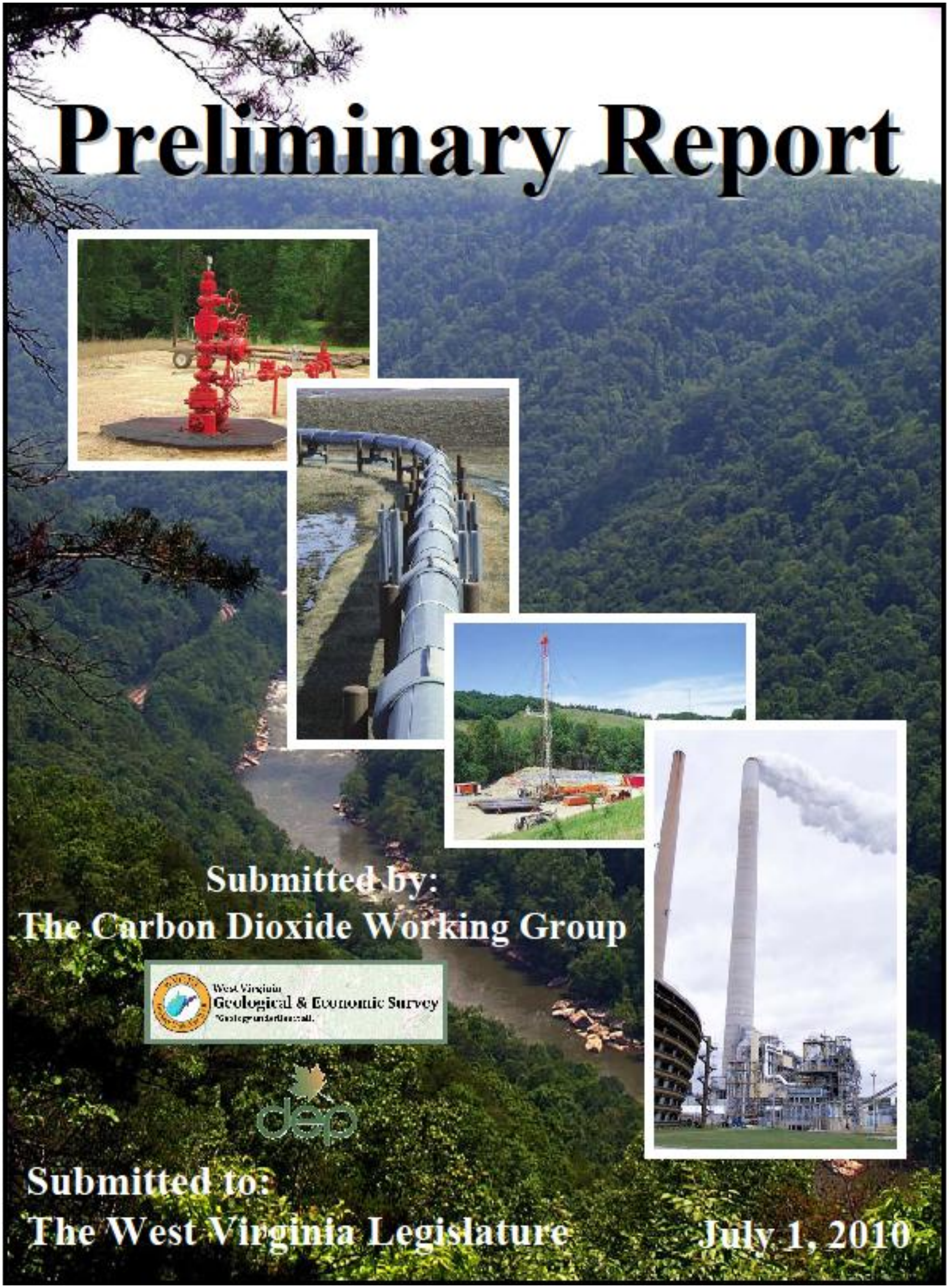
Preliminary Report



Submitted by:
The Carbon Dioxide Working Group

West Virginia
Geological & Economic Survey

dep

Submitted to:
The West Virginia Legislature

July 1, 2010

FOREWORD

The Carbon Dioxide Sequestration Working Group consists of members appointed by West Virginia Department of Environmental Protection ("WVDEP") Secretary Randy Huffman, and West Virginia Geological and Economic Survey ("WVGES") Director Dr. Michael Hohn. The Working Group would like to thank the WVDEP for use of its facilities and resources including the time and assistance of Kristin Boggs, Esq. and Jeff Knepper. Also, special thanks are offered to the WVGES, the West Virginia Division of Energy, the Department of Tax and Revenue, and other state agencies that have provided information and technical expertise. Many experts from these agencies, and from interested groups, traveled long distances to share their valuable experience about Carbon Capture and Sequestration. The Working Group is truly grateful for their assistance.

The Working Group reviewed a substantial body of data and reports related to various aspects of Carbon Capture and Sequestration. This Interim Report incorporates or refers to data and information from a large number of sources including federal and state agencies, and non-governmental organizations. Some of this data and information may incomplete or inaccurate. The citation to these sources does not necessarily mean the Working Group agrees with the data, information, or opinions cited.

This Interim Report provides preliminary conclusions and recommendations. These preliminary conclusions and recommendations are subject to further review and possible modification during the preparation of the Final Report.

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

I.A. BACKGROUND

During the 2009 Regular Session, the West Virginia Legislature passed HB 2860 which was added to the West Virginia Code as Carbon Dioxide Sequestration, Article 11A of Chapter 22. The Legislature listed among its findings that "[i]t is in the public interest to advance the implementation of carbon dioxide capture and sequestration technologies into the state's energy portfolio." Recognizing that there are administrative, technical and legal questions involved in developing this new technology, the Code authorized the West Virginia Department of Environmental Protection (WVDEP) Secretary to establish a Carbon Dioxide Sequestration Working Group ("Working Group"). The Working Group is charged with studying all issues related to the sequestration of carbon dioxide and to submit a preliminary report to the Legislature on July 1, 2010, followed up by a final report due on July 1, 2011. The final report must address, at a minimum, the following:

- A recommendation of the appropriate methods to encourage the development of carbon dioxide sequestration technologies;
- An assessment of the economic and environmental feasibility of large, long-term carbon dioxide sequestration options;
- A recommendation of any legislation the working group may determine to be necessary or desirable to clarify issues regarding the ownership and other rights and interest in pore space;
- A recommendation of the methods of facilitating the widespread use of carbon dioxide sequestration technology throughout West Virginia;
- Identification of geologic sequestration monitoring sites to assess the short-term and long-term impact of carbon dioxide sequestration;
- An assessment of the feasibility of carbon dioxide sequestration in West Virginia and the characteristics of areas within the state where carbon dioxide can be sequestered;
- An assessment of the costs, benefits, risks and rewards of large-scale carbon dioxide sequestration projects in West Virginia;
- An assessment of the potential carbon dioxide sequestration capacity in this state;
- Identification of areas of research needed to better understand and quantify the processes of carbon dioxide sequestration; and
- An outline of the working group's long-term strategy for the regulation of carbon dioxide sequestration in West Virginia.

(W. Va. Code § 22-11A-6(h)(1)-(10))

This Preliminary Report was prepared and submitted in compliance with the Carbon Dioxide Sequestration Act. It describes the efforts of the Group to date and indicates progress toward making recommendations and conclusions.

Notably, after the Carbon Sequestration Act was passed during the regular session in 2009, a Special Session was held in June 2009. During that session, the Legislature promulgated the Alternative and Renewable Energy Portfolio Standard, Article 2F of Section 24 of the West Virginia Code. This new law states that "[t]o continue lowering the emissions associated with electrical production, and to expand the state's economic base, West Virginia should encourage the development of more efficient, lower-emitting and reasonably priced alternative and renewable energy resources."

"Advanced coal technology" is included in the list of defined "alternative energy resources." W. Va. Code § 24-2F-3(c)(1). Advanced coal technology is defined as "a technology that is used in a new or existing energy generating facility to reduce airborne carbon emissions associated with the combustion or use of coal and includes, but is not limited to, *carbon dioxide capture and sequestration technology*, . . . and any other resource, method, project or technology certified by the commission as advanced coal technology." W.Va. Code § 24-2F-3(a) (emphasis added).

It is clear to the Working Group that passage of the Alternative and Renewable Energy Portfolio Standard almost contemporaneous with passage of the Carbon Dioxide Sequestration Act indicates the Legislature's high level of interest in carbon capture and sequestration technology and its desire for West Virginia to be a leader in deployment of such technology if feasible from an environmental, economical, and legal standpoint.

I.B. ORGANIZATION OF THE PRELIMINARY REPORT

While the list of ten items the Working Group is charged with considering may be categorized broadly into three areas, many of them overlap. This constituted some challenge with organization for a useful preliminary report. The Group decided to organize this report by way of discussing feasibility issues first, geology and technology issues second, and legal issues last. In each of these three broad sections, any preliminary conclusions and/or recommendations reached by the Group are clearly stated at the end of the section. Subsequent to that information is a list of items which will be studied over the next year prior to development of a Final Report.

The Preliminary Report provides preliminary conclusions and recommendations. These preliminary conclusions and recommendations are subject to further review and possible modification during the preparation of the Final Report.

I.C. FEASIBILITY SUBCOMMITTEE

The Working Group believes that it is highly likely that West Virginia will be faced with having to significantly reduce the state's emissions of greenhouse gases in the near future. The state currently emits approximately 102 million metric tons of greenhouse gases each year with about 86 million metric tons of that being emitted from coal-fired power plants. The state is one of the nation's largest exporters of electric power to other states. Power plants were originally built in the state to be near the primary fuel source and West Virginia contains enough generating capacity to meet the state demand and provide extensive power to its neighbors.

The United States Environmental Protection Agency ("USEPA") has designated carbon dioxide and other greenhouse gases as "regulated" pollutants and there is a strong desire on the federal level to reduce greenhouse gas emissions. This reality, coupled with increased international pressure on the US in this area, means emissions in West Virginia may soon have to be cut back. With these issues as a backdrop, the Feasibility Subcommittee concentrated on assessing the magnitude of the reductions West Virginia may be asked to make and whether or not CCS[1] technology can contribute to a potential solution to this challenge.

Factors to assess in this investigation include costs of such technology, impacts on the state's economy, public safety and environmental concerns, and goals of the state that may be impacted by CCS. This subcommittee also proposed some incentives the state may want to consider should it be determined that deployment of CCS is in the state's interest (see section IV.A.6.).

In general, the magnitude of the reductions needed to achieve the goals of any currently proposed emissions reduction targets are so large that multiple approaches are needed because no single technology or life style change can achieve them. Current Congressional proposals call for a reduction in US greenhouse gas emissions of 83% by 2050. Elimination of all coal-fired power in the nation would still leave 70% of the greenhouse gas emissions currently emitted from US sources (see Table A.1.). CCS may be part of the solution to greenhouse gas emissions, but significantly more will have to be done to achieve these goals.

The economic cost of CCS technology can be estimated, but because the technology is in the early stages of development, such cost projections are somewhat unreliable. Section IV.A.3. gives a comparative costing for various technologies with varying greenhouse gas impacts, but predicting costs at this time is extremely difficult. Technology development, economic recession and national and international affairs may play a huge role in such projections. Section IV.A.3.b. helps outline some of the information that may be needed to assess the overall impact of CCS on the economy of West Virginia, but acknowledges that much of the needed data are not yet available. The Legislature may want to inquire into this question in the coming near term.

From a public safety and environmental impact point of view, there are some important questions that still need to be resolved. The Mountaineer CCS project in Mason County, West Virginia, is attempting to answer some of these questions. The Legislature will want to carefully consider the observation in section IV.A.4. and continue to insist that appropriate technical consideration be given to designing regulatory structure to assure long term protection of these values.

In the coming year the Feasibility Subcommittee will assess and attempt to resolve some of the following topics:

1. In the face of growing concern over greenhouse gas emissions, should and if so to what extent should West Virginia investigate other methods of generating electrical and other forms of power?
2. Should the Legislature investigate potential regulations and or promotion of intrastate and interstate CO_2 pipelines?
3. What factors need to be considered in the assessment of the value of coal-fired power to West Virginia?
4. The subcommittee will delve deeper into the economic cost and impact on West Virginia of CCS technology.

---

[1] The term "CCS" is used frequently throughout the Preliminary Report. The Working Group agreed that CCS shall be interpreted to refer to Carbon Capture and Sequestration instead of Carbon Capture and Storage. The terms "sequestration" and "storage" are often used interchangeably so the Group agreed to the use of "sequestration" throughout the report. The Legislature defines carbon dioxide capture and sequestration as "the capture and secure storage of carbon dioxide that would otherwise be emitted to, or remain in, the atmosphere." W. Va. Code §22-11A-2(9).

5. What facts need to be brought to the attention of the West Virginia Legislature to enable that body to make an informed decision about the importance of CCS technology development in the state?

I.D. GEOLOGY & TECHNICAL SUBCOMMITTEE

The Geology & Technical Subcommittee (G&T Subcommittee) is addressing three questions posed in the legislation: identifying monitoring sites for geologic sequestration [§22-11A-6(h)(5)], assessing the feasibility of carbon dioxide sequestration in West Virginia [§22-11A-6(h)(6)], and assessing the potential carbon dioxide sequestration capacity in the state[§22-11A-6(h)(8)]. In addition, this subcommittee addressed several technical questions referred to it by other subcommittees.

The G&T Committee reviewed legislation from several states addressing CO_2 sequestration monitoring, verification and accounting (MVA). While these laws directed state agencies to develop regulations, only one state, Washington, has developed regulations administered by a state agency.

Carbon Dioxide Sequestration Capacity

Potential carbon dioxide sequestration beneath West Virginia has been assessed by the Midwest Regional Carbon Sequestration Partnership (MRCSP). Several oil and gas or saline formations in the stratigraphic column have potential for storage or for providing a seal, preventing migration of a carbon dioxide plume. Coal, a valued natural resource in West Virginia, also presents storage potential in unmineable seams. Shale and coal have similar trapping mechanisms for sequestration where the carbon dioxide molecule is bound to the organic material or clay particles found in gas shales.

The MRCSP estimates the potential for geologic sequestration potential of carbon dioxide in West Virginia at about 60,810 million metric tons. This includes an estimate of storage potential in shales. In its second edition of the Carbon Sequestration Atlas of the United States and Canada, the National Energy Technology Laboratory (NETL) provides a range in geologic storage potential for West Virginia of between 4,873 and 14,994 million metric tons[2]. Storage potential in shales is not included in NETL's atlas; more research work needs to be conducted to better understand trapping mechanisms in shale, providing a better understanding of the storage potential in these rocks. Emission data in NETL's Atlas for West Virginia shows 29 sources from all industries emitting 102 million metric tons per year (see Table 4B2) which indicates that there is between 47 years and 147 years of storage capacity for the annual carbon dioxide sources in West Virginia. The third edition of the Atlas is scheduled for release in November 2010. Also, the United States Geologic Service will be providing an assessment of onshore storage potential for CO_2 per Congressional direction in the Energy Independence and Security Act of 2007. Storage potential estimates are resource estimates that need to be proven. This will be done to some degree during site characterization of a potential sequestration site. As with other natural resources such as oil and gas or coal, proved reserves are a smaller value than the resource estimate.

---

[2] NETL will release the 3rd edition of the Atlas in November, 2010.

Monitoring, Verification, and Accounting of CCS

Monitoring geologic sequestration to ascertain the position of the carbon dioxide plume requires knowledge of the geologic setting of the storage reservoir. This geologic knowledge was originally developed during an initial assessment of the regional geology. The ability of this early assessment to provide sufficient details on the character of the geology in the area depends on the quality of the available database. Site characterization is a huge investment. It has been estimated that it will cost $100,000 per square mile to acquire 3-D seismic and $3,000,000 to drill and log an evaluation well plus 30% of these costs for data processing, modeling and other services[3]. One well will evaluate 25 square miles. A storage field covering 25 square miles will cost a little over $7,000,000 to partially characterize as these costs probably do not cover all of the details, including securing rights to the pore space, that need to be accounted for in presenting a storage field proposal before a regulatory body with the intent of gaining a permit. The quality of data available for this initial assessment will provide a level of confidence on whether or not to proceed, and whether or not a further investment in time and money is warranted.

It is during site characterization that the establishment of the MVA system begins. Initial sampling establishes a baseline for groundwater quality, and possibly for soil gases and ambient air quality. Consideration regarding technology to fulfill MVA needs will also be sorted out during site characterization. Direct measurement and sampling of the reservoir, seal and overlying strata can only be accomplished with a well. A core sample will provide direct measurement of porosity and permeability, and if recovered under special conditions, in situ fluid samples. Wireline or geophysical logging tools record physical properties of the stratigraphic section, rocks and fluids, cut by the well. There is well established technology to acquire seismic data. Core data provide the highest level of resolution while surface seismic data provide the broadest areal extent. With computers, core data are used to calibrate wireline logging data which in turn are used to calibrate seismic data; all of which provide an overall picture of the subsurface.

Additional data acquisition from an MVA program includes groundwater sampling from specific monitoring wells or local water wells, and may also include pressure and temperature monitoring from monitoring wells and injection wells, soil gas sampling, and ambient air monitoring around injection facilities.

The goal for any particular MVA program will be to confirm confinement and alert to a possible leak. Development of regulations and permitting standards will be necessary to establish goals that any MVA program will be required to meet.

Transmission of Carbon Dioxide

Delivering captured carbon dioxide to a storage site for sequestration will be accomplished by pipeline. This is a familiar form of transportation as about 3,900 miles of pipeline deliver carbon dioxide to numerous enhanced oil recovery (EOR) projects in West Texas, Wyoming, Mississippi and the Texas-Louisiana Gulf Coast. Through October 2007, there were 18 incidents along the carbon dioxide pipeline network without any injury or fatality. For the natural gas pipeline network, which is 400 times longer, there were 877

---

[3] McCoy, S.T., 2008, The Economics of CO_2 Transportation by Pipeline and Storage in Saline Aquifers and Oil Reservoirs. PhD dissertation, Carnegie Mellon University, January, 2008.

injuries and 252 fatalities. In testimony before the House Subcommittee on Energy and the Environment, Ian Duncan of the Texas Bureau of Economic Geology stated that the rupture of CO_2 pipelines is the largest risk facing CCS deployment.[4] He further points out that "[u]ltimately the risk from pipelines depends on: siting of the pipelines (risks are site specific); operation of the pipelines to minimize possible corrosion (particularly the current industry focus on keeping the water levels in the CO_2 below saturation); and implementation of effective risk management and mitigation plans." Rupture is caused by an outside force which is the cause for only one incident on CO_2 pipeline but is the cause for 35% of the incidents on natural gas pipelines.[5] A distinct advantage for carbon dioxide is that it is not flammable, it will not support combustion. However, two points of concern regarding carbon dioxide are that it is an asphyxiant and heavier than air.

