwc.com/publications/tech_papers/files/TP_CCS_07_02.pdf

equipment costs, and the lack of demonstration of CO2 capture on commercial power plants."[4]

Carbon Storage- Part II

Sequestration in coal seams, with Enhanced Coal Bed Methane, is the method currently pursued by the Virginia Center for Coal and Energy Research and has been demonstrated as the best option for the location of the Wise county plant. CO_2 storage is not related in any way to the actual combustion technology at the plant. In fact, at the storage site, all delivered CO_2 is the same and treated "equally" during the injection process.

In response to the request to review area geology and identify sites in the area of Virginia City that are potential sequestration sites, please note that this work has been done as part of the research undertaken by the Virginia Center for Coal and Energy Research located at Virginia Tech. This was funded in part by the USDoE program known as Southeastern Carbon Sequestration Partnership .

Attachment 2, Figure 1, identifies the characterized region and shows areas of potential sequestration with and without enhanced coalbed methane recovery. Attachment 2, Figure 2, shows the location of the Virginia City plant with respect to the sequestration sites (coal thickness here indicates combined thickness of unminable seams, not individual seam thickness). These maps were provided by Dr. Michael Karmis, Director of the Virginia Center for Coal and Energy Research which is leading Virginia's participation in the SECARB program.

As stated in the rebuttal testimony of James K. Martin, State Corporation Commission, Case No. PUE-2007-00066, on December 19, 2007:

> "As the Virginia Energy Plan notes, preliminary conclusions indicate that coal seams in the Central Appalachian Basin have significant sequestration potential. This region has some of the most promising potential sites for carbon storage and would substantially simplify the process of carbon transport and would enable effective carbon storage. Dominion Virginia Power is focusing closely on this activity, and on November 3, 2007, the Company announced its contribution of $500,000 to the Virginia Center for Coal and Energy Research at Virginia Tech. This contribution is to support the current on-going sequestration effort and tests in Russell County, in close proximity to the Project site and to support the planning of a large-volume carbon storage demonstration project in the southwest Virginia CBM-producing Counties of Wise, Dickenson, Buchanan and Russell surrounding the Project site. The Company's financial support makes it possible for

[4] http://www.naruc.org/Publications/CoalGenerationTechnologies.pdfm

> Virginia Tech to qualify for substantial funding from DOE. This approach is also similar to that pursued in the Nevada MOU, where the developer is 'encouraged' to 'pool resources with the public, academic and/or private sector' to advance research on C02 capture technology and increase the understanding of sequestration opportunities."

One important point to note is the storage capacity assessment for the Central Appalachian Basin. Attachment 3, Summary of the Field Test Demonstrations, which was completed by the Central Appalachian Coal Seam Project team including VCCER, indicates that there are 1,341 MMt of carbon dioxide storage capacity in the Central Appalachian Basin, with 398 MMt deemed technically feasible for sequestration projects.[5] Over the project's lifetime, only 292 MMt of carbon dioxide will be produced. The storage capacity, in turn, would allow complete sequestration of the expected CO_2 emissions for the life of the plant.

As explained in Part I and Part II of this question, there are several options for greenhouse gas mitigation for CFB boilers. Carbon capture, which is the essential link between the power station and storage (sequestration) is being investigated in the case of PC, CFB and IGCC units and will most likely be developed so as to applicable to each of them. Infrastructure issues such as transmission piping and access to storage areas as well as the opportunity for enhanced recovery of coal bed methane all favor location of the proposed power station at Virginia City. There is however little evidence that an IGCC plant would be more amenable to taking advantage of these assets than a CFB facility. The proposed project also offers a unique opportunity to demonstrate carbon storage in unminable coal seams in Central Appalachia. Furthermore, the ability of the CFB technology to utilize biomass allows for additional flexibility in mitigating greenhouse gas emissions.