Carbon Dioxide Risk Assessment

Assessment of the risks of transporting and storing carbon dioxide is necessary to properly quantify liabilities and assure the public that projects awarded a permit have an excellent chance of meeting expectations regarding safe operations. The prime factor of consideration here, both for transportation and sequestration, is pressure. Captured carbon dioxide is most economically shipped in a dense or supercritical phase[6] where carbon dioxide has the viscosity of a gas but the density of a liquid. To optimize storage, carbon dioxide needs to be sequestered at depths that will maintain the supercritical phase. Depending on temperature and pressure gradient, this will be about 2,500 feet and deeper. While oil and gas production deplete the pressure of the reservoir, carbon dioxide sequestration will leave the reservoir at hydrostatic (pre-existing) pressure or slightly higher. Once injection ceases, the storage reservoir pressure will begin to return to pre-injection operation pressures. The USEPA recommends a 50 year post injection monitoring period, although the Administrator may modify this on a case-by-case basis, because it estimates that this is how long it will take the CO_2 storage reservoir pressure to return to regional hydrostatic pressure levels and provide a condition of non-endangerment.[7]

There is a substantial and growing body of carbon dioxide risk assessment literature. Relative to the scale envisioned for CCS, there is some experience in transporting and injecting carbon dioxide for enhanced oil recovery (EOR) for more than three decades. In a publication discussing the risk of CCS, one author contends that the risks of geologic storage of carbon dioxide are no greater than the risks associated with similar industrial activities currently in operation.[8] She further notes that "[b]ecause the technology for characterizing potential CO_2 storage sites, drilling injection wells, safely operating injection facilities, and monitoring will be adapted and fine-tuned from these mature industrial practices taking place today, it is reasonable to infer that the level of risk will be similar." The mathematical models used are undergoing rapid development and remain works in progress and further refinement of the risk assessments will be an iterative process. The risk assessment literature, subject to the limitations expressed, generally supports continuing forward to establish a framework for such projects. There is

---

[4] Ian Duncan, 2009, Regarding The Future of Coal under Climate Legislation; Carbon Sequestration Risks, Opportunities, and Learning from the CO2-EOR Industry. Testimony before the U.S. House Committee on Energy and Commerce, Subcommittee on Energy and the Environment, March 10, 2009.

[5] Ibid

[6] In its critical phase, carbon dioxide is 88°F at 1,073 psi or 31°C at 7.4 MPa.

[7] EPA, 2008, Proposed rules for Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration (GS) Wells. (web link needed)

[8] Benson, A.M., *Carbon Dioxide Capture and Storage, Assessment of Risks from Storage of Carbon Dioxide in Deep Underground Geological Formations*, Lawrence Berkeley National Laboratory, April 2, 2006, p.4.

potential for sequestration of captured carbon dioxide in West Virginia. The state overlies the sedimentary section of a portion of the Appalachian Basin, one of the major sedimentary basins in the continental United States beneath eight states. Storage potential in saline formations, depleted oil and gas reservoirs and unmineable coal seams are all present. Analogous circumstances from natural gas storage and EOR suggest, but do not prove conclusively, that carbon dioxide geologic storage risks are manageable. There will always be some level of geologic risk. Saline formations provide most of the sequestration potential yet the natural gas storage industry much prefers depleted oil and gas reservoirs. Finding suitable saline storage will have a more exploratory aspect than for depleted oil and gas reservoirs which are a known quantity. Regional evaluation, selection of a suitable location for site characterization, acquisition of rights to the pore space, acquisition of permits, and installation of injection wells, pipelines and equipment may take three to four years. The rate at which storage reservoirs can be permitted and developed will likely dictate the rate of deployment of CCS technology. Without storage, there is no need for capture.

Over the next year, additional information on storage assessment is expected to be published. Phase III large-scale injection projects are underway by the Regional Partnerships. These projects will evaluate injectivity, performance of the reservoir, and the MVA program established to track injection activity. The Geology & Technology Subcommittee will evaluate and incorporate this information in the final report.

I.E. LEGAL SUBCOMMITTEE

The efforts of the Legal Subcommittee to assess legal issues began by undertaking a careful review of activities around the country in identifying significant policy, regulatory and legal issues raised by CCS projects. After identifying the universe of issues involved, initial efforts focused on property ownership and acquisition. Research was conducted on activities in other states and by such organizations as the Interstate Oil and Gas Compact Commission, CCSReg and the Midwest Governors Association. In addition, an evaluation was conducted of the consequence of allowing the current legal process already in place to control the acquisition of land to be used for a CCS project. The goal of this effort was to explore all options in order to create a solution tailored to West Virginia legislature’s desire to site commercial scale CCS projects.

The Legislature has requested the Working Group to make recommendations to encourage the development of CCS and to examine factors integral to the construction, maintenance, and operation of CCS facilities, among other things. In response to this request, the Working Group has turned its initial attention to the manner in which pore space rights are to be acquired.

The resulting analysis has focused principally on two overarching factors: (1) the practicality and cost of any approach that required that all owners of pore space be identified and paid for the right to use pore space without regard to the landowners potential for use of the pore space, and (2) the constitutional requirements applicable to the circumstances under which the use of land required compensation as a taking.

With respect to the first of these factors, the Working Group recognizes that in West Virginia and much of the East, the number of property owners that could be within the footprint of a CCS project could be extremely large. It is assumed that a full scale CCS project could encompass an area the size of Mason County, West Virginia. In Mason County alone, there are nearly 20,000 surface owners and 1,000 mineral owners. On the conservative assumption that a typical title examination could cost $5,000 per tract, the cost to do title searches for a project with a footprint this large would be approximately $100 million. Added costs related to compensation to landowners and transactional costs related to acquiring the property rights cause the Working Group to conclude that an alternative course of action should be pursued.

Turning then to the constitutional requirements related to compensation for the use of land, the Working Group recognizes that not all use of private land result in a compensable taking. The United States Supreme Court and other courts have recognized a number of circumstances in which compensation was not required to be paid for the use of land. These cases have included in certain circumstances airplane over-flights of land and injection of material into underground foundations. By reviewing the facts and circumstances surrounding theses cases, the Working Group has developed a statutory mechanism that is believed to pass constitutional muster.

While the approach of dedicating certain pore space below 2,500 feet to public use is the pore space use approach favored by the majority of the Working Group at this time, the Working Group will continue to evaluate this approach, and alternative approaches, between now and the completion of its work.

The next phase of the efforts of the Legal Subcommittee will turn to issues that have not yet been addressed by the committee. These efforts will include attention to such issues as:

1. Permitting.
2. Groundwater Protection.
3. Administrative Fees.
4. Interstate Projects.
5. Preemption.
6. Report to Legislature.
7. Liability transfer.
8. Post Closure Trust Fund.
9. PSC Approval.
10. Ownership and Value of Stored CO_2.
11. Forced unitization.
12. Pipelines.

I.F. SUMMARY

Much research has been conducted by the Working Group through its subcommittees over the past year. The subcommittees will continue to study current law, emerging technologies, and the work of similar entities created in other states. We are committed to tackling the difficult and controversial issues and hurdles to aggressive deployment of CCS in West Virginia. The Working Group appreciates the assistance by way of resources including accommodations, personnel, and data offered by the WVDEP and the WVGES.

II. DETAILS OF THE WORKING GROUP

II.A. WORKING GROUP MEMBERS

The Act requires the appointment of certain members to the Working Group by the Secretary of the WVDEP, and the state geologist, the Director of the West Virginia Geological and Economic Survey. The following current members were appointed in compliance with the Act in July 2009 by Secretary Randy Huffman and Dr. Michael Hohn:

Experts in carbon dioxide sequestration or related technologies:
  Grant Bromhal - National Energy Technology Laboratory
  Cal Kent, Ph.D.- Marshall University
  Ken Nemeth - Southern States Energy Board
  Richard Winschel - Consol Energy, Inc.

Expert in environmental science:
  Stephanie R. Timmermeyer, Esq. - Timmermeyer PLLC

Expert in geology:
  Tim Grant - National Energy Technology Laboratory

Attorneys with expertise in environmental law:
  David M. Flannery, Esq.- Jackson Kelly PLLC
  Leonard Knee, Esq. - Bowles Rice McDavid Graff and Love, LLP

Expert in engineering:
  Paul Kramer - Allegheny Energy, Inc.

Experts in the regulation of public utilities in West Virginia:
  Billy Jack Gregg
  Earl Melton - WV Public Service Commission

Representative of a citizen's group advocating environmental protection:
  Vickie Wolfe - WV Environmental Council

Representative of a coal power electric generating utility advocating carbon dioxide sequestration development:
  Tim Mallan - Appalachian Power

Engineer with an expertise in the underground storage of natural gas:
  John Leeson - Dominion

Chairman of the National Coal Lessors:
  Nick Carter, who designated Greg Wooten as his representative

Representative of the Coal Association:
  Jim Laurita - MEPCO

Representative of West Virginia Land and Mineral Owners Association:
  Alan Dennis – Penn Virginia Coal Company

Representative advocating the interests of surface owners of real property:
  David B. McMahon, Esq.

II.B. MEETINGS

The full Working Group's first meeting occurred on August 12, 2010. During that meeting, the Group elected Stephanie R. Timmermeyer to Chair the Group and Tim Grant as Vice-Chair. The next full meeting was held on September 16, 2010 during which the Group voted to form three subcommittees because the list of ten items may be categorized into three discrete areas: feasibility, geology and technology, and legal.

The Feasibility Subcommittee is tasked with items 1, 2, 4, 7, 9, and 10 (with an emphasis on items 1, 2, 4, and 7). In addition, the Group asked this subcommittee to consider transportation and public outreach. Members consist of Tim Mallan, Chair, Cal Kent, Jim Laurita, Earl Melton, Stephanie Timmermeyer, and Vickie Wolfe.

The Geology and Technology Subcommittee is responsible for items 2, 5, 6, 8, 9, and 10 on the task list (with an emphasis on items 5, 6, and 8). Members include Tim Grant, Chair, Grant Bromhal, Leonard Knee, Paul Kramer, and John Leeson.

The Legal Subcommittee is responsible for items 2, 3, and 10 (with an emphasis on item 3). In addition, the Group asked this subcommittee to consider issues related to liability. Members include David Flannery, Chair, Alan Dennis, Dave McMahon, Greg Wooten.

The three subcommittees met numerous times over the next several months in person and via phone conference. The full Working Group met on four more dates: December 9, 2009, February 3, 2010, April 21, 2010, and May 25, 2010. During the April meeting, the Group made an informal decision to form a Drafting Committee made up of the Chair of the Working Group and the three Subcommittee Chairs to facilitate merging the subcommittee reports into this Preliminary Report.

II.C. RESOURCES

As stated in the Foreword, the Working Group reviewed a substantial body of data and reports related to various aspects of Carbon Capture and Sequestration. This Preliminary Report incorporates or refers to data and information from a large number of sources including federal and state agencies, and non-governmental organizations. Some of this data and information may incomplete or inaccurate. The citation to these sources does not necessarily mean the Working Group agrees with the data, information, or opinions cited.

A webpage was created on the WVDEP's website to post these resources, minutes from the meetings, subcommittee reports, and presentations of various speakers. The link is http://www.dep.wv.gov/executive/Pages/ccsworkinggroup.aspx.

III. STATUS OF THE REGULATION OF GREENHOUSE GASES

Even in advance of Congressional activity related to CO_2 emissions, many legislative, regulatory and judicial activities are underway at the state and federal level which have as their objective reducing the amount of CO_2 emitted to the atmosphere.

In West Virginia, in addition to the passage in 2009 of Carbon Capture and Sequestration legislation, the West Virginia Legislature passed the Alternative Generation Portfolio Standard bill which sets targets for electric utilities to provide for a mix of traditional and alternative sources of electricity. This legislation creates not only incentives for renewable sources of energy, but also electricity generation using alternative methodologies, including CCS.

On June 3, 2010, the USEPA published the final version of its "Prevention of Significant Deterioration (PSD) and Title V Greenhouse Gas Tailoring Rule" (75 Fed. Reg. 31,514) which establishes greenhouse gas emission requirements for stationary sources subject to the federal Clean Air Act PSD and Title V programs. The Tailoring Rule is the last of several actions being taken by USEPA in response to the U.S. Supreme Court's 2007 decision in *Massachusetts v. EPA* that the USEPA must regulate GHG emissions under the federal Clean Air Act if the agency determined that such emissions endanger the public health or welfare.

Finalization of the endangerment finding in December, 2009, authorized the agency to promulgate GHG control regulations for all sources of emissions. (74 Fed. Reg. 66,496 Dec. 15, 2009). The promulgation of USEPA's Motor Vehicle Rule in May 2010 triggered an obligation for the agency to regulate stationary sources of GHG emissions under the PSD and Title V permitting programs. The USEPA promulgated the Tailoring Rule to avoid the "absurd consequences" the agency itself identified would result from subjecting stationary sources of GHGs to the existing parameters of those programs.

Finally, in April, 2010, USEPA established a phase-in schedule for stationary source GHG obligations under the PSD program. 75 Fed. Reg. 17,004 (April 2, 2010).

The USEPA's regulatory initiatives are the subject of multiple legal challenges that may require many months to resolve.

On May 28, 2010, the U.S. Court of Appeals for the Fifth Circuit dismissed a plaintiff's appeal of a district court decision in a climate change tort case (*Comer v. Murphy Oil*). The district court held that property owners did not have standing to sue for climate change related damages and that climate change was a "political question" that should be decided by Congress. The Fifth Circuit decision conflicts with a Second Circuit decision in *Connecticut v. AEP*, which overturned the lower court's decision and remanded that case for trial.

These and other climate change initiatives will undoubtedly continue to play out, even as the Working Group continues to address the issues related to CCS.

IV. SUBCOMMITTEE REPORTS

IV.A. FEASIBILITY SUBCOMMITTEE REPORTS

IV.A.1. Introduction

The decision as to whether individual West Virginians or other greenhouse gas generators in West Virginia will be required to reduce emissions of these materials is apparently, at this time, not something the Legislature will be able to control. The U.S. House of Representatives passed a comprehensive bill in June 2009 (American Clean Energy and Security Act of 2009) and work has been proceeding on Senate counterparts. In addition**,** USEPA is proceeding on the basis of a 2008 decision by the United States Supreme Court to promulgate regulations that would require the control of greenhouse gas active materials.

Internationally a number of nations have embarked on programs to require reductions in the emissions of greenhouse gases in response to the Kyoto Protocol and many nations, including the United States, are actively involved in programs to mandate additional greenhouse gas emissions.

With the understanding that reductions in greenhouse gas emissions will be imposed on West Virginia sources, the Feasibility Subcommittee ("FSC") provides discussions of the following issues to the Legislature for its consideration.

Using §22-11A-6.(h) as a guide, the FSC was assigned the task of developing information and discussion of all or part of the following subsections:

(1) Recommend appropriate methods to encourage the development of carbon dioxide sequestration technologies;

(2) Assess the economic and environmental feasibility of large, long-term carbon dioxide sequestration operations;
(4) Recommend methods of facilitating the widespread use of carbon dioxide sequestration technology throughout West Virginia;
(7) Assess the costs, benefits, risks and rewards of large- scale carbon dioxide sequestration projects in West Virginia;

The Feasibility Subcommittee discusses these issues in Section A.2. through A.7 as follows:

A.2. Background - The Magnitude of the Task
A.3. Is CCS Feasible for West Virginia?
A.4. Cost of Various Technologies and Estimating the Economic Impact of Implementing CCS in West Virginia.
A.5. Environmental and Health Related Factors.
A.6. Incentives for CCS Technology.
A.7. Conclusions and Recommendations Being Discussed for the Final Report.

IV.A.2. Background – The Magnitude of the Task

Due to the large amount of coal produced in West Virginia the state is able to provide all the electric power needed to meet its own needs and is the second largest provider of electric power for export to other states.[9] West Virginia also produces the majority of its electric power by burning coal,[10] a process that releases more greenhouse gas in the form of CO_2 than other commonly used methods of power generation.[11] In view of the relatively large amount of CO_2 produced in the state and the contribution of coal production and utilization to the economy, the West Virginia Legislature should be aware of the impact that requirements for significant reductions in CO_2 could have on the state.

It is very likely that sources in West Virginia will be faced with having to reduce CO_2 emissions over the next few years by significant amounts. Currently there is no method to make such reductions without either curtailing in-state generation or constructing new lower carbon or zero carbon power plants. However, the development of CCS technology could allow West Virginia to continue as a major coal producing and electrical power exporting state.

As of October 2009 West Virginia became the first place in the world in which a slipstream carbon capture and geological sequestration facility associated with a commercial coal-fired electric power plant has come into operation. A great deal of operational and technical knowledge is being gained from this new facility. The state now has the opportunity to take part in the development of the administrative and legal processes needed to make this technology a useful tool for addressing greenhouse gas reduction throughout the world. This section of the report discusses the magnitude of the challenge to reduce CO_2 from a state, national and international perspective.

As stated previously in this report, in all likelihood West Virginia, the United States and many other nations will be committing to some form of greenhouse gas reductions in the near

---

[9] West Virginia Energy Profile – USDOE EIA, retrieved 11/30/09.
http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=WV

[10] Ibid

[11] USDOE EIA Frequently Asked Questions – Environment, list of CO_2 emissions for various fuels per BTU.
http://tonto.eia.doe.gov/ask/environment_faqs.asp#CO2_quantity retrieved 11/30/09.

future. The West Virginia legislature can help set the course for the actions to be taken by the state to answer this challenge. The Legislators should be aware of two important factors in addressing these challenges. First these challenges will require significant changes to be accomplished within the state. Second, these challenges may present many opportunities for the state to use our natural, human and intellectual resources in a manner that benefits our citizens.

In the area of challenges, consider, for instance, the requirements that would be imposed on power generation in West Virginia by the American Clean Energy and Security Act of 2009(ACES)[12] which was passed by the U.S. House of Representatives in June of 2009. In essence, this act would require that total greenhouse gas emissions in the US from specified sectors of the economy should be reduced by 3% in 2013, 17% by 2020, 42 % by 2030 and 87% by 2050.[13] The base year for these percentage reductions is 2005, a year in which US Total GHG emissions were 7206 mmt CO_2 eq.[14]

To put these challenges in perspective, assume that West Virginia sources are required to reduce emissions by the percentages specified in the Act. As shown in the attached Table A.1, in 2007 West Virginia coal-fired power plants emitted approximately 85.6 million metric tons of CO_2 and in the base year of 2005 emissions from coal-fired electric production amounted to 84.1 mmt.[15]

Under the proposed ACES legislation, West Virginia sources would be required to reduce CO_2 emissions by approximately 2.52 mmt in 2012, 14.28 mmt in 2020 and 35.32 mmt by 2030. Note the allowance allocations available each year during the interims between these target dates also decline on a sliding scale (for instance in 2014 there would be a requirement for a 7.3% reduction from 2005 emissions).

On a national basis HR 2454 would limit emissions from certain sources to only 4,627 mmt in 2012, 5,056 mmt (from a broader list of sources) in 2020 and 3,533 mmt in 2010 from “capped sources” (which include coal-fired power plants).[16] Note that the allowed emissions allocations do not recognize any growth in electrical demand.[17]

---

[12] For a short discussion of ACES see article in Wikipedia at: http://en.wikipedia.org/wiki/American_Clean_Energy_and_Security_Act This article also reports acronym as ACES although some sources Quote as ACESA.

[13] American Clean Energy and Security Act of 2009 - HB 2454 (as placed on Senate Calendar) Title VII, Section 703.

[14] For the purpose of this discussion when talking about emissions of CO_2, the term “mmt” (million metric tonnes) will be used as opposed to emissions of all GHGs which are reported in terms of mmt CO_2eq (CO_2 equivalent includes the emissions of the other so-called Kyoto greenhouse gases reported as the product of their actual tons emitted and the gas’s global warming potential(GWP). Thus 1 ton of methane is reported as 21 tons of CO_2eq since the GWP for methane = 21). To confuse matters further, most listing of total emissions is now being reported internationally in terms of teragrams (Tg) of CO_2eq. A teragram is, however, equal to 1 million metric tons.

[15] USDOE EIA. State Historical Tables for 2008 Emissions by Energy Source, January 21, 2010 .http://www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls

[16] Note that the rise in allowances in 2020 is due to an increase in the types of sources that are to be considered to be in the capped category between 2012 and 2020.

[17] The Energy Information Agency projects that in years 2008 through 2035 electrical demand in the US will increase at a rate of about 1% / year. Coal generation capacity would increase by about 24 GW using the assumptions used in their analysis. EIA admits that economy and concern about GHG emissions could significantly change that projection. USEIA, “Annual Energy Outlook 2010,” Electrical Generation, December 2009. http://www.eia.doe.gov/oiaf/aeo/overview.html ,(Accessed 2/9/10)

TABLE A.1[18]

Some important numbers when considering emissions of Greenhouse Gases.

Electric Power Produced in US	4156 TWh[19] [20]
Electric Power Produced by Coal in US	2016 TWh[21]
World Production of Electric Power	18,778 TWh[22]
World non-Hydro Renewable Production	473 TWh[23]
West Virginia Coal-fired Electric Power	94 TWh[24]
West Virginia Renewable Power (Wind)	0.168 TWh[25]
Amount of CO_2 emitted in US Energy Production	5912 mmt[26]
Amount of CO_2 emitted by US coal-fired electric power	2155 mmt[27]
World Coal-fired Electric Production CO_2	12,496 mmt[28]
West Virginia Coal-fired Electric Power CO_2	85.6 mmt[29]
Total US GHG Emissions	7150 mmt CO_2eq[30]
Total World CO_2 Emissions (Anthropogenic)	29,914 mmt[31]

Options Available To West Virginia to Reduce CO_2 Emissions

While reductions in any listed greenhouse gas will count toward achieving the reductions required in the ACES proposal, the reductions most likely to occur in West Virginia will involve reductions in CO_2.[32] While technology is developing almost daily a number of facts should be

---

[18] All data in this table is based on calendar year 2007, unless otherwise noted.

[19] A terawatt hour (TWh) is the amount of electrical power meeting a demand of 1 trillion watts for one hour. 1 TWH equals 1 million megawatt hours or 1 billion kilowatt hours, all of these terms are commonly used to designate large quantities of electrical power. To put this measure into perspective, 1 TWh is the amount of electrical power that would be used by a 100 watt incandescent light bulb if it burned continuously for approximately 1.2 million years.

[20] USDOE EIA. Net Generation by Energy Source, May 14, 2010. http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html.

[21] Ibid.

[22] USDOE EIA. International Energy Statistics – Coal - Generation http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12

[23] Reference is listed as *Non-hydro* as hydro is not considered to be renewable in many definitions. USDOE EIA. International Energy Statistics – Generation - Renewables http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=34&aid=12&cid=&syid=2004&eyid=2008&unit=BKWH&products=34

[24] USDOE EIA. State Historical Tables for 2008 – Generation by Energy Source http://www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls

[25] Ibid

[26] Includes all energy production, electric generation, transportation, etc. USDOE EIA. Emissions of Greenhouse Gases Report – 2008, December 3, 2009. Table 5 Emissions of Carbon Dioxide for Energy and Industry. http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html#total

[27] Ibid.

[28] USDOE EIA. International Energy Statistics - Coal –Generation – CO_2 Emissions http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=90&pid=44&aid=8&cid=&syid=2003&eyid=2007&unit=MMTCD&products=1

[29] USDOE EIA. State Historical Tables for 2008 Emissions by Energy Source, January 21, 2010 http://www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls

[30] USEPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007 Executive Summary p. 6, April, 2009.SDOE EIA. http://www.epa.gov/climatechange/emissions/downloads09/ExecutiveSummary.pdf

[31] Note this is only for burning of fossil fuels, other GHGs not included. See: USDOE EIA. H.1co2 World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels, 1980-2006 http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls

[32] The West Virginia 2005 baseload value represents the best estimate of total GHG emissions according to the Energy Information Agency. ACES does not specify the actual 2005 emissions to be used in determining individual compliance limits, only the national total of 7206 mmt. While demonstrated reductions in other GHG gases would yield larger reduction credit than CO_2 (e.g. 1 ton methane reduction = 21 tons CO_2 reduction) a discussion of CCS

borne in mind when looking at the options available to West Virginia CO_2 sources to achieve the reductions envisioned in this proposal.

Assuming there is some required reduction based on the timetable in the ACES proposal:

- In 2012 there is no technology currently forecast to be commercially available to actually remove CO_2 from the emission stream of coal-fired power plants.
- If ACES is able to move through the legislative process with most of its current language intact, there will be opportunity for much of the early compliance to be met by the use of offsets, which would allow West Virginia coal-fired sources to continue to operate.[33]
- West Virginia utilities could back off in-state generation and either build zero carbon generation or purchase such generation from others (including out of state sources).[34]
- West Virginia could reduce electrical demand by the percentages listed in ACES but would also have to increase the amount of reduction to account for any growth in demand.
- With each year seeing increasing requirements for reductions at some point actual reductions in the emissions of CO_2 from West Virginia sources would have to be accomplished.

What Carbon Capture and Sequestration Means

Carbon capture and storage is a technology that would remove carbon in the form of CO_2 from the emission stream of a power plant and store the removed material in a manner that would prevent it from entering the atmosphere. Methods being investigated for carbon capture have looked at either biological processes, using some form of living organisms that utilize CO_2 as a carbon source, or chemical processes which use a chemical reaction that absorbs or incorporates $CO_{2.}$

It is possible to design bioreactors that use living organisms to synthesize molecules that can be further processed into carbon-based fuel which can replace fossil based fuel. An example of such a process would use CO_2 captured from a power plant emission stream to enhance production of specific types of algae. The algae could then be processed into material that could be substituted for fossil fuel. The net effect would be a reduction in CO_2 emission.

Another possible biological sequestration strategy involves the uptake and long-term storage of carbon in biomass such as trees. This postpones the release of greenhouse- active materials to a point in the future. This type of storage requires some guarantee that the biomass is not handled in manner that would rapidly re-introduce the captured $CO_{2.}$[35]

---

involves only CO_2 as this technology has not been proposed for other GHGs. If other deductions are shown to be feasible the impact of such deductions would proportionally lessen needed lowering of CO_2 quantities.

[33] ACES Title VII, Part D – OFFSETS

[34] For instance using WV's total 2007 production of 94 TWh and emissions of 85.6 mmt (see Table A.1) gives a state average of 0.91 mmt/MWh. With a reduction of 2.52 mmt needed for 2012, state utilities would have to reduce output by 2.77 TWh in 2012 and 15.70 TWh in 2020. It appears that WV would have to increase renewable generation by a significant amount (see Table A.1) to provide in-state generation to replace idled coal power.

[35] See for instance WORKING PAPER ON CARBON SEQUESTRATION SCIENCE

In general, chemical capture processes have come to focus on the geological storage of the captured material. In this process, captured CO_2 in a supercritical or dense phase is pumped underground to reside in a geological stratum that has been demonstrated to have the capacity to hold the material for very long time periods (thousands to millions of years).[36]

Biological capture and storage is a developing field of scientific interest. The Working Group feels that for this method of achieving greenhouse gas reduction any requirements the state may have to meet should not be ignored. The Group would encourage the state to support such research and development. However, the Working Group interprets the focus of §22-11A to be centered on the geologic sequestration of CO_2.[37] This report will therefore concentrate on techniques involving the capture of CO_2 from power plant emissions and the geologic storage of the captured CO_2.

Is There a Need For CCS?

Many references have stated that the development of CCS technology is critical to achieving the goal of reducing the emissions and atmospheric concentration of greenhouse gases. For instance in expressing disappointment with a decision by the Mississippi Public Service Commission to severely restrict funding for Southern Company's proposed IGCC plant with CCS, the position of Secretary of the Department of Energy, Stephen Chu, was described in Energy Daily as follows:

> "The energy secretary said the nation has to build large-scale CCS projects that will allow the continued use of coal in a carbon-constrained regulatory environment. 'Nothing ranks as high as CCS . . . among the tools that could be used to decrease carbon emissions,' Chu said. He acknowledged that that CCS projects are 'very costly and expensive,' but added: 'I think we have to push ahead.'"[38]

A look at the magnitude of CO_2 emissions listed in Table A.1 gives some idea of the amount of CO_2 that is emitted from electrical production on a worldwide, national and West Virginia basis. West Virginia coal-fired plants emitted 85.6 mmt of CO_2 in 2007 and, according to the timetable in ACES, would have to reduce that to roughly 50 mmt by 2030. The nation would have to reduce CO_2 from coal-fired plants by at least 908 mmt in that time frame. If the world were to try to meet the same reduction schedule, world coal-fired power would have to reduce emissions by another 4,800 mmt from current coal emission rates. Worldwide it is estimated that by 2030 overall coal use will increase to a level approximately 1.6 times the amount used in 2004. [39]

AND TECHNOLOGY, Office of Science, Office of Fossil Energy, U.S. Department of Energy, February 1999, available at: http://www.netl.doe.gov/publications/press/1999/seqrpt.pdf for an extensive discussion of the whole issue of biological sequestration.

[36] There are a lot of documents available dealing with geological sequestration. One of the most comprehensive references that is often quoted is IPCC Special Report on Carbon Dioxide Capture and Storage, Bert Metz, et al, Prepared by Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2005

[37] §22-11A-1(12) states that development of carbon dioxide capture and sequestration technologies is in the public interest. §22-11A-2(b) then defines Carbon dioxide sequestration as "…the injection of carbon dioxide and associated constituents into subsurface geologic formations intended to prevent its release into the atmosphere."

[38] Energy Daily "Chu Urges Mississippi Regulators. Southern Co. To Reach IGCC Deal." Friday, May 7, 2010 ED Vol. 38, No. 86 p. 4

[39] World Energy Council, "2007 Survey of Energy Resources" p. 2. The council projects that coal use would increase from 2772 mtoe in 2004 to 4441 mtoe in 2030. (mtoe = million tonnes of oil equivalent). http://www.worldenergy.org/documents/ser2007_final_online_version_1.pdf

In any discussion of world emissions, China is often of peak interest due to the fact the country exhibits the most significant emissions growth of any country in the world. In 2006 alone China increased its electric generation capacity by 74,660 MW.[40] While some of this capacity may be attributed to the installation of generators at the Three Gorges hydroelectric project, a significant amount likely involved coal-fired generation.[41] In fact between 2000 and 2006, China increased its generation capacity by about 72%.[42]

With so much coal-fired generation capacity currently installed and much of this capacity still brand new, especially in developing nations, much of the physical plant devoted to coal-fired power generation is likely to continue in service. Generally newly constructed power plants are expected to operate for 30 to 50 years. In an era in which reduction of CO_2 emissions is seen as critical, CCS provides a method to preserve this critical infrastructure and still make progress toward reducing greenhouse gas emission. The World Resources Institute states in the Executive Summary to its Guideline for Carbon Dioxide Capture, Transport, and Storage:

> "CCS is a critical option in the portfolio of solutions available to combat climate change, because it allows for significant reductions in CO_2 emissions from fossil-based systems, enabling it to be used as a bridge to a sustainable energy future."[43]

Is CCS the *"Only"* Solution to Climate Change?

The West Virginia Legislature must be clear on one very important point about CCS. No one who has a firm understanding of the challenges facing us in trying to find a solution to reconciling the world's energy needs with the desire to reduce atmospheric concentrations of greenhouse gases is proposing that CCS is the "only" solution to climate change. CCS is a method that if effectively demonstrated and widely deployed could have dramatic and potentially permanent impact on the emissions of CO_2 from large stationary sources. But with coal-fired electric production accounting for roughly 42% of world anthropogenic CO_2 emissions (see Table 1), even a total and immediate cessation of all coal-fired electric production (a totally impossible occurrence) would fall short of the 50% reduction by 2050 in human emissions identified as a combined US/European Union goal in the November 3, 2009 EU/US Summit meeting in Washington DC.[44]

Nor is CCS the least expensive of the many options identified for the reduction of greenhouse gas emissions.[45] For instance, The McKinsey Report proposes that on a per ton basis, CCS is not the least expensive method of reducing GHG emissions by a very large margin. However in looking at the amount of greenhouse gas reduction being proposed by many authorities, some will conclude that even with the employment of all the easier and less

---

[40] USDOE EIA. 6.4 World Total Electricity Installed Capacity, January 1, 1980 - January 1, 2006 http://www.eia.doe.gov/pub/international/iealf/table64.xls

[41] As an example of the magnitude of such a construction schedule, the Appalachian Power Kanawha River Plant near Glasgow in Kanawha County has two 200MW units and is considered to be a major US generation facility. In 2006 China built plants at a rate that would be equal to bringing one of the Kanawha River generating units on line every single day for the entire year. During the same year US generating capacity increased by a total of 8,081 MW or roughly 11% of the Chinese capacity added in that year.

[42] USDOE EIA. 6.4 World Total Electricity Installed Capacity, January 1, 1980 - January 1, 2006 http://www.eia.doe.gov/pub/international/iealf/table64.xls

[43] World Resource Institute, Guidelines for Carbon Dioxide Capture, Transport, and Storage, 2008, p.8

[44] 2009 EU – US Summit Declaration, accessed 11/25/09, available at: http://ec.europa.eu/external_relations/us/sum11_09/docs/declaration_en.pdf

[45] See for instance McKinsey&Company Reducing U. S. Greenhouse Gas Emissions: How Much at What Cost, December 2007, Executive Summary, U.S Mid-Range Abatement Curve 2030 p. xiii.

expensive methods of reduction there will still be a pressing need for even some of the most expensive technologies.

Wedge Stabilization Analysis

To understand the magnitude of this effort, the Legislature needs to look at the multiple factors involved in a total remake of the electric power system in the state, in the nation and in the world. In an article in the journal *Science* in August 2004, S. Pacala and R. Socolow of Princeton University proposed the now-famous Stabilization Wedges process of looking at how current technology could address the challenge of climate change.[46] The authors looked first at the levels of rising emissions over the last 50 years. They then projected what the atmospheric concentration would be in the 2050s assuming the same rate of increase as the historical data. Using the result they had calculated, they postulated the employment of existing technologies that would be needed to reach a concentration in 2050 that did not exceed the level reached in 2004. In other words their proposal would not reduce emissions from current levels but only recreate the emissions level that existed in 2005.

The analysis shows that by 2050 the technologies employed would have to result in a total worldwide reduction of 8 billions tons per year of CO_2eq. The authors then assigned to each of 8 specific strategies an annual reduction goal of 1 billion tons each. On a graph each of these goals develops into a wedge shaped figure that starts representing a small deployment of the technology which reaches 1 billion tons in 2050 as the technology is more widely adopted (Figure A.1) The basic idea is to achieve a lifestyle for all the world's inhabitants that approaches that common in the western world and still meet the projected greenhouse gas emissions goals.

Over the roughly 50 years of the process each wedge represents a total reduction equal to 25 billion tons. Different technologies are then analyzed to determine what level of deployment of the technology would be needed to achieve one wedge. For instance replacing every single incandescent light bulb in the entire world with CFLs would yield ¼ of one wedge. For CCS to achieve a single wedge it would have to be installed at 800,000 MW of coal-fired power plants. Currently this would equal the total number of coal plants in the US plus almost all the generation capacity of China (regardless of power source). The authors note that at the time of the report there were three projects in the world (all were natural gas treatment projects) injecting 1 mmt/year each. By 2055 there would have to be 3500 such projects to achieve one wedge.

Other technologies that would equal one wedge:

- Efficiency – Double the fuel efficiency of every automobile on earth or reduce the total numbers of miles driven by ½.
- Efficiency – Double the efficiency of all plants producing electrical power but keep electrical demand at its current level.
- Fuel Switching – (Note CCS is included in this category) Replace 1400 coal-fired power plants by an equal number of natural gas plants.
- Renewables – Replace an equivalent capacity of coal-fired plants by 1 million wind turbines each with a capacity of 2 MW.

---

[46] Pacala, Stephen W., and Robert H. Socolow, 2004: *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*. *Science*, **305**, doi:10.1126/science.1100103 968-972

- Renewables – Replace an equivalent capacity of coal-fired plants with 20,000 square kilometers of solar panels. [47]

This analysis lists 15 different technologies that the authors consider to be currently available and notes that no technology would have to necessarily supply an entire wedge on its own for the program to achieve its goals. Any combination of methods contributing either parts of or multiple wedges could be employed to achieve the stabilization desired. It should be noted again that this analysis would not achieve an emission reduction below the 2005 baseline. It would only preserve the emissions status quo of the base year.

Figure A.1
Error! Objects cannot be created from editing field codes.

Note: Figure 1.A is a slide from *Wedges PowerPoint Presentation: Carbon Mitigation Project. For access information see Footnote 47.*

The Wedge Stabilization discussion illustrates the important point that any reduction scheme is going to have to utilize multiple tools. But all reduction strategies have to take into account the growing electrical demand in a world where over 1.6 billion people still have no access to electrical power.[48]

CCS is not a perfect solution to concerns over climate change. There is no single solution currently known and the world is going to have to embark on many new paths in an attempt to stabilize greenhouse active emissions.

West Virginia is already in the lead by virtue of its having the first coal-fired power plant CCS project in the world operating in Mason County. A project such as this, along with others being planned and developed around the world, may be able to demonstrate that CCS can have an immediate and lasting impact on atmospheric carbon content. The state is in the position to learn much about how such a project actually will work. The opportunity to help develop the administrative processes, laws and regulations that will be a model for others to follow can be in the hands of the West Virginia Legislature.

IV.A.3. Is CCS Feasible for West Virginia?

With the acknowledgement that there is a significant probability that CCS is likely to be one of the methods needed to achieve the greenhouse gas reduction goals the world and the nation are likely to set, the questions to be considered by West Virginia may be summarized as follows:

1. What factors need to be considered in determining if CCS is feasible and beneficial for West Virginia?
Question 1 is addressed in this section and Section.A.4

2. What factors need to be addressed to be able to assure the citizens of West Virginia that CCS is safe in terms of human health and the environment?
Question 2 is addressed in Section.A.5.

---

[47] To learn more about Wedge Stabilization see the web page at: http://cmi.princeton.edu/wedges/
for a quick PowerPoint see: http://cmi.princeton.edu/wedges/Wedges_slides_8.ppt#12

[48] USDOE EIA. International Energy Outlook 2009, Chapter 5 – Electricity, May 27, 2009
http://www.eia.doe.gov/oiaf/ieo/electricity.html, accessed 12/1/09.

3. What are the technical issues (both engineering and geological) that must be addressed to ensure the efficacy of CCS in West Virginia?
Question 3 is addressed in Section IV.B

4. What legal and liability issues need to be decided before CCS can be pursued in West Virginia? And finally,
Question 4 is addressed in Section IV.C

5. If the Legislature were to decide that CCS would be beneficial to West Virginia, what actions should be undertaken by the Legislature and the State Administration to ensure the realization of these benefits for the citizens of the state?

Other aspects will be part of the Working Group's efforts over the next year.

The Working Group suggests that the following factors will have to be considered by the West Virginia Legislature before an informed decision can be made.

- Will West Virginia have a need for CCS?
- If so, when will that need become a reality?
- What is currently available to meet such a need using CCS?
- Are there alternatives to CCS for meeting those needs?
- What are the projected costs and benefits to West Virginia and how do these compare with the costs and benefits of alternatives?

Looking at these factors individually the Working Group offers the following discussion.

Will West Virginia have a need for CCS?

Earlier in this report there was a discussion of the probability for CO_2 emission reductions in the near future. West Virginia currently has 14,715 MW of coal-fired power plants and approximately 39 utility-owned coal-fired generating units.[49] Table A.1 shows that in 2007, West Virginia coal-fired generation emitted 85.6 mmt of CO_2eq. West Virginia could choose to meet upcoming GHG reduction goals by simply backing off generation. As the state is a net exporter of electrical power this could be done without reducing in-state electrical power usage. However, before choosing this option the state would want to further examine the economic impact of such an action. As stated previously in this report, CCS could provide a method whereby existing coal-fired generation could continue at the same or even increased levels.