[5] http://www.energy.vt.edu/secarb/index.asp

ATTACHMENT 1

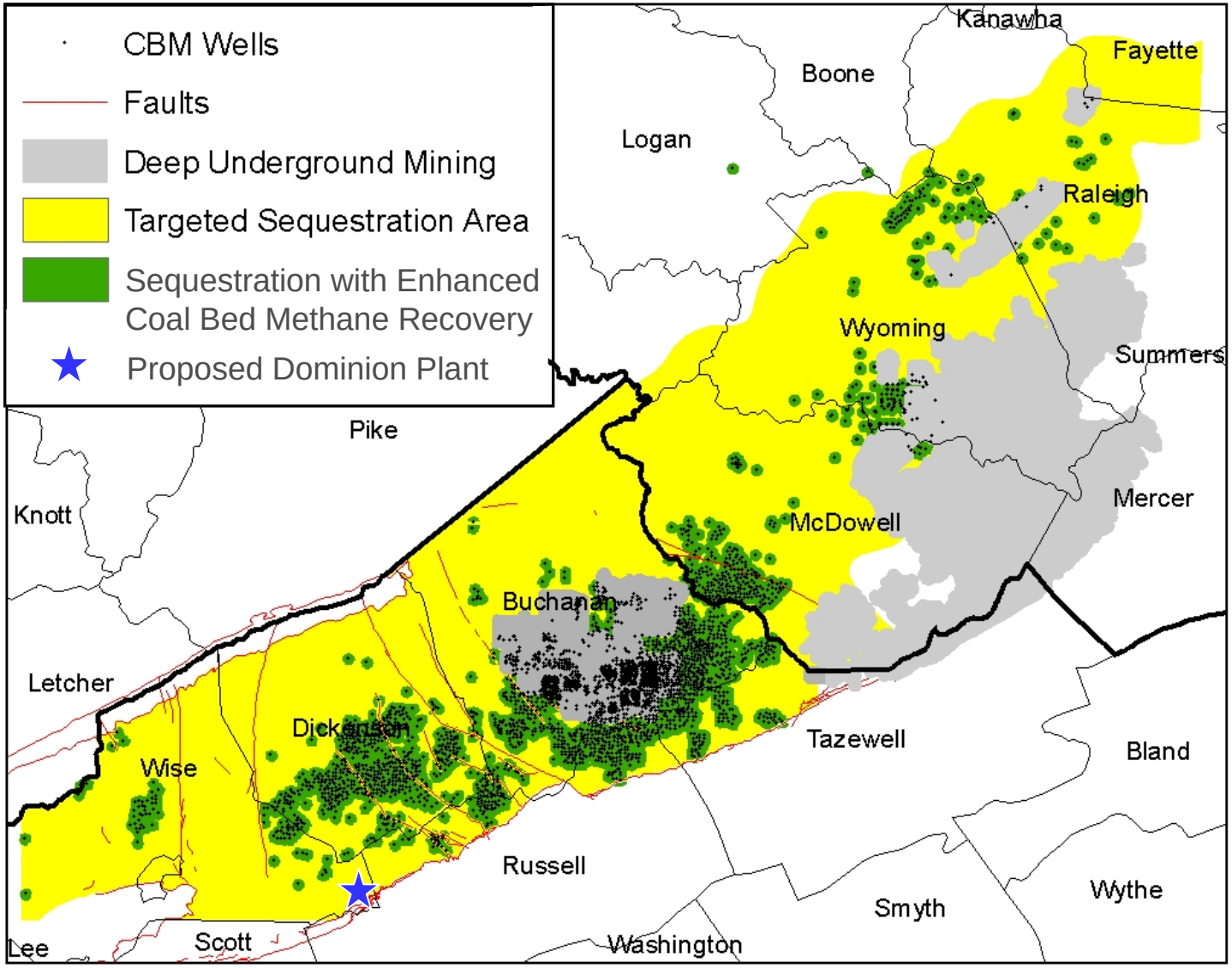
Attachment 1, Figure 1: AEP and Climate Legislation, Presentation at Sanford C. Bernstein 2007 Carbon Symposium