From a national perspective, as of 2005 there were approximately 1470 coal-fired generating units in the United States representing 313,380 MW of capacity.[50] A simple proportional reduction could mean that 53,275 MW of this total would have to achieve 100% reduction in CO_2 emissions by 2020 to meet the 17% reduction goal listed in ACES. While there may be other methods of achieving compliance with the requirements outlined in ACES,[51] at some point a significant portion of the 313,380 MW of coal-fired power will either have to be retrofitted with CCS or retired. In addition, as shown in Table A.1, there is considerable coal-fired generation world wide, In many countries, especially in developing nations, the often

---

[49] USDOE EIA. Generating Units - http://www.eia.doe.gov/cneaf/electricity/page/capacity/existingunits2005.xls
Total MW - http://www.eia.doe.gov/cneaf/electricity/st_profiles/sept04wv.xls

[50] USDOE EIA. Electric Power Industry 2008: Year in Review, Table 1.1. Existing Net Summer Capacity by Energy Source and Producer Type, 1997 through 2008 http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile1_1.pdf

[51] For instance carbon offsets, energy efficiency measures, energy conservation practices and repowering with lower or zero carbon emitting resources.

readily available coal may still be the most economic option for these countries to provide the standard of living that they have not yet been able to achieve. It is possible that many of these nations will choose to continue to build new coal-fired generation and will not have the ability to develop low carbon technology to do so. CCS technology, developed in West Virginia and other US states could be shared with some of these nations in a manner to lower world-wide emissions.

It may not be possible to say that the development of CCS in West Virginia is absolutely essential. However, the challenges discussed above demonstrate that CCS could be an integral part of achieving the goal of greenhouse gas reduction pending a satisfactory resolution of issues such as listed in questions 2 through 4 above.

When will a need for CCS become a reality?

There are a number of unknowns in answering this type of question. The first is the prospect for the establishment of binding legislative or regulatory action mandating some form of reduction in greenhouse gas emissions. The second is the actual form that such reduction requirements will take and what other methods may be allowed to enable emitting sources to develop technical and administrative processes needed to achieve reductions.

Regarding legally binding requirements ACES has now been joined by the American Power Act (also called the Kerry – Lieberman bill) which is the Senate version of ACES. There are many similarities between the bills both of which follow a cap and trade program for greenhouse gases. There are many different projections regarding the possible approval of the bill in the US Senate, but should it pass, there would need to be a conference version agreed to by both houses. The timing of such a consensus between the two houses is unknown at this time.

The USEPA, on May 14, 2010, released its “Tailoring Rule” which sets a roadmap of how the Agency will handle air quality permitting for stationary sources of greenhouse gases in the wake of its endangerment declaration. This declaration issued on December 7, 2009 states that the emission of greenhouse gases in the United States constitutes an endangerment to public health and welfare. As of January 2, 2011 power plants (and other sources) emitting greenhouse gases will have to consider these emissions in any decisions made regarding their impacts on air quality.

There are currently conflicts between the programs that would be set up under the congressional action and those established under the USEPA actions, but under either approach the emissions of greenhouse gases, including $CO_{2,}$ will be controlled to some extent in the near future.

The actual form of whatever regulatory or legislative requirements are chosen for GHG emission control will have a very large impact on the timing for the need for CCS. For example in the proposed ACES there is an allowance for a phase-in for CO_2 reduction from coal-fired power plants as such sources could use emission offsets in the early years. In such a case the need for CCS could be postponed until the post-2020 period.

However if reductions are called for too early or are too stringent to be compatible with the technical, administrative and economic demands of CCS, coal-fired generation may be precluded from using CCS. Utility generators may then be forced into investment in lower carbon natural gas generation (with a CO_2 emission approximately ½ of that emitted by coal) in the years before CCS is ready.[52] In this situation, a market for coal-fired CCS may not ever exist. A need to shift to natural gas generation in the next ten years could also tend to lock in generators to using gas for a period long enough to allow the recovery of the cost associated with the investment Natural Gas CCS is, of course, an option although the technology is currently not being developed. In determining whether CCS is indeed in the best interest of the state, the Legislature may have to decide whether coal or natural gas generation of electrical power allows the best future for the state of West Virginia.

Such a situation could be encountered in some legislative actions or if the USEPA must proceed with regulatory controls under existing Clean Air Act requirements. If the USEPA carries through with its proposed regulation of CO_2 some have argued that the Agency could have to set limits in a manner that may force utilities into programs that would take effect in ways the Agency may not have considered.[53] If the USEPA must develop restrictions that impose large reductions before CCS is commercially available this may cause CCS to become less attractive and accelerate any move away from coal as a power source.

The best atmosphere for the use of CCS and for the continued ability for the nation to be able to use coal as an energy source, would be one in which significant reductions in CO_2 emissions would not be required until the demands noted above have time to be resolved. Estimates of when CCS will become commercially available (i.e. technically developed and economically feasible) vary depending on who is making the projection. In general, it is anticipated that this is most likely to happen in the 2020 -2030 time period.[54]

What is currently available to meet such a need

There are currently a number of technologies that are being considered for providing efficient, commercially available CCS at the lowest possible cost. Any currently considered methods (none of which are commercially available) tend to be energy intensive and thus very expensive. Some proposed methods of carbon capture would require a different from of boiler technology while others would involve extensive boiler retrofit. The Working Group will postpone analysis of the available technologies until the final July 2011 report.

However, it should be noted that various businesses operating in West Virginia are already taking a leading role in investigating and developing CCS.

- The AEP/APCo Mountaineer Plant CCS Process Validation Project is the first project in the world in which an actual 20 MW slipstream from the emissions of a coal fired power plant is subjected to a carbon dioxide capture process with the captured material sequestered in a geological strata

---

[52] For example, Calpine Corporation in a presentation discussing its new Russell City Energy Center cited its proposed permit limit for CO_2 of 1100 lbs/MWh but referenced reports of NGCC plants achieving results of 800 lbs/MWh. A coal plant, usually emitting 2000 lbs/MWh, would emit <800lbs/MWh with a removal efficiency of 60%. Calpine Corporation. GHG BACT Analysis Case Study. Presentation to EPA Climate Change Work Group, November 19, 2009 (as updated February 3, 2010). Slides 8-9. http://www.epa.gov/air/caaac/climate/2010_02_GHGBACTCalpine.pdf (Accessed February 10, 2010)

[53] See, for instance, Greenhouse Gas Regulation under the Clean Air Act Does Chevron *Set the EPA Free?* December 2009 Resources For the Future. Available at: http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=20964

[54] See for instance "Facts and Trends: Carbon Capture and Storage (CCS)" World Business Council on Sustainable Development, October 2006 which in 2006 predicted a 20 year time frame or "Future of Coal," Testimony before the Committee on Energy and Natural Resources, United States Senate by Bryan Hannegan, Vice President, Environment, Electric Power Research Institute, March 22, 2007 who stated that to achieve the goals being discussed in upcoming legislative efforts all new plants would need CCS after 2020.

approximately 8000 feet below surface grade at the plant. The project has been actively operating since October 1, 2009 and is successfully capturing and sequestering CO_2. The capture technology being demonstrated in this project is the chilled ammonia process developed by Alstom, an international company that designs, manufactures and supplies products and systems for power generation.

- AEP and APCo are also performing the preliminary work on developing the first commercial scale CCS project in coordination with a grant from USDOE. The 235 MW project will also capture and sequester carbon dioxide from a portion of the emissions from the Mountaineer 1300 MW generating unit using the Alstom chilled ammonia process.

  The project is being undertaken in conjunction with a diverse technical advisory committee that includes recognized experts in the field of geologic carbon dioxide storage. This group will include participants from Schlumberger Limited, Battelle, Lawrence Livermore National Laboratory, Massachusetts Institute of Technology, The Ohio State University, West Virginia University, The University of Texas, West Virginia Geological Survey, Ohio Geological Survey, CONSOL Energy and the West Virginia Department of Commerce Division of Energy. Additionally, Battelle and Schlumberger will work directly with AEP to design and deploy the carbon dioxide storage system.
- Alstom and Dow CO_2 Capture Pilot Plant **-** On September 10, 2009, The Dow Chemical Company (Dow) and Alstom dedicated a carbon dioxide (CO_2) capture pilot plant at the South Charleston facility. In 2008, the two companies entered into a Joint Development Agreement to develop this technology, and in March 2009 announced plans to design and construct the pilot plant.

  This pilot plant will capture CO_2 from the flue gas of a coal-fired boiler at the South Charleston plant. The pilot plant will use proprietary advanced-amine technology to capture approximately 1,800 metric tons of CO_2 per year. The pilot plant will operate for two years, generating and collecting data that can be used to optimize and implement this technology at coal-fired power plants worldwide. This new process will significantly reduce the amount of energy required for CO_2 separation and capture.

  The Alstom pilot plant is running well. The process in on-line daily, recovering CO_2 from the Dow coal-fired boiler flue gas. Data from the plant is being used for R&D purposes and process information for future pilot scale and full-scale carbon capture projects throughout the world. Tests include long-term chemical degradation, carbon capture efficiency, energy efficiency, analytical methods, operating procedures and control strategies. Current test plans project operation into 2011.[55]
- CONSOL Energy, with partial funding from the U.S. Department of Energy and in collaboration with West Virginia University, began injecting CO_2 into an “unmineable” coal seam in Marshall County, West Virginia, in September 2009 to simultaneously sequester the CO_2 and to enhance the projection of coalbed methane. The WVDEP issued a Class II Underground

---

[55] Amos, J. , Dow Environmental Manager – Personal communication, June 1, 2010.

> Injection Control permit for the project. The team expects to inject up to 20,000 tons of CO_2 over the course of two or more years and to continue to monitor the site for up to two additional years.[56]

Are there alternatives to CCS for meeting those needs?

Using ACES as a surrogate for predicting future reduction requirements and the 2005 base emission rate from West Virginia sources of 84.1 mmt, electric generation sources in West Virginia would have to reduce emissions to 83 mmt CO_2eq in 2012, 71 mmt by 2020, 50 mmt by 2030 and 15 mmt by 2050.[57] Such reductions in emissions cannot be achieved without either a technology to remove and permanently store CO_2 from power plant emissions or a significant reduction in coal use for electric generation.

Natural Gas

One suggestion, a large shift to natural gas generation, would perhaps postpone the need to capture and store CO_2 but as stated above natural gas still emits roughly one half the CO_2 that results from coal-fired generation. Emission reductions outlined in either ACES or the American Power Act would require further controls in the post 2020 period.

Nuclear Power

More reliance on nuclear power could be an alternative to CCS. Nuclear power is widely used in Europe and throughout the US. Despite fears about its safety, it has the best safety record of any fuel for electric generation. There are currently 26 applications for nuclear power plants in the US pending before the NRC.[58] West Virginia, however, has not pursued such options in the past. Conceivably, this is an option that the state could pursue. However, if this course were to be pursued, the Legislature may have to revisit the apparent barrier to the employment of nuclear power in articles §16-27A-1 and §16-27A-2 of the state code, which require that a nuclear power plant must be economically feasible and that a permanent national repository for nuclear waste disposal has been proven safe and functional.

Hydro Generation

West Virginia does have access to significant water resources, a factor that has contributed to the ability of the state to utilize its coal supplies to export electrical power. Hydropower could be further developed in the state. West Virginia has areas with significant elevation change across the state that could allow the exploitation of the stored energy located in upland areas. While the construction of dams for energy generation is not favorably considered under current public sentiment, in an era of changing energy options and increasing CO_2 concerns, the state may be able to further investigate hydropower. In addition, small scale hydro which does not involve building dams is a promising use of West Virginia's water resources. While the contribution will be small and not a major offset to coal production for dispersed use it should be considered an option.

Wind

Wind power is becoming an important state resource. West Virginia is already one of the leading states for commercial wind development in the eastern US and other sites are under

---

[56] Winschel, R. A., Director of Research Services, CONSOL Energy, Inc. Personal Communication, June 7, 2010.

[57] Based on % reductions listed in ACES Title VII section 702 and base 2005 emission from all generating sources of 85,649,741mmt from US Energy Information Agency, State Historical Emissions Tables for 2008, line 21929. http://www.eia.doe.gov/cneaf/electricity/epa/emission_state.xls retrieved January 22, 2010.

[58] Deutch, J et. al. *Update of the MIT 2003 future of Nuclear Power,* Massachusetts Institute of Technology, Cambridge MA

construction and in the planning stage. As of the date of this report, West Virginia has 330 MW of wind capacity producing commercial electrical power.[59] This makes West Virginia the state with the 5th largest installed capacity east of the Mississippi River.[60] Wind power may be becoming more difficult to build as public opposition is often seen to utility scale plants. Major wind resources in West Virginia appear to be located on the eastern ridge lines, an area that many feel needs to be protected. Utilization of commercial wind development is also extremely reliant on the availability of adequate transmission capacity. West Virginia may not have sufficient wind capacity to ever become self sufficient in electrical production using wind alone, but appropriate utilization of the state's wind resource could be an important aspect of a diversified energy portfolio.

Biomass

Biomass co-firing and wood-fired power generation are two other sources of base-load electricity that could be produced in West Virginia. Based on physical quantities, wood residue available in the State could support several power plants of up to about 50 MW. However, the variability of transport costs due to the fuel's locations relative to a plant site could restrict plant size. A single such 50 MW plant operating at an 80 to 90 percent capacity factor would provide less than half a percent of electricity currently generated in the State. The relative capital cost of such a plant is competitive and production tax credits could apply depending on how associated forestry management contributes to carbon levels.

Biomass produced to be co-fired with coal could play a larger role but is not widely developed. Switchgrass or some other energy crop, as well as wood residue, can be compressed into bricks or pellets that on a ton-per-ton basis contain an energy value comparable to Powder River Basin coal.[61] Trial switchgrass crops on former surface-mined lands in West Virginia are presently being evaluated for yield. Generally, pilot scale tests co-firing no more than 20% biomass with 80% coal have been assessed.[62] Overall, biomass represents a modest and underutilized energy resource that if it became available could theoretically, employing the mix cited in these pilot studies supply up to 20 percent of energy inputs for base-load power generation. This would, of course, depend heavily on the supply of low cost biomass within an economically viable distance from the power plant.

Solar

It is sometimes assumed that West Virginia has limited potential for solar electricity due to low insolation. However, Germany, whose population is about 50 times that of West Virginia, currently obtains about one percent of its electricity from solar. Insolation should be greater in West Virginia than in Germany, since our state lies roughly 12 degrees further south. Much of Germany's solar capacity has been installed since its Feed-In Tariff (FIT) law was restructured in 2000. Additional incentives for solar installation could be considered in West Virginia.[63]

It should be noted that the city of Nitro has received monies from the the USEPA to conduct, in partnership with the West Virginia Brownfields Assistance Center, "a one year study to collect critical solar data to evaluate the potential for solar power development at the commercial, community and local business scale by using some of the over 800 acres of former

---

[59] American Wind Energy Association, West Virginia Profile http://www.awea.org/projects/Projects.aspx?s=West+Virginia , retrieved 1/26/10

[60] American Wind Energy Association, Summary map of state wind capacity. http://www.awea.org/projects/ retrieved 1/28/10.

[61] Presentation by Mid-West Biofuels on October 28, 2009.

[62] http://www.eesi.org/files/cofiring_factsheet_030409.pdf

[63] http://www.worldwatch.org/node/5449#notes

industrial properties. Data collected will be compared to existing NREL (Department of Energy's National Renewable Energy Lab) information on solar generation potential, as well as provide valuable clean energy information for the Nitro community and surrounding areas."[64]

Energy Efficiency

In its *2009 State Energy Efficiency Scorecard*[65], the American Council for an Energy Efficient Economy ranked West Virginia at 45 and included it among the states that "most need to improve." Based on studies of this type some may conclude that enhanced energy efficiency programs would dramatically reduce the need for CCS retrofits, would be less expensive, and would involve none of the environmental and legal issues associated with CCS. Discussions regarding energy efficiency will continue in the Feasibility Subcommittee.

Maryland and Ohio both mandate that utilities have plans to reduce consumer demand by 15 % by 2015. Through energy efficiency programs, West Virginia could meet a significant portion of its greenhouse gas reduction requirements and save money for consumers in the process. . According to the American Council for an Energy Efficient Economy, implementation of the energy efficiency provisions in the ACES Act could result in creation of 2700 jobs annually in West Virginia, save consumers $521/year (2007 $/household), and lower CO_2 emissions by 6 mmt.[66] An energy efficiency bill has been introduced in the West Virginia legislature in 2009 and 2010 (HB 4012 for 2010). In the 2009 session, the West Virginia Legislature recognized the importance of energy efficiency measures by including "*energy efficiency technologies*" as methods to be used for compliance with the state's goals as established in the West Virginia Alternative and Renewable Energy Portfolio Standard Act.

CO_2 Transport

Another potential alternative to CCS would involve the participation by West Virginia in some of the various projects currently being proposed involving the transport of captured CO_2 to places where it may be considered to be a valuable commodity. CO_2 can be effectively utilized and potentially geologically stored in enhanced oil and gas recovery operations. There are many areas of the United States with recoverable oil and gas reserves that can not be economically produced with other methods. Many of these reserves still possess significant reserves but are not being worked due to a lack of useable $CO_{2.}$

In addition almost any commercial scale CCS project would require multiple injection sites, some of which may be located at areas some distance from the point of generation of the CO_2. This could involve the construction of intrastate and potentially even interstate pipelines. There are technical, legal, administrative and public safety issues involved that West Virginia may need to address. The Working Group is looking at further development of this subject for the final report in July 2011.

What are the projected costs to West Virginia?

In any assessment of the cost of deploying CCS in the state there are a number of areas that must be addressed to answer the question. First is the actual economic cost of installing and operating CCS feasible for facilities operating in the state. Second what impact would the installation of such technology have on the overall economy of West Virginia. And third what

---

[64] http://www.epa.gov/reg3hscd/bf-lr/newsletter/2009-Fall/repower.html

[65] http://aceee.org/pubs/e097.pdf?CFID=1338466&CFTOKEN=56457960

[66] Gold, R., L. Furrey, S. Nadel, J. Laitner, and R. N. Elliott, 2009. Energy Efficiency in the American Clean Energy and Security Act of 2009: Impacts of Current Provisions and Opportunities to Enhance the Legislation. American Council for an Energy-Efficient Economy, Report E096.

are the potential impacts on the safety and health of the people of West Virginia and the overall environmental integrity of the state. These areas are addressed in the next two sections of this report.

Question 1: What factors need to be considered in determining if CCS is feasible and beneficial for West Virginia?

IV.A.4. Cost Comparisons of Various Technologies

How expensive is the installation of possible technologies expected to be and is such an expenditure in the best interest of the state? A literature-based study was performed in an attempt to estimate some of the cost associated with constructing and operating a CCS facility and how these costs may compare with other low-carbon alternatives.

It should be noted that the costs included in this section should be considered as a comparison type analysis and should be viewed as representing the result of a specific set of assumptions which may vary over time. The Subcommittee would like to caution those reading this report that even comparative rankings listed herein may change as conditions evolve. As discussed earlier (see page 20) CCS may not be the least expensive of a number of different means of achieving some of the goals associated with a desire to reduce carbon dioxide emissions. The Feasibility Subcommittee will continue to evaluate the need for CCS to be part of the State's efforts to achieve these goals. The Legislature will have to decide which of the proposed means of achieving these goals are in the best interest of the citizens of West Virginia.

Cost of Various Technologies

The purpose of this study was to determine the economic feasibility of Carbon Capture and Sequestration (CCS) for fossil fuel electric generation in the State of West Virginia as compared with alternative electric generating technologies. We have reviewed publicly available documents for the costs of electric generating technologies and CCS technologies. The cost data vary widely as there is little operating history of CCS costs. The published CCS information that is readily available consists of projected costs based upon data from operating generation plants, and information learned generally from experimentation and demonstration CCS projects.

The widely accepted method of evaluating the economic feasibility of an electric generation technology is to determine the Levelized Cost of Electricity (LCOE) produced. The levelized cost considers all of the components of cost including permitting, financing and capital cost, as well as the components that make up a plants fixed and variable operating costs levelized over the life of the facility. A number of studies are available which examine the capital and levelized costs of a variety of electric generating technologies. Data was selected from the Energy Information Administration Annual Energy Outlook 2009 and three studies prepared under the auspices of the DOE/NETL. The first DOE study *"Cost and Performance Baseline for Fossil Energy Plants DOE/NETL 2007/1281 Volume I Bituminous Coal and Natural Gas to Electricity"* Rev1 examined the cost of new electric generating facilities. The second DOE study: *"Carbon Dioxide Capture from Existing Coal Fired Power Plants DOE/NETL-401/110907"* examines the cost associated with adding CCS to existing facilities. The third study: *"CO_2 Capture Ready Coal Power Plants DOE/NETL 2007/1301 Final Report April 2008"* examined the cost effectiveness of including in the original design of a coal-fired power plant the capability to retrofit a CCS system.

The competing energy forms were compared on a levelized cost of electricity basis to determine relative cost competitiveness. The results of the effort in executive summary format are contained herein.

As noted above, the data varied widely. The final projected costs in this report are not to be construed as projected costs of production on an individual generating site basis. The inputs for O&M can vary widely for each source depending on geographic location, fuel supply costs, etc. A true cost analysis would need to be performed on a case by case basis taking into consideration additional variables such as local legislation, demand for base load vs. peaking power needs, capacity factors of the various generating forms to meet demand, infrastructure needs, etc. The reported costs should be used to generally compare competing technologies to determine whether CCS is in the realm of competitiveness, and therefore whether the State of West Virginia should even consider legislation to promote its use.

The capital costs as published in the studies are provided in Table A.2 for plants without and with CCS. The reported capital costs are listed to show the relative size of initial investment needed for the competing technologies, however, many of the figures are dated, and actual current capital costs are likely significantly higher.

In Table 2, the IGCC with CCS $/kw cost is listed at $3496/kw. A company is planning to build a $1.75 billion coal gasification power in Ector County, Texas. Summit Power Group's Texas Clean Energy Project calls for it to be a 400-megawatt net (560 MW gross) integrated combined cycle (IGCC) plant that is designed to capture 90 percent of the carbon dioxide produced. According to a news release, the plant will capture 3 million tons of CO_2 annually, which will be used for enhanced oil recovery in the Permian Basin. Using the numbers being proposed by Summit Power as current estimates for IGCC Construction (hard costs) with 90% CO_2 capture, the data would translate to approximately $3125/kw (gross) or 4375/kw (net).

Another proposed IGCC facility in Mississippi is expected to be in service in 2013 has a total system cost of $3000/kw with 50% carbon capture. This information is from Southern Company's public comments.

The costs of a nuclear power facility as stated in the EIA report appear to be much lower that the current estimates by utilities and others which are in excess of $6000/kw.[67] Ontario Hydro recently announced canceling a large Nuclear power plant project as the capital costs have now exceeded $10,000/MW. The capital cost estimate shown in Table 1 is approximately 50% of the current low end estimate of the cost of an advanced nuclear plant currently under consideration.

The reported capital costs for adding CCS to an existing PC coal plant include the initial capital for constructing the plants, and therefore are overstated.

Cost figures in Table A.2 do not include the offsite capital costs of power transmission or infrastructure, which could be substantial particularly for wind and solar since the generating capacity per power unit is very small and substantial expansion of the current transmission would be required for infrastructure to accommodate many smaller generating units. The capital costs for infrastructure requirements of solar powered generation could be negated to a degree with alternative roof top installations.

---

[67] Federal Energy Regulatory Commission Increase Costs in Energy Markets (Staff Report) June 9, 2008.

TABLE A.2
Capital Cost $/kw

Capital Cost				
			EIA Study 2007$	
			Note 2	
Natural Gas Combined Cycle (NGCC)			948	
NGCC with CCS			1890	
Wind			1923	
New Pulverized Coal (PC)			2058	
Integrated Gasifier Combined Cycle (IGCC)			2378	
Nuclear			3318	
IGCC with CCS			3496	
Biomass			3766	
New PC with CCS		Note 3	3846	
Solar			5021	
Existing PC with retrofit CCS		Note 4	5050	
Notes:				
1) Source: US Energy Information Administration Annual Energy Outlook 2009 except as otherwise noted. Cap Ex costs taken from EIA Annual Energy Outlook 2009 Assumption to the Annual Energy Outlook 2009 Table 8.2 Cost and Performance Characteristics of New Central Station Electricity Generating Technologies				
2) Overnight capital costs including contingency factors, excluding regional multipliers and learning effects. Interest charges are also excluded. These costs represent new projects initiated in 2008 expressed in $2007. Capital costs are shown before investment tax credits are applied where applicable				
3) The capital cost of a PC unit with CCS was not included in the EIA study. The data provided in the Cost and Performance Baseline for Fossil Energy Plants DOE/NETL 2007/1284 Volume I Bituminous Coal and Natural Gas to Electricity Rev 1 August 2007 was used to determine the incremental cost of adding a CCS to a PC unit as a percentage of the capital cost of a PC unit without CCS. That percentage was applied to the capital costs of a PC unit as defined in the EIA study to estimate the cost of a PC unit with CCS.				
4) The capital cost of retrofitting a PC unit with CCS was not included in the EIA study. The data provided in the CO_2 Capture Ready Coal Power Plants DOE/NETL 2007/1301 Final Report April 2008 was used to determine the incremental cost of adding a CCS to an existing PC unit as a percentage of the capital cost of a new PC unit without CCS. That percentage was applied to the capital costs of a new PC unit as defined in the EIA study to estimate the cost of an existing PC unit with CCS. The total cost is conservatively high as the retrofitted PC unit would have a depreciated value with respect to the capital cost of a new PC unit and thus the total capital cost would be less than the cost of a new PC unit and a retrofitted CCS as stated herein.				

TABLE 3.A
Ranking of Levelized Costs $/mwhr

			EIA Study 2007$					
			w/o CCS	Rank		w CCS	Rank	Notes
Nuclear			107.3	4		107.3	1	
Biomass			107.4	5		107.4	2	
IGCC with CCS at DOE Target Price			N/A			113.9	3	4
NGCC			79.9	1		115.7	4	
IGCC			103.5	3		122.6	5	
New PC with CCS at DOE Target Price			N/A			127.7	6	3
Wind			141.5	6		141.5	7	
New PC			94.6	2		175.6	8	
Existing PC Retrofitted w CCS			N/A			201.2	9	2
Solar			263.7	7		263.7	10	
Notes:								
1) Overnight capital costs including contingency factors, excluding regional multipliers and learning effects. Interest charges are also excluded. There costs represent new projects initiated in 2008 expressed in $2007. Capital costs are shown before investment tax credits are applied where applicable								
2) The levelized cost of energy (LCOE) of retrofitting a PC unit with CCS was not included in the EIA study. The increase in LCOE as a result of retrofitting a CCS was defined in Carbon Dioxide Capture from Existing Coal-Fired Power Plants DOE/NETL-401/110907 (Final Report Original Issue Date, December, 2006 Revision Issue Date November, 2007). The percent increase over the base case (no CCS) was applied to the base case LCOE of a PC unit as defined in the EIA study to determine the incremental LCOE to retrofit CCS to an existing PC unit. The LCOE of a retrofitted PC unit as stated here is conservatively high as the retrofitted PC unit would have a depreciated value with respect to the capital costs of a new PC unit and thus the LCOE would be less than the cost of a new PC unit with a retrofitted CCS as stated herein.								
3) DOE's goals for CO_2 capture in combustion systems as stated in DOE document: Existing Plants, Emission and Capture - Setting CO_2 Program Goals, dated April 20,2009 (DOE/NETL-2009/1366) are to limit the maximum increase in LCOE to 35%. This value was used to determine the LCOE in the table above.								
4) DOE's goal for CO2 capture in gasifier systems is to limit the maximum increase in LCOE to 10%. This value was used to determine the LCOE in the table above.								

Table 3.A presents the levelized costs of the various technologies. In the EIA data, for cases without CCS, NGCC is the low cost alternative followed by pulverized coal, IGCC, nuclear, biomass, and wind. Specific site factors and other factors would weigh into the selection of a specific technology for a selected site. Solar appears to be higher than the other technologies.

When CCS is included, fossil fuel technologies would incur an incremental increase in LCOE due to the capital and operating costs of the CCS. Table 3.A includes the EIA estimates of the LCOE based on current CCS technology development. However, DOE has established goals of advancing technology such that the incorporation of CCS in a gasification process or in a combustion process will not increase the LCOE by more that 10% and 35% respectively. Therefore estimated LCOE's for those technologies were also provided which reflected the achievement of the DOE goals.

In the study, the ranking of nuclear improves with the requirement for CCS. The results indicate that nuclear provides a low LCOE. However, the capital and operating costs of the advanced nuclear design are the least known among all of the technologies and as stated earlier, the capital cost estimate shown in Table A.2 is approximately 50% of the current low end estimate of the cost of an advanced nuclear plant currently under consideration.

Biomass provides a low LCOE when CCS is a requirement. This is due to the fact that biomass would not be required to install CCS systems. Biomass is followed in succession by IGCC achieving DOE cost goals, NGCC with CCS, IGCC with current pricing, PC achieving DOE cost goals and wind. The cases of a new PC with current CCS cost estimates and an existing PC with retrofit CSS cost estimates follows with the solar option resulting in the highest LCOE.

On a levelized basis, with CCS included, the ranking of some of the renewable technologies improves (nuclear and biomass). The fossil fuel technologies remain economically viable when compared to the other renewable technologies particularly if the DOE costs goals are at least partially achieved.

The data compilation suggests that CCS technologies should continue to be pursued to provide not only a viable means to capture and store carbon, but also to retain the competitiveness of the fossil fuels we are abundantly blessed with in West Virginia. The actual supply of electricity in a region will be a makeup of several sources of supply based upon the actual LCOE of each source, and its capacity for base load supply.

Study Scope: Estimating the Economic Impact of Implementing CCS in West Virginia

Second, in our consideration of the costs of CCS, what must we know before we can estimate the impact that such a program would have on the economy of West Virginia? An additional study looked at what would need to be done to address this question.

Implementing carbon capture and sequestration (CCS) will require Federal mandates and/or financial incentives. West Virginia-based emitters will not undertake the expenses associated with CCS without being required to do so or being faced with a more expensive alternative to reduce CO_2 emissions such as cap-and-trade or carbon taxes. Because it participates in regional markets for electricity and coal, West Virginia will not implement CCS on its own due to competition. An analysis of the impact of CCS in West Virginia is highly linked with the impacts of doing so in most of the Eastern U.S.

CCS is a capital-intensive activity and most emitters have little experience with it. While the use of CO_2 injection in the oil and natural gas industry is a highly developed technology, that experience is only partially transferable to emissions from electric generators using coal. To fully implement CCS will take many years, and the nature of capture will change as the technology used by emitters changes.

The economic impact of CCS in West Virginia depends much on the timeframe desired to be evaluated. The need for new fossil-powered electricity generation capacity will depend on growth in demand. In the next 20 years, much new generating capacity will be built to meet state renewable portfolio standards, which emphasize the use of alternative and renewable fuels. Under the West Virginia Alternative and Renewable Energy Portfolio Standard, electricity generated from coal with CCS counts; however, this is not the case in other states. Energy efficiency measures could also suppress demand growth. Thus, it is likely that most carbon will initially be captured with equipment added onto existing units. However, in 20 to 40 years a different type of generating capacity may be needed and new fossil units may be built with capture technology. As with all forecasting analyses, the longer the time-frame of evaluation the more assumptions will need to be made about demand and technology.

Pending Legislation

The current movement toward carbon regulation is generally focused on either carbon taxation or cap and trade. CCS is a stand-alone alternative if mandated or would be incentivized with a sufficiently large tax or very low cap on carbon emissions. If an imposed tax or the cost of emission permits under cap-and trade in terms of costs per ton of emitted carbon is greater than the cost of CCS, then affected industries will elect to do CCS.

Based on historical experience it is reasonable to assume that the costs of CCS technology will fall dramatically as implementation and research continue. The pace of this progress is difficult to predict and becomes more uncertain the longer the time frame used for evaluation. Any public policy which makes coal less competitive will provide an additional incentive for private research, but much of that research will require subsidization. For good reason firms are reluctant to make major financial commitments to newer technologies. Often the cost is high, the technology unproven and the certainty that even newer technologies with lower costs and increased efficiencies will emerge, makes the commitment of private capital less likely at the outset of CCS implementation.

Depending on market forces, the regulatory environment and the pace of introduction of alternative fuels, it may be possible for coal generators to pass the costs of CCS on to the consumers of electricity. Evaluating the ability of electric generators to do this would have to be part of any impact analysis. Incurring the costs of CCS in West Virginia could be better economically for the State than for its utilities to simply pass along the cost of the tax or to participate in cap-and-trade, because a new industry will develop around CCS and with it jobs and expertise. The trade-off between the creation of a new CCS industry and the possibility of forward shifting of the CCS cost would also need investigation.

Scale of Implementation

There are 14 or 15 coal-fired power plants in West Virginia that would currently be affected by carbon legislation. Carbon dioxide emissions from these plants amount to a little more than 86 million metric tons, about 3.4% of national levels from the electric power industry. It is likely that one or two of these plants would be retired if carbon capture were to be mandated. This would be determined by the costs of retrofitting older plants. If cap-and-trade is used these plants would be eligible for carbon emission credits. Closing them and using the credits to offset emissions elsewhere could prove to be a viable business strategy. A handful of industrial direct coal users would also be affected. In any analysis of the future of generation in West Virginia some assumptions would need to be made about which plants might be subject to closure.

Current Projects

West Virginia is the site of several projects developing CCS Technology. A short description of these projects is found on pages 26-27. Because of these pilot projects, West Virginia is now a leader in deployment of CCS. If CCS becomes widespread the State will benefit from this experience. But the small scale of most of these projects, while producing valuable information, are only the first steps in proving the feasibility of CCS.

Categories of Impact

There will be both positive impacts from spending and negative impacts from increased costs due to implementation of CCS. The primary costs of CCS will be borne by coal-fired power plants. Primary Impacts:

Higher electricity prices for residential, industrial and commercial consumers

The estimated costs of CCS vary by type of generator. Capture can take place pre or post-combustion, with pre-combustion costs appearing more costly at present compared to adding technology to existing steam units. Older estimations have been as low as around $36/tonne (IPCC in 2002) but more recent figures are closer to $90 for CCS post-combustion. In 2007, MIT estimated that a carbon price of $30/tonne would make CCS cost competitive. In West Virginia rates could more than double, with residential rates expected around 18 to 19 cents per KWh.[68]

Because West Virginia's electricity mix is 98 percent coal and other states in the region have lower coal shares, the price impact will be higher in West Virginia than in other states. The indirect effects will include reducing any competitive advantage that exists for manufacturing inputs and to disproportionately reduce disposal income for households. Correlated federal incentives to induce energy efficiency investment for all sectors and to reimburse low-income households will offset some of the negative impacts and could cause some manufacturers to remain in West Virginia rather than moving to areas where products costs are lower.

Reduced and less competitive electricity exports

West Virginia is among the largest exporters of coal-fired electricity. Based on its overall generation mix, West Virginia exported nearly 59 million MWh of coal-fired electricity in 2007, more even than large coal-fired generating states such as Texas and Pennsylvania, which exported 25 million MWh and 40 million MWh respectively of coal-fired electricity in 2007.[69] Electricity exports contribute to low electricity prices for WV customers. While it is expected that coal-fired power generation in WV will need to be maintained at current levels or more for at least 20 years, the long-term generation mix could be significantly different. Carbon capture at a power plant also requires diverting a portion of the plant's output to that capture, thus reducing the amount of electricity that can be delivered to customers.

Changed sourcing of coal for power generation

The cost of carbon capture could change the origin of coal supply as some regional power plants may choose to substitute cheaper, low-btu or other coal for West Virginia coal. Sub-bituminous coal from Wyoming's Powder River Basin can be brought to West Virginia at competitive prices and WV power plants with new pollution control technologies can purchase

---

[68] Presentation by Mark Dempsey of Appalachian Power at the "Energy and Natural Resources Symposium" on October 29, 2009. It is uncertain what technology cost assumptions are incorporated within these figures.

[69] US DOE, EIA. 2007 State Electricity Profiles.

cheaper coal from areas like the Illinois Basin. On the other hand, IGCC technology is not compatible with PRB coal which greatly reduces the fuel options for that type of plant.

Creation of a new industry with uncertain cost and indirect effects

Industries that buy carbon byproducts can be indirectly impacted by the industry. Capture costs can be offset when there is a market for chemical byproducts resulting from the separation of carbon. For example, when CCS is linked to enhanced oil and gas recovery, the economies improve. The most similar existing industry to a CO_2 transport and storage industry is probably drilling oil and gas wells. Studies estimate the cost of transport and storage of CO_2 at around $15 per ton.[70]

Dynamic Modeling

Estimation of the economic impact of CCS on the West Virginia economy must be modeled dynamically to capture net impacts and because it will only be accomplished over several years. Assumptions regarding the phasing of implementation, the number of years to full implementation and the percent of carbon captured each year in the interim are important variables. In the next 20 years, the impact will be seen largely as retrofits to existing fossil units, while in the following 20 years new fossil and/or nuclear units will be built. The phasing of implementation can also be influenced by the availability and costs of alternative fuels.

The net effect of higher generation cost and less generation will depend on the timing of CCS implementation, demand response and other electricity suppliers. Quantification will require development of a credible set of assumptions to simulate consumer and industrial response.

There is also a question of a long-term health impact from reducing carbon emissions. Will West Virginia see a direct or indirect positive impact to reducing emissions or will the benefits be felt more in coastal areas? Research should be done to evaluate the option of including such impacts.

Methodology

Review of the literature

It will be necessary to review the relevant articles and reports related to CCS. A primary focus must be on costs of CCS and the anticipated pace of introduction of new technology. Further, the literature must be queried to determine the price responses of consumers to changes in electric consumption. This will allow a determination of what the loss of demand for coal generated electricity in West Virginia will be. In addition, the literature will be searched to determine the costs of switching to alternative or renewable fuels. So long as CCS is cost competitive with these substitutes the loss of markets will be reduced.

Consultation

Much, if not most, of the relevant information and data will have to come from the electric and coal industries themselves. Extensive work has already been accomplished on CCS

---

[70] J. J. Dooley,R. T. Dahowski, C. L. Davidson, "*On The Long-Term Average Cost of CO2 Transport and Storage,"* US Department of Energy, Washington, DC, March 2008 http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17389.pdf

by them. That work will be incorporated into the analysis. Also, those with pertinent information in energy related research organizations should be contacted.

Statement of assumptions

For any analysis to proceed, certain key assumptions must be made and clearly identified. The validity of the analysis will rest on the validity of the assumptions. Different assumptions will lead to different outcomes. Considering that West Virginia electricity is primarily exported to users out of state, all assumptions must be region wide and not limited to West Virginia. Among the assumptions to be considered are:

- The current and projected costs of CCS under various technologies
- The level of demand response to increased prices for coal generated electricity
- The costs and availability of alternate fuels
- Uses and markets for CO_2
- Public policies regarding CO_2

Development of scenarios

For that reason it may be necessary to develop alternative scenarios using different sets of assumptions in order to capture as many as possible of the projected outcomes. What scenarios would be considered would have to be a decision based on input from affected parties. The choice of scenarios would have to be limited to those “most likely” to happen.

Analysis

The analysis being dynamic must use a dynamic economic model. The most widely used dynamic model is REMI. REMI allows for a determination of the impact on income, output and employment from alternative public policies. It can project outcomes up to 20 years. It also can pinpoint the impact of those policies by most major industries. The output from the model would be translated into both written and graphic formats for distribution.

Review

The analysis should have extensive review prior to public distribution. It should be considered by those who have consulted on the project as well as additional reviewers familiar with CCS and electric energy markets.