Attachment 1, Figure 2: IPCC 2005 Report, “Carbon Dioxide Capture and Storage”

Attachment 1, Figure 3: Post Combustion Capture at AEP Facilities

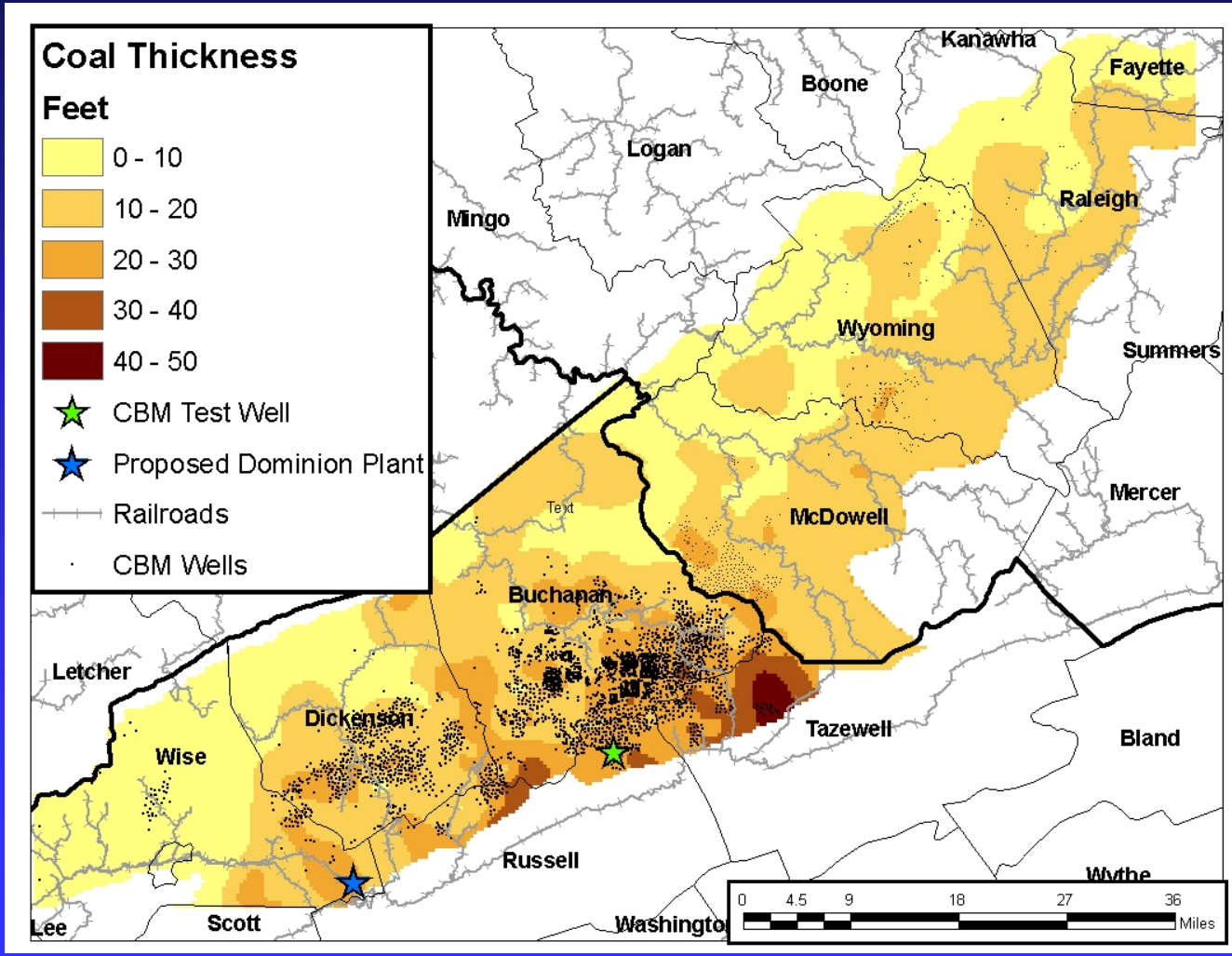
ATTACHMENT 2
Figure 1

Potential Sequestration Region Using Unminable Coal Seams, Characterized by VCCER