Distribution

Following the review and inclusion of the results of that review, the report should be made public. Particular attention should be made to placing it in the hands of the decision makers.

An analysis this complex would take at least a year for completion.

Summary

The impact of implementing CCS in West Virginia depends on the relative impact of doing so in the region. Other states in the region will also be impacted and have different resources that can be used to meet the requirements of CCS. Isolating West Virginia's share of the impacts will require developing 20 to 40-year assumptions related to market share of power generation, coal production, biomass production and the industry of carbon storage itself. Assumptions regarding technology and the timeframe of implementation are equally important. Considering the importance of coal to the West Virginia economy an analysis of CCS impacts would provide important information for both industry and government.

Question 2: What factors need to be addressed to be able to assure the citizens of West Virginia that CCS is safe in terms of human health and the environment?

IV.A.5. What potential environmental and health related factors need to be addressed prior to reaching a decision regarding the feasibility of encouraging CCS in West Virginia?

The known potential human and environmental issues relevant to the feasibility of CCS include asphyxiation; explosiveness; risk to groundwater; effects on plant life; effects on seismic activity; effectiveness of CCS as a means of decreasing greenhouse gas emissions; increases in energy requirements due to efficiency losses; increases in water use; and increases in other air emissions.

Three avenues of release of CO_2 to the surface where it can present a human hazard are pipeline leaks, well leaks and seepage through the subsurface to ground level.

Asphyxiation

CO_2 is heavier than air and when concentrated it can pool near the ground, displacing oxygen. Proper siting, construction, maintenance and monitoring of CO_2 injection wells is vital to avoiding leaks into confined spaces such as basements, cellars, or other structures in or near the storage field. Should a well blowout or pipeline leak occur out in the open, the CO_2 likely would disperse quickly enough as to pose minimal risk of asphyxiation of human and animals.

Explosiveness

Unlike natural gas, CO_2 is <u>not</u> flammable. However, in order to maintain the supercritical or dense phase state, it is transported under high pressures. A sudden release of pressure due to a pipeline puncture would be 'explosive' in character but not flammable. There would be, however, considerable potential for harm to humans and animals in the immediate area of such an explosion.

With respect to transport, it should be noted that 3,769 miles of CO_2 transport pipeline are already in place in the U.S., and during the period 1994-2006, 18 "incidents" resulted in no fatalities or injuries (See Table IV.B.3). Based on historical data, the probability of injuries and fatalities from CO_2 pipeline "incidents" appears much lower than that for natural gas transmission pipelines. Still, extreme care should be taken in decisions as to siting of pipelines, operation of the pipelines to minimize possible corrosion, and implementation of effective risk management and mitigation plans.

Risks to groundwater

The protection of groundwater throughout a CCS project is vital to the water resources in West Virginia. Risks to groundwater quality arise from the potential for CO_2 to mobilize organic or inorganic compounds, acidification and contamination by trace compounds in the CO_2 stream, intrusion of native saline groundwater into drinking water aquifers, and the potential for the CO_2 to displace subsurface fluids. The probability of many of these risks occurring may be decreased by a thorough site characterization, sound injection well construction, sufficient monitoring, and enforcement of existing regulations. More detail can be found in Section IV.B.

Effects on plant life

Elevated levels of CO_2 in the soil from well leaks, pipeline leaks or seepage can negatively affect soil ecosystems and potentially kill plants if sufficient oxygen displacement and/or soil acidification occurs. Proper siting, construction, maintenance and monitoring of CO_2 injection wells is vital to avoiding leaks into soil. See Section IV.B.V.2 for more details.

Seismic activity

Proper siting of CO_2 storage reservoirs and proper injection procedures are vital to avoid inducing seismic activity. Geomechanical considerations include:

- Avoid regional tectonic stress near breaking strength of rock
- Avoid potential reservoir where fracture porosity is dominant
- Avoid low permeability reservoirs
- Avoid injection rates that can significantly increase pore pressure over a wide area.

Effectiveness

Does CCS make coal "carbon neutral"?

The goal for carbon capture from stationary sources is 90 percent. Modeling of IGCC, NGCC and pulverized coal (PC) technology[71] shows capture from gross power output (see Tables A.4 and A.5) between 86.98% (ConocoPhillips IGCC) and 89.44% (GE IGCC). Capture measured at net power output is between 88.33% (NGCC) and 85.26% (subcritical PC).

What is the likelihood the CO_2 will "stay put" after it's injected?

If it does not, then all our efforts and expense are for naught. Regarding retention of sequestered CO_2, the Intergovernmental Panel on Climate Change has stated that "Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years."[72]

---

[71] NETL, 2007, Cost and Performance Baseline for Fossil Energy Plants. DOE/NETL 2007/1281. Found at: http://www.netl.doe.gov/energy-analyses/baseline_studies.html

[72] IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyer (eds)]. Cambridge University Press, Cambridge, United Kingdon and New York, N.Y., USA, 442 pp.

Impact of capture technology on power generation

The amount of energy required to power carbon capture equipment increases parasitic load (see Total Auxiliaries Table A.5) reducing the net output of electricity. Each technology was modeled to maintain either gross power output for gas turbines or net power for steam turbines[73]. For each technology modeled, the difference with and without capture equipment is posted in Table A.4 and the percent change is posted in Table A.5. Compensating for this increase in parasitic load, 45.49% to 57.28% for IGCC technology and 288.21% to 290.07% for NGCC and PC technology is reflected in the increase consumption of coal by 2.19% to 4.54% for IGCC technology and 42.63% to 47.72% for PC technology. This combination of higher parasitic load and higher fuel consumption to compensate decreases the efficiency of coal plants by an amount ranging from 14.92% to 22.14% or IGCC technology and 30.43% to 32.34% for pulverized coal technology (see Tables A.4 and A.5). If CCS is employed on a large scale, therefore, significant additional amounts of coal may be consumed to maintain electricity generating output. If the additional coal consumption is focused on pulverized coal technology instead of IGCC technology, the amount of coal required is expected to increase by more than 42% (Table A.5). This will result in a concomitant increase in coal-related environmental, property and human health effects; these include, but are not limited to, water pollution, land degradation, loss of ecosystem services, flooding, generation of slurry from the processing of coal, damage to roadways from heavy coal trucks, and coal ash disposal.

Increases in water requirements

Tables A.4 and A.5 show that CCS is expected to increase water requirements for coal plants by an amount ranging from 10.06% (Conoco-Phillips IGCC) to 126.95% (subcritical PC).

Effects on other air emissions

Tables A.4 and A.5 also show that, while CCS will result in decreased emissions of SO_2 and NO_x at IGCC plants, emissions of NO_x, particulates and mercury will increase at pulverized coal plants. This could necessitate the installation of additional pollution control equipment in order to comply with permit requirements.

---

[73] Ibid 71, see exhibits 3-18 & 3-34, 3-51 & 3- 67, 3-84 & 3-100, 4-7 & 4-17, 4-28 & 4-38, 5-7 & 5-17.

Table A.4

Change in power generation, consumption of raw materials and generation of by-products due to installation of Carbon Capture equipment[74]

		Changes due to installation of Capture Equipment				
	General Electric Energy IGCC	Conoco Phillips E-Gas^{TM} IGCC	Shell Global Solutions IGCC	Subcritical PC	Supercritical PC	NGCC
Gas Turbine/Steam Turbine Power - kWe	-290	-30	-400	96,608	83,185	0
Sweet Gas Expander Power - kWe	-870	-	-	-	-	-
Steam Turbine Power - kWe	-24,230	-48,640	-54,065	-	-	-50,110
Total Power - kWe	-25,390	-48,670	-54,465	-	-	-50,110
Total Auxiliaries - kWe	59,185	56,460	64,250	97,440	87,340	28,360
Net Power - kWe	-84,575	-105,130	-118,715	-832	-4,155	-78,470
Net Plant Efficiency - %(HHV)	-5.7	-7.6	-9.1	-11.9	-11.9	-7.1
Net Plant Heat Rate (Btu/kWe)	1,583.0	2,076.0	2,368.0	4,448.0	3,813.0	1,094.0
Consumables						
As-Received Coal/NG Feed - (lb/h)	10,745.0	13,966.0	20,556.0	208,890.0	175,345.0	0.0
Thermal Input - kWt						
Raw Water Usage - m^3/min (gpm)	575.0	378.0	771.0	7,886.0	6,718.0	2,168.0
SO_2 (lb/MWh)	-0.019	-0.022	-0.004	Negligible	Negligible	Negligible
No_x (lb/MWh)	-0.040	-0.033	-0.025	0.164	0.143	0.006
Particulates (lb/MWh)	0.003	0.005	0.007	0.030	0.027	Negligible
Hg (lb/MWh)	0.3×10^{-6}	0.4×10^{-6}	0.5×10^{-6}	2.7×10^{-6}	2.4×10^{-6}	Negligible
CO_2(Gross) (lb/MWh)	-1,305.0	-1,263.0	-1,260.0	-1,555.0	-1,472.0	-697.0
CO_2(Net) (lb/MWh)	-1,549.0	-1,477.0	-1,459.0	-1,608.0	-1,519.0	-704.0

---

[74] NETL, 2007, Cost and Performance Baseline for Fossil Energy Plants. DOE/NETL 2007/1281. Found at: http://www.netl.doe.gov/energy-analyses/baseline_studies.html

Table A.5:
Percent change in power generation, consumption of raw materials and generation of by products due to installation of Carbon Capture equipment.

		Changes due to installation of Capture Equipment				
	General Electric Energy IGCC	Conoco Phillips E-Gas^{TM} IGCC	Shell Global Solutions IGCC	Subcritical PC	Supercritical PC	NGCC
Gas Turbine/Steam Turbine Power - kWe	-0.06%	-0.01%	-0.09%	16.56%	14.34%	0.00%
Sweet Gas Expander Power - kWe	-12.20%	-	-	-	-	-
Steam Turbine Power - kWe	-8.11%	-17.47%	-19.04%	-	-	-25.05%
Total Power - kWe	-3.30%	-6.55%	-7.28%	-	-	-8.79%
Total Auxiliaries - kWe	45.49%	47.39%	57.28%	296.44%	290.07%	288.21%
Net Power - kWe	-13.21%	-16.86%	-18.67%	-0.15%	-0.76%	-14.00%
Net Plant Efficiency - %(HHV)	-14.92%	-19.34%	-22.14%	-32.34%	-30.43%	-13.98%
Net Plant Heat Rate (Btu/kWe)	17.74%	23.91%	28.51%	47.95%	43.72%	16.28%
Consumables						
As-Received Coal/NG Feed - (lb/h)	2.19%	3.01%	4.54%	47.72%	42.63%	0.00%
Thermal Input - kWt						
Raw Water Usage - m^3/min (gpm)	14.36%	10.06%	20.33%	126.95%	123.47%	86.31%
SO_2 (lb/MWh)	-20.21%	-24.18%	-4.55%	Negligible	Negligible	Negligible
No_x (lb/MWh)	-9.85%	-7.62%	-6.05%	26.75%	24.70%	10.00%
Particulates (lb/MWh)	5.66%	9.62%	14.00%	26.32%	25.23%	Negligible
Hg (lb/MWh)	7.14%	9.52%	12.50%	27.00%	21.28%	Negligible
CO_2(Gross) (lb/MWh)	-89.44%	-86.98%	-89.43%	-87.36%	-87.57%	-89.02%
CO_2(Net) (lb/MWh)	-88.26%	-85.38%	-88.00%	-85.26%	-85.67%	-88.33%

IV.A.6. Incentives for CCS Technology

The decision concerning whether or not to take steps to provide incentives for the deployment of CCS Technology in West Virginia obviously must come subsequent to determining whether or not this technology is feasible. However, in advance of that determination, the Legislature has tasked the Working Group with researching plausible incentives.

Regulatory Certainty

Regulatory certainty is arguably the single most important step the state can take to incentivize deployment of CCS technology in West Virginia. To that end, the legal issues concerning pore space ownership and liability for sequestered CO_2 need to be resolved and are being considered by the Working Group. A clearly defined set of regulations and a definitive agency authority needs to be named to handle these projects. Further, a multi-agency team should be formed to address all issues for a permit applicant during the submittal process. At a minimum this would include WVDEP, PSC, WVDNR, WVEGS and WVDO.

The American Clean Energy and Security Act (ACES Act)

While the ACES Act has not been promulgated, it remains the most viable bill currently being considered by Congress concerning a carbon cap-and-trade program. Language in the bill also promotes R&D and early deployment of CCS primarily by the creation of a carbon storage research corporation which uses funds to issue grants and financial assistance for commercial scale CCS projects. The bill proposes funding of $1.1 billion per year for no more than 10 years. If the Act or an Act with similar provision is passed by Congress, the Working Group recommends that the Governor charge the West Virginia Development Office to make an extraordinary effort to make use of these monies by mandating at least one grant application be submitted each year.

The ACES Act also proposes to provide allowances to the first facilities that implement capture and secure geologic storage that results in a 50% reduction in annual CO_2 emissions. The West Virginia Alternative and Renewable Portfolio Standards Act, promulgated in 2009, places a mandate on the electric industry to utilize renewable and alternative fuels, and does allow generators to meet the standards by employing CCS. This legislation should be reviewed to ensure that West Virginia is maximizing the incentive and that it is actually useful for generators as written.

The American Recovery and Reinvestment Act (ARRA)

The ARRA was passed by Congress in 2009 and included tax incentives for CCS technology. It expanded tax credit bonds allocated to states and large local governments to finance clean energy projects including those incorporating CCS technology. There was also money made available for an “advanced energy property investment credit” providing 30% credit for investment in property designed to capture and sequester CO_2 as part of a qualified advanced energy manufacturing project. After consulting with the West Virginia Department of Tax and Revenue to explore whether a similar property tax credit for West Virginia is feasible, the Working Group has learned that there are many tax credits available in West Virginia for R&D, business expansion, and pollution control devices. The Feasibility Subcommittee will perform further research to ensure that the existing credits are accessible for those willing to invest in CCS technology in the state so that the state credits may dovetail the federal incentives.

Rate Incentive

The PSC is currently directed to provide rate incentives for clean coal technologies which reduce SO_2 and NO_x emissions via the following law:

> **§24-2-1g. Rate incentives for utility investment in qualified clean coal and clean air control technology facilities.**
>
> (a) The Legislature hereby finds and declares that the state of West Virginia has been a major supplier of coal to the electric power industry both within and

> outside of the state of West Virginia; the congress of the United States is currently considering legislation to limit the emissions of oxides of sulfur and nitrogen from coal-fired electric generating plants; the continued use of coal for generating electrical energy can be accomplished in an environmentally acceptable manner through the use of current state of the art and emerging clean coal and clean air technology; it is in the interest of the economy of West Virginia to encourage the use of such technologies for the production of electricity and steam; revenues from the continued production of coal are important to the State of West Virginia and are necessary for the funding of education and other vital state services; the construction of electric utility generation and transmission facilities may continue for many years following the finalization of plans for such facilities; and the prudence of the construction of such facilities may be affected by changing conditions during the extended interval between finalization of plans and completion of construction.
>
> (b) Upon a finding that it is in the public interest of this state, as provided in section one, article one of this chapter, the public service commission shall authorize rate-making allowances for electric utility investment in clean coal and clean air technology facilities or electric utility purchases of power from clean coal technology facilities located in West Virginia which shall provide an incentive to encourage investments in such technology
>
> (c) For purposes of this section a qualified clean coal or clean air technology facility must use coal produced in West Virginia for no less than seventy-five percent of its fuel requirements.
>
> (d) The public service commission shall determine, at such time and in such proceeding, form and manner as is considered appropriate by the commission, the extent to which any electric utility investment or purchases of power qualify for incentive rate-making pursuant to this section.

The Working Group suggests that a bill be proposed that adds CCS technology to this law.

Pre-qualifying Storage Sites

“Pre-qualifying” storage sites would entail a group of state agencies taking steps to locate and ensure the viability of potential sites as locations to sequester CO_2. Many factors would be considered such as topography, infrastructure, geology, etc. While entities would still be required to follow the normal permitting process that is established, investment in the process would be incentivized given that initial steps have been taken to certify that the storage site is permittable. This procedure will be further investigated by the Feasibility Subcommittee.

IV.7. Conclusions and Recommendations Being Discussed for the Final Report

IV.7.A Conclusions

1. The timeline for requirements to restrict the emissions of greenhouse gases is, at present, uncertain. However regulation at some point n the next few years is near certainty.

2. The task of reducing greenhouse gas emissions to the levels that many contend are necessary to avoid negative impacts of predicted climate change is monumental and will require major changes in the manner of producing and using energy. There is currently no proposed technology or acceptable life style adjustment that can meet these goals. In short, no one currently knows how to meet the projected goals for GHG reduction.

3. Carbon Capture and Sequestration is one of many tools that can be used to meet the goals of reducing carbon emissions. The development and deployment of CCS may also allow West Virginia to continue to use its current electrical power generation infrastructure and coal supplies.

4. Technology that is commercially able to capture and store carbon dioxide emissions from coal fired electric generation is not currently available.

IV.7.B. Recommendations Being Discussed for the Final Report

1. Should the CCS Work Group discuss and determine if a recommendation be made stating: West Virginia should continue to investigate ways to remain a net producer of energy. The state has many natural resources that can be utilized to produce marketable energy and is ideally located to provide energy to energy hungry heavily populated areas of the nation. The state should actively pursue renewables, conventional, hydro and all other primary sources of electrical production while developing technology and administrative procedures aimed at aligning energy production with the environmental and societal goals of its citizens.

2. The Feasibility Subcommittee will consider if West Virginia should investigate whether participation in interstate pipeline projects for the transportation and storage of carbon dioxide may be beneficial to the state and its citizens.

3. The feasibility of establishing CCS in West Virginia is heavily related to the importance of coal to the state. While the revenues associated with the state’s coal industry have been the subject of several studies, others have suggested that there are significant economic and social costs associated with the use of West Virginia coal that should be included in any assessment of coal’s impact on the state welfare. The FSC had some discussion of these issues and will engage in further inquiry prior to the drafting of the Final Report.

4. The economic impacts of actively participating in the development of CCS are still uncertain. The SC will attempt to reach more resolution on this.

5. With the USEPA’s regulation of GHG in by January, 2010 and a large interest in congressional action and potential international implications, the SC will attempt to present an understandable update of where WV stands in the area of Climate Change in the final report.

Question 3: What are the technical issues (both engineering and geological) that must be addressed to ensure the efficacy of CCS in West Virginia?

IV.B. GEOLOGY & TECHNOLOGY REPORT

IV.B.1. Introduction

The Geology & Technology subcommittee was asked to focus on three questions posed in the legislation: identifying monitoring sites for geologic sequestration [§22-11A-6(h)(5)], assessing the feasibility of carbon dioxide sequestration in West Virginia [§22-11A-6(h)(6)], and assessing the potential carbon dioxide sequestration capacity in the state[§22-11A-6(h)(8)]. In addition the technical subcommittee addressed several technical questions referred to it by other subcommittees. The Geology & Technology subcommittee notes that carbon capture and storage research and development is an area of rapid change. These technologies are undergoing substantial change and refinement. There are many unanswered technical, policy and regulatory questions. The West Virginia Legislature recognized this with the establishment of the Carbon Dioxide Sequestration Working Group. The technical subcommittee fully expects that changes will occur that West Virginia will have to adapt to.

West Virginia has a history of oil & gas and coal production and both indicate the potential for sequestration of captured CO_2. The Midwest Regional Carbon Sequestration Partnership (MRCSP) has identified several stratigraphic horizons that may have potential for sequestration[75]. Initial estimates of the geologic storage capacity for carbon dioxide in West Virginia suggest that there is between 47 years and 147 years[76] of injection for the annual carbon dioxide emissions from 29 sources[77] in West Virginia. These values for storage potential will be refined as additional information is obtained on suitability of geologic formations, storage capacity and potential injectivity other relevant factors.

Establishment of a monitoring, verification and accounting (MVA) system to confirm the position of the CO_2 plume in the reservoir as well as detect a possible leak will be required. Initial MVA activity will be based on limited information available prior to site characterization when acquisition of baseline data is initially considered. Site characterization activities in integrating surface and subsurface data will improve understanding of the geologic setting and the design of a suitable MVA program. Development of regulations and permitting standards will be necessary as will the establishment of the appropriate expertise within state agencies.

Assessment of the risks of transporting and storing carbon dioxide is necessary and essential in developing a MVA program as well as establishing levels for financial liabilities. There is a substantial body and growing body of carbon dioxide risk assessment literature. There is, relative to the scale envisioned for CCS, limited experience in transporting and injecting carbon dioxide for enhanced oil recovery (EOR). Analogous areas of experience such as natural gas transportation and storage, and underground injection of wastes suggest, but do not establish that carbon dioxide can be safely transported and stored.

---

[75] Wickstrom, L.H. et al., 2005, Characterization of Geologic Sequestration Opportunities in the MRCSP Region, Phase I Task Report Period of Performance: October 2003-September 2005, DOE/NETL DE-PS26-05NT42255

[76] NETL, 2008, Carbon Sequestration Atlas of the United States and Canada, second edition. Found at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/index.html

[77] See Appendix xx – List of WV sources from NATCARB

Identify geologic sequestration monitoring sites to assess the short-term and long-term impact of carbon dioxide sequestration - §22-11A-6(h)(5)

Monitoring, Verification and Accounting (MVA)

Injection of captured CO_2 in a supercritical or dense phase is a high pressure operation that increases the pressure in the storage reservoir for some radial distance from the injection well. It is essential to monitor two fundamental factors during and following injection of captured CO_2: the plume itself and pressures associated with the plume[78]. These two factors will be monitored over the injection, post-injection (both are within the short-term time period) and long-term stewardship time periods for each CO_2 storage reservoir. A basic goal is to know the location of the edge of the plume and associated pressure front. Surface and subsurface monitoring provides the necessary data needed to demonstrate that the CO_2 plume is not migrating beyond the boundaries of its trap and presenting an endangerment[79] situation, either to groundwaters (underground source of drinking waters (USDW)), the atmosphere, ecosystems and for human health.

Monitoring of the injected CO_2 will be done in the subsurface and at the surface. The most obvious location for monitoring is in well bores and more specifically at the injection well. Well bores are a data point providing direct measurement of the storage reservoir, the seal or cap rock and overlying stratigraphic horizons including groundwater aquifers. Aside from injection wells, monitoring wells located at some distance from injection wells can provide observation points to monitor storage reservoir pressure as well as formation water/CO_2 plume chemistry. Groundwater wells in proximity to the underlying CO_2 plume are also important points of observation and measurement. Surface measurements will be conducted at surface facility locations including delivery point of captured CO_2, point of separation to storage field pipeline system, injection wells and within the area of as well as at the perimeter of the expanding CO_2 plume in the subsurface.

An MVA program will be established prior to site characterization because a key component for a successful MVA programs, baseline measurements, will be collected during site characterization. A known location for MVA activity is the injection well but location of these wells depends on storage reservoir geology which in turn will dictate monitoring well locations. The areal extent of the CO_2 plume will depend on storage reservoir architecture. Knowledge of reservoir architecture will depend on well control and seismic data. Knowledge of reservoir architecture will improve with operations and continuous data collection by a MVA program. The USEPA proposed rules for Class VI injection wells will require an update of the Area of Review (AoR) for each injection well every 10 years or less[80]. A MVA program will be unique to each CO_2 storage reservoir and will reflect the geologic characteristics present in the subsurface. The details of a MVA program, the selection of technology and location of monitoring sites is the decision of the operator with the approval of the regulatory oversight board.

A wide range of technology is available to monitor, verify and account for the character and lateral extent of a CO_2 plume in the subsurface. Application of this technology begins during site characterization when baseline measurements are established. This information is

---

[78] NETL, 2009, Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations. DOE/NETL-311/081508. Found at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/MVA_Document.pdf

[79] As proposed, an operator can be released from obligations under a Class VI injection permit when non-endangerment can be demonstrated.

[80] EPA, 2008, Proposed rules for Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration (GS) Wells.

critical in providing recognition and assessment of data deviations away from baseline measurements.[81]

Technologies are available for all aspects of captured CO_2 injection operations. Geophysical methods at the surface which includes 2-D and 3-D seismic that if repeated over consistent time intervals can provide 4-D seismic provide broad geographic coverage of subsurface stratigraphy. In the wellbore, geophysical or wireline logging tools can provide subsurface measurements of formation fluids and the rock material that can be tied to and calibrate the surface seismic data. Wireline logs are run after a well is drilled before casing is set (i.e. open hole well logs) and also after casing is set. Cased-hole logging is done to verify quality of the cement job binding the casing to the surrounding rock and to detect leaks or potential paths of migration behind casing. Vertical seismic profiles (VSP) or cross-well seismic is data gather from wellbores that can be tied to surface seismic data. Cores or sidewall cores are taken when wells are drilled and provide direct measurement of the porosity and permeability of the storage reservoir, cap rock or seal and other formations sampled.

The USEPA's proposed Class VI injection well rules will require continuous monitoring of injection pressures of the injection well[82]. This provides for continuous mechanical integrity testing (MIT) they believe is important and which is usually done at 5 year intervals for Class I, II and V wells[83]. Subsurface pressures can also be acquired from non-injection wells with downhole pressure sensors.

Surface monitoring will include leak detection from surface equipment used for injection, soil gas analyses and ambient monitoring of the near surface atmosphere. Airborne monitoring techniques are also available. Perhaps one of the more important, especially during site characterization, is an aeromagnetic technique for detecting old wellbores[84].

Legislative Activity

Several states have passed legislation regarding carbon capture and sequestration. With respect to monitoring, each piece of legislation only provides general direction to the appropriate regulatory body to develop more specific requirements for monitoring and verification. Location of specific monitoring sites will depend upon the question to be answered the technology selected. Regulations will provide the questions and the site operator will select the technology with the understanding that they, the operator, are responsible for providing a suitable and acceptable answer. It must be recognized by all involved that available technology for recording geologic information at depth has some limitations regarding degrees of accuracy and/or level of resolution.

Only the state of Washington has developed specific regulations in response to legislation. Washington's legislation only required that the governor "develop policy recommendations on how the state can achieve the greenhouse gasses emissions reductions goals established under section 3 of" of the bill[85]. The Department of Ecology, with the help of a working group, established rules for CO_2 injection projects[86]. These rules require that a Permit Application include, among other items, information regarding "Location of all pertinent surface

---

[81] EPA, 2008, Vulnerability Evaluation Framework for Geologic Sequestration of Carbon Dioxide. Technical Support Document. EPA430-R-08-009

[82] Ibid 95

[83] Ibid 95

[84] SEQURE™ Well Finding Technologies, see: http://www.netl.doe.gov/newsroom/netlog/sept2007/Sep07netlog.pdf

[85] Engrossed Substitute Senate Bill 6001. Found at: : http://apps.leg.wa.gov/documents/billdocs/2007-08/Pdf/Bills/Session%20Law%202007/6001-S.SL.pdf. Retrieved: February 23, 2010

[86] Norman, D.K. and J. Stormon, 2007, White Paper: Feasibility of Using Geologic Formations to Sequester Carbon Dioxide (CO_2), Department of Ecology. Found at: http://www.ecy.wa.gov/climatechange/docs/co2sequestrationfinal_082807.pdf. Retrieved February 23, 2010.

facilities, including atmospheric monitoring within the boundary of the project", a "leak detection and monitoring plan using subsurface measurements to monitor movement of the CO_2 plume both within and to detect migration outside of the permitted geologic containment system." (WAC 173-218-115)[87]. This leak detection and monitoring plan includes "monitoring of pressure responses and other appropriate information immediately above caprock of the geologic containment system." One of the terms and conditions attached to a permit is that "The monitoring program shall include observations in the monitoring zone(s) that can identify migration to aquifers as close stratigraphically to the geologic containment system as practicable."(WAC 173-218-115). Specific items to monitor as specified in the regulations are:

- Characterization of injected fluids
- Continuous recording of injection pressure, flow rate and volume
- Continuous recording of pressure on annulus between tubing and long string casing
- Monitoring zone leak detection
- Sufficient monitoring to confirm the spatial distribution of the CO_2 in the subsurface

Each specific item to be monitored suggests a monitoring location but the regulations avoid suggesting or mentioning specific locations. Location of monitoring devices will depend on the technology and the parameter that needs to be recorded. Washington's regulations are comprehensive but not prescriptive; they provide the potential operation a good sense of what is expected for safe operations of a captured CO_2 storage field and what questions need to be answered. It will be up to the operator to select suitable technology that will record the necessary information with which to answer the questions.

Montana legislation (Senate Bill No. 498)[88] specifies that captured CO_2 injection permits include requirements for applicable pressure and fluid chemistry data as well as monitoring and verification. One specific request is an "adequate baseline monitoring of drinking water wells within 1 mile of the perimeter of the geologic storage reservoir." One mile from the perimeter of the geologic storage reservoir could be quite a distance from the CO_2 plume on initial injection. It will be interesting to see what regulations appear per this specific request.

Louisiana legislation (House Bill No. 661) provides the commissioner of conservation the duties and powers to promulgate rules and regulations requiring "interested person to place monitoring equipment of a type approved by the commissioner . . . ," and that monitoring will be regulated by rules developed by the commissioner.[89]

North Dakota legislation (Senate Bill No. 2095) requires the industrial commission to determine before a permit is issued "that the storage operator will establish monitoring facilities and protocols . . . ." The commission is also required to "take action that carbon dioxide does not escape from a storage facility." This will require an MVA program.

Each of the legislatures from Washington, Montana, North Dakota and Louisiana provided direction to their respective executive departments charged with captured CO_2 sequestration regarding overall goals. The specifics are left to the regulator to develop as Washington's Department of Ecology did for that state. Washington's regulations deferred to the prospective operator the selection of specific technology with which to fulfill regulatory requirements.

---

[87] Washington UIC Program, Dept. of Ecology, Found at: http://www.ecy.wa.gov/biblio/wac173218.html

[88] Montana, 61st Legislature, Senate Bill No 498, found at: http://data.opi.mt.gov/bills/2009/billpdf/SB0498.pdf

[89] Louisiana, Regular Session, 2009, House Bill No. 661, found at: http://www.louisianalawblog.com/uploads/file/HB-661(1).pdf

Assess the feasibility of carbon dioxide sequestration in West Virginia and the characteristics of areas within the state where carbon dioxide could be sequestered- §22-11A-6(h)(6)

IV.B.1.a. The kinds of geological formations which might work.

Feasibility for carbon dioxide sequestration in West Virginia is a reflection of the geology of West Virginia. West Virginia is, essentially, located entirely within the extents of the Appalachian Basin. This is a foreland basin[90] oriented along a general northeast-southwest axis, extending from north central Tennessee to central New York. Structurally, the strata within the basin becomes deeper to the southeast where it is bounded by the Allegheny Structural Front[91](Figure 4B3). Within West Virginia, this general trend is broken by two northeast-southwest trending structural features, the Rome Trough and the Upland Horst which is bounded by the Allegheny Structural Front (Fig.4B3). In southern West Virginia the Rome Trough is structurally deeper to the Upland Horst but both features merge to a common depth in northeastern West Virginia. The sedimentary section ranges from 8,000 feet to more than 20,000 feet in the Rome Trough and in the northeastern corner of the state.

Clastics, carbonates, and coal seams comprise the stratigraphic section found in West Virginia. The two dominant carbonate sedimentary rocks are limestones and dolomites. Sandstones and shales are clastic rocks. Sandstones and carbonates are the dominant reservoir rocks for oil and gas with shale commonly providing the seal. Sometimes a tight (very low to essentially no permeability) carbonate rock will act as the seal trapping oil and gas within a reservoir. Long known as a source rock as well as an excellent cap rock for reservoirs, organic rich shales have been recognized, as early as the 1970s, as a reservoir from which natural gas can be produced. A trap rock or seal represents a sharp reduction in permeability blocking further migration of fluids or gas.

All four of these sedimentary rock types can provide suitable conditions for sequestration of captured carbon dioxide. Sandstones, carbonates and (unmineable) coal seams are recognized as potential reservoir rocks while shale or a tight carbonate can provide the seal, or confining barrier. MRCSP provided an estimate of storage potential for shales in their Phase I report.[92] In their Sequestration Atlas, NETL did not provide an estimate of storage potential for shales.[93] The ability of shale to act as a sequestration reservoir is still under study.

The Midwest Regional Carbon Sequestration Partnership (MRCSP), one of the seven regional partnerships created by DOE/NETL, encompasses West Virginia and most of the states overlying the Appalachian Basin. The MRCSP conducted an evaluation of sequestration potential within the area of the partnership during Phase I of their project period.

The stratigraphic section present under West Virginia is illustrated in Figure 4B1. Formations with sequestration potential are illustrated in blue and formations that can provide a seal or act as a confining unit are illustrated in lime green.

---

[90] Wickstrom, L.H. et al., 2005, Characterization of Geologic Sequestration Opportunities in the MRCSP Region, Phase I Task Report Period of Performance: October 2003-September 2005, DOE/NETL DE-PS26-05NT42255.

[91] Roen, J.B., and B.J. Walker, 1996, The Atlas of Major Appalachian Gas Plays, West Virginia Geological a nd Economic Survey, Publication V-25.

[92] Wickstrom, L.H. et al., 2005, Characterization of Geologic Sequestration Opportunities in the MRCSP Region, Phase I Task Report Period of Performance: October 2003-September 2005, DOE/NETL DE-PS26-05NT42255

[93] NETL, 2008, Carbon Sequestration Atlas of the United States and Canada, second edition. Found at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/index.html

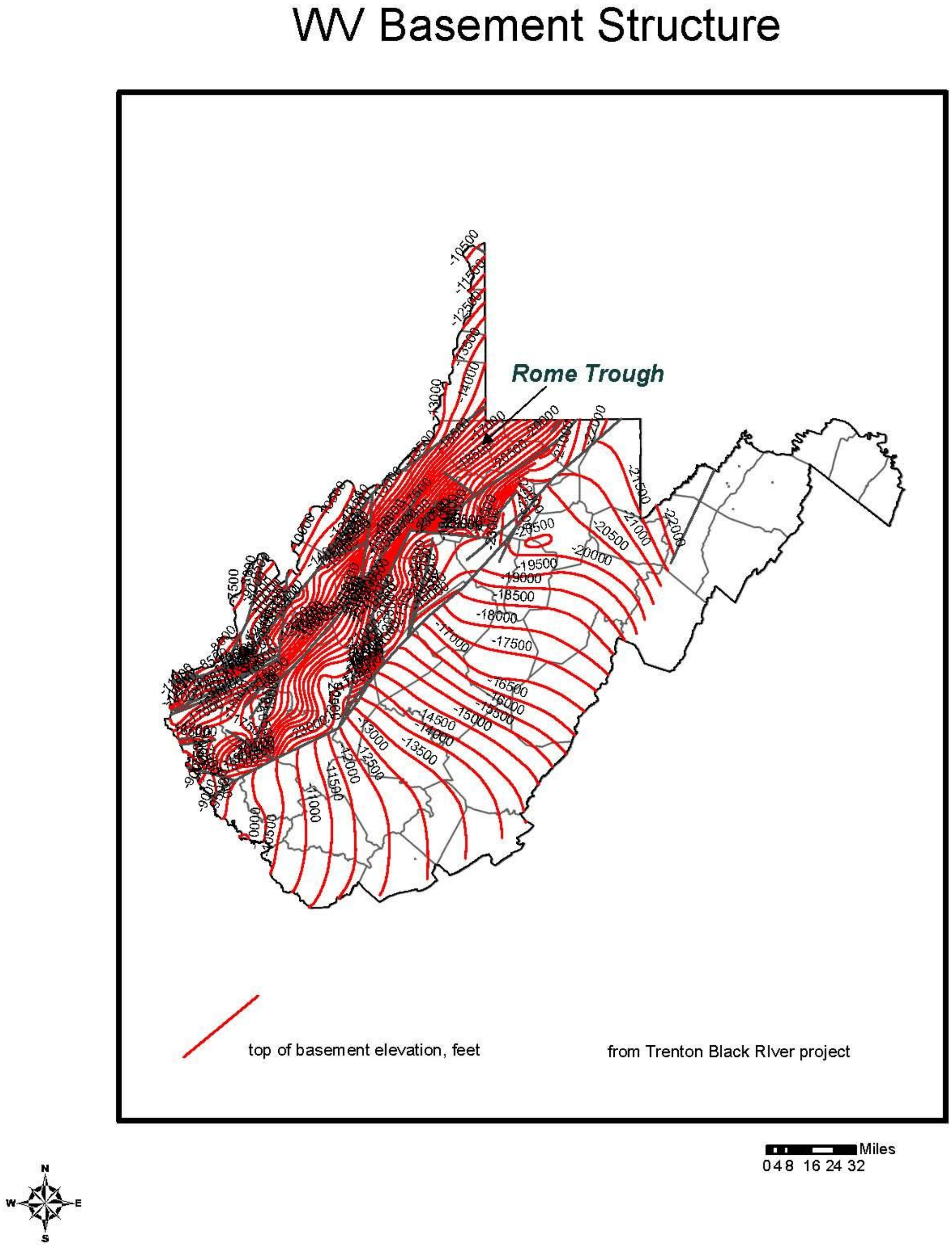


Figure 4B1: Structure contours on top of crystalline basement rock

Figure 4B2: Illustrative schematic of potential sequestration horizons in the stratigraphic section of West Virginia.

Geologic Systems & Series		Terminology Used on 1968 State Geologic Map		Former Terminology if different (WV Geological Survey County Reports)		Oil & Gas “Sands” (Drillers’ Terms)
Permian		Dunkard Gp				Carroll
Pennsylvanian	Upper	Monongahela Gp				Minshall, Murphy, Moundsville, Cow Run, Little Dunkard, Big Dunkard
		Conemaugh Gp				
	Middle	Allegheny Fm				Burning Springs Gas & Lower Gas, Horse Neck
	Lower	Pottsville Gp				Salt Sands (1st, 2nd, 3rd)
Mississippian	Upper	Mauch Chunk Gp				Princeton, Ravencliff, Maxon, L. Maxon, Little Line
	Middle	Greenbrier Gp				Blue Monday, Big Lime, Keener, Big Injun, Squaw, Weir
	Lower	MacCrady Fm				
		Price Gp				
Devonian	Upper	Hampshire FM		Catskill		Berea, Gantz, Fifty Foot, Thirty Foot, Gordon Stray, Gordon, Fourth, Fifth, Bayard, Elizabeth, Warren First & Second, Clarendon(Tioga), Speechley, Balltown(Cherry Grove, Riley, Benson, Alexander, Elk, Sycamore
		“Chemung Gp”				
		Brallier Fm		Portage		
	Middle	Harrell Shale	Millboro Shale	Genesee		
		Mahantango Fm		Hamilton		
		Marcellus Fm				
		Onesquethaw Gp	Onondaga Ls	Huntersville		Corniferous
			Huntersville Chert			
			Needmore Shale			
	Lower	Oriskany Ss				
		Helderberg Gp				
Silurian	Upper	Tonoloway Fm		Bossardville	Cayugan (Salina) Series	
		Wills Creek FM		Rondout		
		Williamsport Fm		Bloomsburg		Newburg Sand
	Middle	McKenzie Fm		Niagara	Niagaran Series	Lockport Dol. Newburg Dol.
		Rochester Shale		Clinton		Keefer Ss, Big Six Sand
		Keefer Ss				
		Rose Hill Fm				
	Lower	Tuscarora Ss		White Medina		Clinton Gas Sand, Medina Gas Sand,
Ordovician	Upper	Juniata Fm		Red Medina		
		Oswego FM		Gray Medina		
		Reedsville Shale				
	Middle	Martinsburg Fm	Trenton Gp	Martinsburg		Trenton-Black River, Glenwood at base.
		Nealmont Ls		Chambersburg	Moccasin	
		Black River Gp			Stones River	
		New Market Ls	St. Paul Gp (St Peter Ss)	Chazy		Chazy-Stones River, St. Peter
		Row Park Ls				
	Lower	Pinesburg Station Dol	Beekmantown Gp (Rose Run, Copper Ridge)		Knox	Knox Dol., Rose Run Sand
		Rockdale Run Fm				
		Stonehenge Ls				
Cambrian	Upper	Conococheague Fm				Trempealeau
	Middle	Elbrook Fm				
	Lower	Waynesboro Fm				
		Tomstown Dol				
		Antietam Fm	Chilhowee Gp			
		Harpers Fm				
		Weaverton-Loudoun Fm				
Pre-Cambrian		Catoctin Fm				
		Crystalline Rock				

Confining Unit	Sequestration Target	Organic Shale	Coal –bearing Interval	Basement

Sequestration potential is present in the:

- Upper Devonian Sandstones
- Lower Devonian Oriskany Sandstone
- Lower Silurian Sandstones
- Ordovician St. Peter Sandstone
- Cambrian Rose Run Sandstone & Copper Ridge Dolomite
- Basal Rome Trough Sandstone

Confining units are present above each formation with sequestration potential presenting multiple barriers to migration. At the top of the stratigraphic section are the Pennsylvanian coals.