ATTACHMENT 2
Figure 2

Proposed Dominion Plant Location, CO2 Sequestration Area and CBM Sites



- Plant less than 7miles from nearest significant CBM field and 2.5 miles from the nearest CBM well
- Plant is about 24 miles from Phase II test well in Russell County

ATTACHMENT 3

secarb.org

Southeast Regional Carbon Sequestration Partnership (SECARB)

Central Appalachian Coal Seam Project

Field Test Location
Russell County, Virginia

Amount and Sources of CO_2
1,000 Tons from Commercial Source

Primary Contacts

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Field Test Partners

Primary Sponsors
DOE/NETL
SSEB

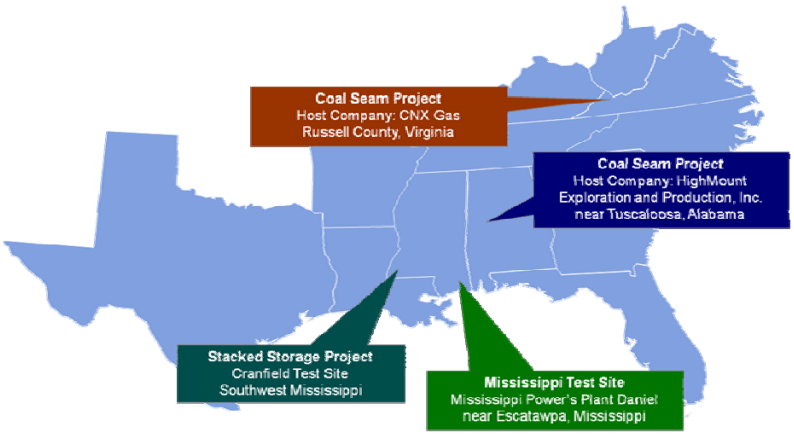
Industrial Partners
Alpha Natural Resources
AMVEST
Buckhorn Coal
CDX Gas
Dominion
GeoMet
McJunkin Appalachian
Natural Resource Partners
Penn Virginia
Piney Land and Pocahontas Land

Summary of Field Test Site and Operations

The Southeast Regional Carbon Sequestration Partnership's (SECARB) Central Appalachian Coal Seam Project field test partners have finalized indemnification and operating agreements to use a donated CNX Gas and Buckhorn Coal well for the field test in Russell County, Virginia. Design and implementation of the test are underway. The selection of the well was based on geologic considerations for the site, preliminary reservoir modeling, surface access and landowner and mineral owner negotiations.

The regional study area is located within the Central Appalachian Basin, a northeast-to-southwest-trending basin encompassing approximately 10,000 square miles in southwestern Virginia and southern West Virginia. The principal area of investigation for most of the detailed geologic mapping consists of portions of five counties located within southwestern Virginia including Buchanan, Dickenson, Russell, Tazewell and Wise Counties and four counties in West Virginia, including Fayette, McDowell, Raleigh and Wyoming.

The coals evaluated in this investigation include those of the Pocahontas and Lee Formations. The Pocahontas Formation directly overlies the late Mississippian Bluestone Formation. The sediments comprising that formation were deposited along an unstable basin that rapidly subsides to the southeast. Regionally, the formation is thickest to the southeast and generally thins to the northwest. Coal seams of the Pocahontas Formation are normally high rank, medium to low-volatile, high gas content coals that include the Pocahontas Nos. 1 through 9. The most laterally extensive and thickest of those beds is the Pocahontas No. 3 seam. Other seams within the formation may also provide favorable carbon sequestration targets.



SECARB Phase II Geographic Region and Field Test Site Locations

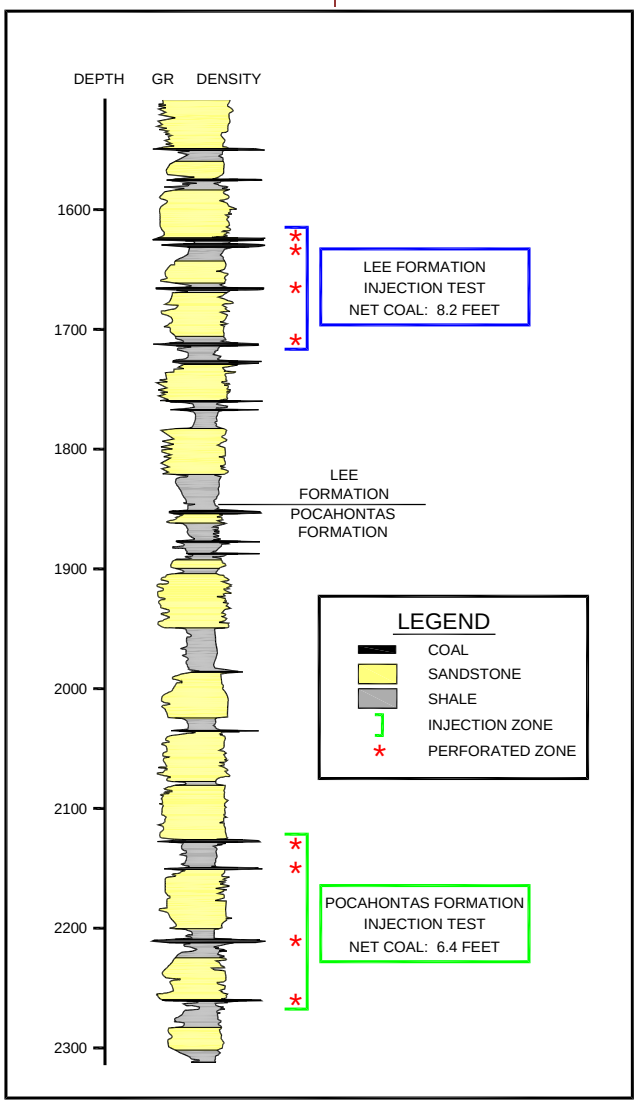


Figure 1. Field Validation Test Site Injection Zones

The sediments comprising the Lee Formation unconformably overlie Pocahontas Formation strata within the study area. Overall, the thickness of the formation decreases from southeast to northwest reflecting the progradation of the deltas from a southeastern source area across the basin to the northwest. The major seams recognized for the Lee Formation include the Upper Seaboard, Greasy Creek, Middle and Lower Seaboard, Upper and Middle Horsepen, C-Seam, War Creek and Lower Horsepen coals. The Lee Formation coals are typically medium to low-volatile bituminous in rank within the study area. The Lee and Pocahontas Formation coals are favorable reservoirs for carbon sequestration due to their thickness, depth, rank and permeability characteristics.

For the field validation test, an existing coalbed methane (CBM) well will be converted for carbon dioxide (CO_2) injection. The surface of the proposed site is mountainous terrain at 2,000' above sea level that was previously strip-mined. Access to the site will be on coal strip roads and the off-set core hole sites will be on stable strip benches. This will allow for minimal land disturbance.

The targeted coal seams are in the Pocahontas and Lee formations and include the Pocahontas Nos. 3 - 9 coal seams. The formation depth is approximately 2,200 feet to bottom of formation. The targeted coal seams range from 1,600-2,200 feet deep. The regional dip of the targeted coal seam at the proposed site dips 1.4 feet per 1,000 feet from West to East and 1.2 feet per 1,000 feet from South to North. The thickness of each of the three targeted seams range from 2.0 – 2.6 feet thick for a total thickness of 6.8 feet. The total thickness of coals completed at the well site is 18.2 feet. The average temperature of the bottom coal seam across the area is 74 degrees Fahrenheit. The permeability ranges from 5-20 millidarcies in the producing coal seams throughout the area. The porosity is approximately one percent in the producing coal seams. Salinity values range from 40,000 – 130,000 parts per million.

The targeted coal seams are commonly interbedded with carbonaceous shale. These geophysically identified shale layers above the coal seams are known seals that should contain the CO_2 injected into the target coal seams. A regional structure map was generated that includes thrust faults, transverse faults, anticlines and synclines. The potential leakage points could include these fault systems and networks, joint systems or existing borehole penetrations related to CBM or natural gas production.

The principal construction requirements under this program will include the drilling of core holes and the installation of monitoring apparatus. Two core holes will be drilled around the injection well at approximately 150-300 feet, the exact distances to be determined on the basis of reservoir models. After the cores are removed for analysis, the core holes

will be converted into monitor wells and pressure transient tests will be performed in both the core holes and injection wells. Isolation packers and slim-hole monitoring equipment will be installed to observe reservoir pressure and gas composition during injection of CO_2. The injection operation will include the injection of 1,000 tons of CO_2 into two different coal seams.

The formation is very well characterized based on core hole data and immense amounts of geophysical data throughout the area. The following two figures illustrate a geologic stratigraphic column (Figure 1) showing the target formation and potential seals of the proposed field validation test site and the locations of the potential test sites (Figure 2).

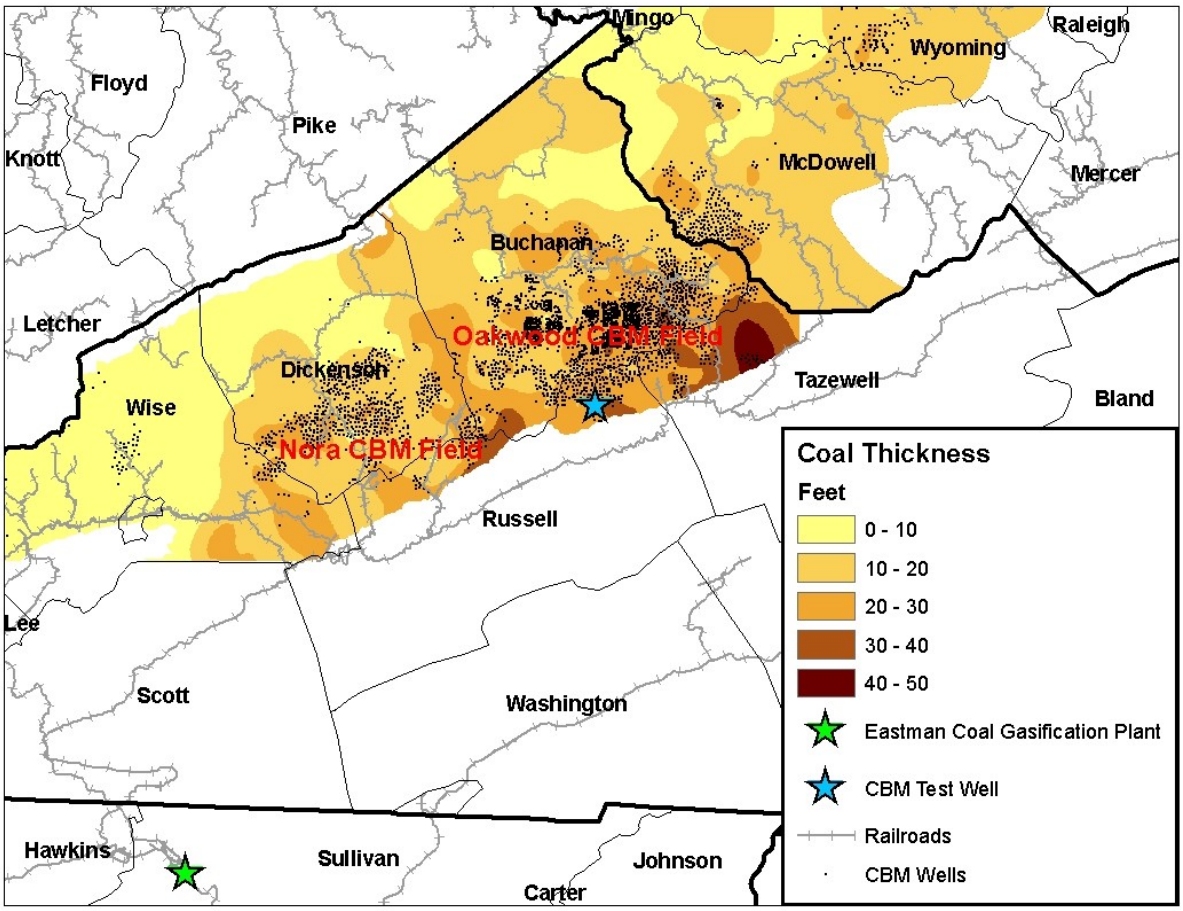


Figure 2. Field Validation Test Site

Research Objectives

The objectives under this field validation test are to assess and to verify the sequestration capacity and performance of mature CBM reservoirs in the Central Appalachian Basin through injection-falloff and production testing, as well as the implementation of subsurface monitoring programs. These tests will demonstrate the potential geologic sequestration into Appalachian coals as a safe and permanent method to mitigate greenhouse gas emissions. The objectives of the project are directly related to the following tasks: expanded geologic characterization, pilot site selection, reservoir modeling, core hole drilling and evaluation, pilot preparation and risk analysis, pilot testing and injection operations, data interpretation and assessment, and public outreach and technology transfer.

Summary of Modeling and MMV Efforts

Reservoir modeling activities are lead by a team from Advanced Resources International using their COMET3 reservoir simulator, the industry-leading choice for desorption-influenced reservoirs. Reservoir modeling is an important component in understanding the mechanisms involved in carbon sequestration within coal seams. Four types of reservoir modeling efforts will be necessary during the course of the project. These will be: (1) review of the selected primary injection sites within the Central Appalachian Basin; (2) rigorous history matching and assessment of the preferred CO_2 injection sites, including numerous sensitivity runs, prior to CO_2- sequestration demonstration; (3) mid-course reservoir modeling to assess the performance of the project against expectations, enabling mid-course corrections to be made; and, (4) post-project history matching and performance prediction of the CO_2- sequestration pilots and their implications to CO_2 storage in the basin.

Monitoring and verification will focus on both surface and deep well monitoring and will include water composition, soil analysis, subsurface pressure and well log analysis. After the two core holes are drilled at each test site, they will be converted into deep monitor wells. Packers will be installed to isolate separate coal zones. Slim-hole equipment for observing reservoir pressure and gas composition will be installed between the isolation packers to monitor reservoir pressure and gas composition (CO_2 and CH_4). Pressure response and gas composition will be mapped using the data from the observation wells, and reservoir models will be refined on the basis of the data.

Accomplishments to Date

1. A detailed regional assessment of the Central Appalachian Basin potential carbon sequestration capacity and enhanced CBM recovery has been completed.
2. A comprehensive suite of production maps for the active CBM wells in the Central Appalachian Basin has been performed and finalized.
3. Preliminary reservoir modeling on field validation test site has been completed.
4. Site selection of the field validation test site has been completed.
5. A technology transfer and outreach program has been initiated that includes a website, publications and numerous technical and non-technical presentations at conferences and workshops.

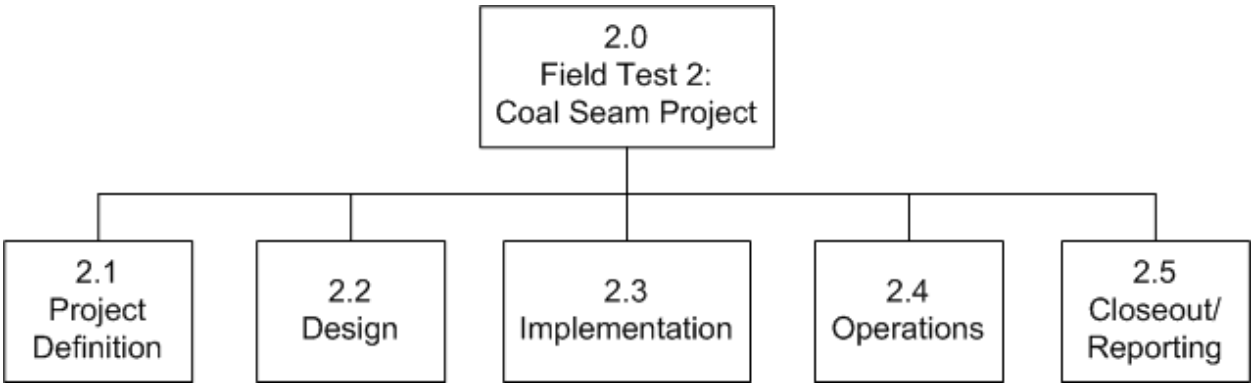
Summarize Target Sink Storage Opportunities and Benefits to the Region

The most favorable areas delineated for the proposed Central Appalachian sequestration field test are located within the coalbed methane production region in Buchanan, Dickenson, Russell, Tazewell and Wise Counties, Virginia, and in Fayette, McDowell, Raleigh and Wyoming Counties, West Virginia. Economic production in the Central Appalachian region began in 1988 with the development of the Nora CBM field by Equitable Production Company, located primarily in Dickenson County, Virginia. CONSOL Energy later commenced drilling CBM wells in the prolific Oakwood Field located in Buchanan County, Virginia, in 1990. Since that time, over 4,000 CBM wells have been drilled and completed through year-end 2005 in the Central Appalachian Basin. The prospective coal seams are known to be high rank (low to medium volatile bituminous), have high gas contents and occur at favorable depths for storage. CBM development in the area has provided extensive geological, engineering and production data, which will be made available for reservoir modeling. The CBM productivity of the province indicates that coal permeabilities should be acceptable for carbon dioxide injection. The sequestration capacity assessments for the Central Appalachian basin indicate 1,341 Million tons (MMt) of carbon dioxide storage capacity, with 398 MMt deemed technically feasible for sequestration projects. The corresponding enhanced CBM recovery potential of these coals is 0.79 – 2.49 trillion cubic feet (TCF) of gas production. Sources of CO_2 in the area are large coal-fired power plants that maybe able to supply CO_2 for sequestration projects. If the technology proves successful, the possibility exists for large economic development gains in the form of enhanced CBM production and carbon sequestration industries for the region.

Cost	Field Project Key Dates
Total Field Project Cost (Years 1-4): $2,718,223	Baseline Completed: 01/2007
DOE Share: $2,173,469 80%	Site Selection Completed: 10/2007
Non-DOE Share: $544,909 20%	Drilling Operations Begin: 03/2008
	Install Monitoring Equipment: 06/2008
	Injection Operations Begin: 07/2008
	Site Closure: 08/2009

Field Test Schedule and Milestones (Gantt Chart):

The field test schedule for SECARB's Central Appalachian Coal Seam Project can be seen in the following diagram and Gantt Chart.



Tasks	Year 1				Year 2				Year 3				Year 4			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
2.1 Project Definition																
2.2 Design																
2.3 Implementation																
2.4 Operations																
2.5 Closeout/Reporting																

Tasks Completed Tasks to be Completed