It should be pointed out that West Virginia has a naturally occurring CO_2 reservoir. Indian Creek field is located in Kanawha County, West Virginia. The reservoir is the Lower Silurian Tuscarora Sandstone. As is the case with all the Tuscarora fields, it is located on an anticline (the northeast plunging nose of the Warfield anticline). Porosity is developed in the fractures associated with the structure. The Warfield anticline is asymmetric and water is reported downdip to the southeast of the productive wells. Apparently porosity pinches out downdip to the northwest and also off the northeast plunging nose of the anticline.

More than 30 wells were drilled in the field between 1973 and 1987. Food grade carbon dioxide along with methane are produced; the gas is reported to be more than 60% carbon dioxide.[94,95,96] Approximately 20 bcfg has been reported as produced from 1981 through 1992.[97]

IV.B.1.b. The extent and location of potentially feasible formations

The occurrence of oil & gas production in West Virginia illustrates the general extent of potentially feasible geologic formations for sequestration (Figure 2). Oil and gas fields are primarily found northwest of the Allegheny Structural Front to the Ohio River (Figure 2) and this will be the general area within which saline storage potential will be found.

---

[94] Hamak, J.E., and Sigler, Stella, 1991, Analyses of natural gases, 1986-1990: U.S. Bureau of Mines Information Circular IC 9301, 315 p.

[95] Hamak, J.E., and Gage, B.D., 1992, Analyses of natural gases, 1991: U.S. Bureau of Mines Information Circular IC 9318, 97 p.

[96] Jenden, P.D., Drazan, D.J., and Kaplan, I.R., 1993, Mixing of thermogenic natural gases in northern Appalachian basin: American Association of Petroleum Geologists Bulletin, v. 77, p. 980-998.

[97] Avary, K.L., 1996, Play Sts: The Lower Silurian Tuscarora Sandstone Fractured Anticlinal Play: *in* Roen, J.B. and Walker, B.J., eds., The Atlas of Major Appalachian Gas Plays: West Virginia Geological and Economic Survey, Volume V-25, p. 151-155.

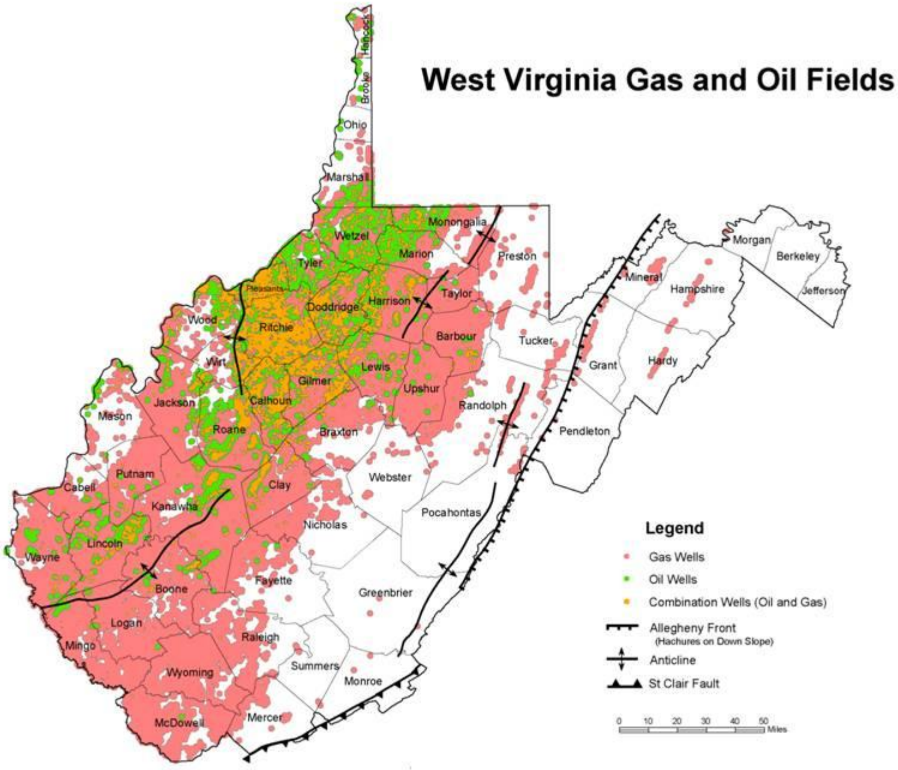


Figure 4B3: Distribution of oil & gas fields in West Virginia

It should be noted here that the Appalachian Power Company Mountaineer Plant along the Ohio River in New Haven (Mason County), West Virginia recently began injection of captured CO_2 into the Rose Run sandstone and Copper Ridge dolomite. A seal is provided by the Beekmantown dolomite which immediately overlies the Rose Run[98].

IV.B.1.c. Ability to assess specific CO_2 storage project feasibility

The purpose for any CO_2 storage field is to sequester the CO_2 captured from the source(s) with whom they have a contract. The operator of a storage field believes they have a certain amount of storage volume that will accept injection over a period of time. The source(s) hopes the storage field will be in operation over the life of their plant. Why does the storage field operator believe that they have sufficient storage capacity? Why was that location selected? Where was the necessary information found?

The ability to assess any specific project location and potential depends on the quality of the initial data available or that can be acquired. NATCARB data published in the Carbon Sequestration Atlas of the United States and Canada suggest a range of storage potential for the various states. These values represent a storage resource that needs to be proven. When an exploration well discovers oil and/or gas and establishes production, a portion of the oil and gas resource has been proven. Carbon sequestration reverses the process in a sense. Here, the resource is potential storage capacity representing the ability to inject captured carbon dioxide over a period of time. This potential needs to be proven, a process that begins with site characterization. But why select any particular site for CO_2 storage operations? We know oil and gas fields have storage capacity but these potential storage fields represent only a small

---

[98] Mountaineer Injection Well Geological Report,

portion of the storage capacity needed to meet proposed legislative mandates. Saline reservoirs represent the largest potential for sequestration of captured carbon dioxide. Oil and gas exploration did its best to avoid discovering water. Unless it occurs above a producing field, saline horizons are not well drilled and there will be less data available. Any potential storage field developer may or may not have a need to sequester a specific volume of captured CO_2. They may only be conducting an opportunity search. Emission sources though will have specific needs that must be met. An initial assessment will provide some perspective on the size of potential storage fields. Publicly available data and information will be critical for initial evaluation of storage potential, selecting a site for further site characterization. Sources of this information will be the state geological survey, publications in professional journals and academia. With this data, a prospective storage field developer should be able to determine prospective areas, how much territory will be required to cover the extent of a potential plume of sequestered CO_2 and what additional data needs to be acquired. John Tombari of Schlumberger Carbon Services estimates that it will cost $100,000 per square mile to acquire 3-D seismic and $3,000,000 to drill and log an evaluation well plus 30% of these costs for data processing, modeling and other services[99]. He estimates that one well will evaluate 25 mi^2. With 3-D seismic and one new well with modern data, characterizing a storage field covering 25 square miles will cost a little over $7,000,000. These costs probably do not cover all of the details that need to be accounted for, for example spotting all plugged and abandoned wells, in presenting a storage field proposal before a regulatory body with the intent of gaining a permit. The quality of data available for this initial assessment will provide a level of confidence on whether or not to proceed, whether or not a further investment in time and money is warranted.

Assess the potential carbon dioxide sequestration capacity in this state-§22-11A-6(h)(8)

IV.B.1.d. Calculation of available sequestration capacity

IV.B.1.d.i. Existing estimates

As noted above, the potential storage capacity for sequestering captured CO_2 is a resource value. Like any other natural resource, such as oil & gas or coal, actual storage capacity has to be proven. For oil & gas or coal, this involves drilling a well to gain an actual measurement of the resource and establishing a proved reserve. With production, a better understanding of an oil & gas reservoir is gained over time. Having a better understanding of the reservoirs potential, proved reserve values are sometimes increased. A proved reserve, while a more certain value, is also smaller than the value attached to the resource. For CO_2 sequestration, proving the resource potential will be done by site characterization and injection during field operations will further refine the understanding of a reservoir's storage capacity.

The Midwest Regional Carbon Sequestration Partnership (MRCSP) is one of seven regional partnerships assembled by DOE/NETL to evaluate, test and demonstrate carbon sequestration potential across the United States. States within the MRCSP are Michigan, Ohio, West Virginia, Maryland, Pennsylvania, New York, the northeastern half of Indiana and the eastern half of Kentucky. Geologic horizons or formations (Figure 4B2) considered for sequestration potential by the Midwest Regional Carbon Sequestration Partnership are:[100]

---

[99] McCoy, S.T., 2008, The Economics of CO_2 Transportation by Pipeline and Storage in Saline Aquifers and Oil Reservoirs. PhD dissertation, Carnegie Mellon University, January, 2008.

[100] Ibid, 90

- Upper Devonian: Hampshire Group (Berea Sandstone)
  - Greenland Gap Group
  - Rallier Formation
- Lower Devonian: Oriskany Sandstone*
- Lower Silurian: Newburg Sandstone
  - Keefer Sandstone
  - Brassfield Formation
  - Cabot Head Formation
  - Tuscarora Sandstone* (Medina Group)
- Upper Ordovician: Black River Group
  - St. Peter Sandstone
- Upper Cambrian: Rose Run Sandstone*
  - Copper Ridge Dolomite
- Lower Cambrian: Un-named Basal Sandstone*
  - (below Rome Formation)

At the top of the stratigraphic section in West Virginia are the coal bearing strata:

- Pennsylvanian*: Monongahela Group
  - Conemaugh Group
  - Allegheny Group
  - Pottsville Group
  - Kanawha Group
  - New River Group
  - Pocahontas Formation

The sequestration potential for the organic rich shales was also evaluated:

- Devonian*: Ohio Shale
  - Java Formation
  - West Falls Formation
  - Sonyea Formation
  - Genesee/Harrell Formation
  - Marcellus Formation

The MRCSP estimated the potential storage volume for each state within the partnership[101] (for West Virginia an * designates which units above contribute to the estimates in Table 4B1). Volumetric capacity for saline and oil & gas reservoirs was calculated at 10% efficiency. In a volume of sedimentary rock, the intergranular space is known as porosity, the pore space. This pore space represents some portion of the rock volume expressed as a percentage and is occupied by fluids, water or oil, or gases. Storage efficiency with respect to captured CO_2 is the percentage of pore space that may be occupied by the injected CO_2. A 10% storage efficiency means that the sequestered CO_2 will only occupy 10% of the pore space for that particular oil & gas reservoir or saline formation. While an organic rich shale will have some storage capacity within its fracture system, a much larger volume of captured CO_2 may be stored by adsorption onto the clay minerals and organic matter. Storage capacity for the coals is also an adsorption process. There are several factors that can impact sequestration potential for organic rich shales and coals. The potential storage for each was calculated at 10% efficiency as

---

[101] Ibid 90

applied to saline and oil & gas reservoirs. It should be noted that only unmineable coal seams are considered in these estimates of storage potential in coal for captured CO_2.

NETL has combined the work of the seven regional partnerships in the Carbon Sequestration Atlas of the United States and Canada[102]. This publication posts the potential storage for captured CO_2 for each state (or province) in the partnerships as well as an estimate for offshore capacity. The storage potentials posted in the Atlas represent a high-low range reflecting storage efficiency for saline reservoirs of between 1 and 4 percent. A recent analysis of storage efficiency by the IEA confirms the 1 to 4 percent range used by NETL[103]. The impact of the efficiency value on storage potential, a resource that needs to be proven, is apparent in Table 1. NETL did not apply storage efficiency to oil & gas reservoirs. Instead, CO_2 storage potential is calculated using volumetric and production based methods. Oil & gas storage potential is a single value in NETL's Atlas. Since coals retain CO_2 by adsorption, storage potential for unmineable coal seams is a range based on pressure gradient for a particular basin, average formation temperature, and coal rank if available. The Atlas did not consider shale storage potential. The range of storage potential in Table 4B1 is due to saline storage potential as unmineable coal seams only contribute about 1 to 3 percent of onshore lower 48 potential.

Table 4B1: Potential Storage Capacity for Captured CO_2 in West Virginia

	Shales	O & G	Coal	Saline	Total	Efficiency
MRCSP	19,000	600	110	41,100	60,810	10%
NETL (low)	-	1,353	177	3,343	4,873	1%
NETL (high)	-	1,353	177	13,463	14,994	4%

All values are in million metric tons (NETL's Atlas 3rd edition due Nov 2010).

As required in the Energy Independence and Security Act (EISA) of 2007, USGS will assess the onshore storage potential for captured CO_2.[104]

Except for oil & gas reservoirs, the area over which these storage estimates apply is the geographic extent of each horizon evaluated. As noted earlier, these values represent a resource that needs to be proven which will be accomplished to a large degree by the characterization process. Like any other resource such as coal or oil, while proving a resource provides a more reliable value upon which to base economic decisions, this value is usually a reduction of the earlier resource value.

---

[102] NETL, 2008, Carbon Sequestration Atlas of the United States and Canada. Found at: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/index.html

[103] IEA Greenhouse Gas R&D Programme (IEA GHG), "Development of Storage Coefficients for CO_2 Storage in Deep Saline Formations", 2009/13, October 2009.

[104] USGS, 2009, Development of Probabilistic Assessment Methodology for Evaluation of Carbon Dioxide Storage, OFR 2009-1035.

IV.B.2. Refinements of estimates

IV.B.2.a. Information needed

Storage capacity in any potential reservoir is a function of porosity or void space found within any suitable rock. Permeability connects the pore space and allows flow through the reservoir. This available porosity and permeability has a top and bottom (height), a net portion of the whole formation or stratigraphic interval within which it occurs. This available porosity and permeability also is not uniformly distributed over the areal extend of the formation or stratigraphic interval within which it occurs. Estimates of storage potential presented in this report assume an areal distribution of porosity over the extent of the prospective formation or stratigraphic interval. That is why these resource values need to be proven. It will take time, money and acquisition of suitable data.

Pore space is not empty. In oil & gas reservoirs there is some percentage of oil, gas and water in each pore space and below the oil/water contact the pore space is 100 percent water with some amount of dissolved solids. Pore space in saline formations or reservoirs will be fully occupied by water with some amount of dissolved solids. Knowledge of what is occupying the pore space in a prospective storage reservoir will be essential to reservoir modeling for site characterization and developing an MVA program. This critical reservoir information is provided by a combination of drilling data, core data, wireline or geophysical log data and seismic data.

IV.B.2.b. Unknowns

Good permeability is essential for injectivity and good porosity is essential for storage capacity. The use of ‘good’ here is relative, using ‘suitable’ or ‘sufficient’ would have sufficed but all illustrate the elusive nature of porosity, permeability and injectivity. We know that high numerical values for each are what every storage field operator is looking for. A souce will capture so many tonnes of CO_2 day in and day out. Every captured tonne needs to be sequestered and it is up to the storage field operator to provide the injection rate necessary. If permeability values are low then more injection wells will be need or more height over which to inject, a greater net injection interval. A second horizon for injection or another field area may be necessary to meet the needs of a source.

How these two critical variables, porosity and permeability, are distributed over any geographic extent is determined by reservoir architecture reflecting the depositional environment and post-depositional processes that can modify porosity and permeability of the host sediment, clastic or carbonate. Oil & gas reservoirs have some number of wells drilled within and around their boundaries that can provide some sense of reservoir architecture. Saline reservoirs will probably have less well control with which to determine reservoir architecture. Drilling evaluation wells and acquiring seismic data will provide critical information and both will be part of the site characterization process. The quality and areal extent of the seal may be less problematic in that bulk characterizations can satisfy concerns on seal integrity. Even though a site might be well characterized, sufficient to gain a permit, there will always be some level of geologic uncertainty.

IV.B.2.c. How much CO_2 needs to be stored

Amount generated by a power plant

A 1,000 MW bituminous pulverized coal power plant, operating at 85 percent capacity and capturing 90 percent of its carbon dioxide emissions will produce 6.24 million tonnes of

Table 4B2: List of emission sources with annual emissions in metric tons

Plant / Facility	Company	Industry Sector	County	Annual CO_2 Emissions
John E Amos	**Appalachian Power Co.**	**Power**	**Putnam**	**15,231,230**
Harrison	**Monongahela Power Co.**	**Power**	**Harrison**	**12,862,820**
Mt. Storm	**Dominion Virginia Power**	**Power**	**Grant**	**10,961,580**
Mitchell	**Ohio Power Co.**	**Power**	**Marshall**	**7,973,820**
Mountaineer	**Appalachian Power Co.**	**Power**	**Mason**	**7,663,480**
Pleasants	**Monongahela Power Co.**	**Power**	**Pleasants**	**7,224,740**
Fort Martin	**Monongahela Power Co.**	**Power**	**Monongahela**	**6,895,640**
Big Sandy[1]	**Kentucky Power Co.**	**Power**	**Lawrence**	**6,048,400**
Philip Sporn	**Central Operating Co.**	**Power**	**Mason**	**5,383,580**
Weirton Steel	**Weirton Steel Corp.**	**Iron & Steel**	**Weirton**	**3,957,880**
Kammer	**Ohio Power Co.**	**Power**	**Marshall**	**3,449,410**
Mingo Country CBM	**CONSOL**	**Gas Processing**	**Varney**	**2,836,420**
Kanawha River	**Appalachian Power Co.**	**Power**	**Kanawha**	**2,338,270**
Albright	**Monongahela Power Co.**	**Power**	**Preston**	**1,760,340**
Willow Island	**Monongahela Power Co.**	**Power**	**Pleasants**	**1,367,590**
Martinsburg	**Capital Cement Corp.**	**Cement**	**Martinsburg**	**831,020**
Grant Town Power Plant	**Edison Mission Power**	**Power**	**Marion**	**790,850**
Rivesville	**Monongahela Power Co.**	**Power**	**Marion**	**608,430**
Natrium Plant	**PPG Industries Inc.**	**Power**	**Wetzel**	**593,320**
Kenova	**MarkWest Hydrocarbon Inc.**	**Gas Processing**	**Wayne**	**498,350**
Copley Run		**Gas Processing**	**Lewis**	**491,278**
Hastings	**Dominion Resources**	**Gas Processing**	**Wetzel**	**486,190**
North Branch	**Dominion Virginia Power**	**Power**	**Grant**	**485,310**
Morgantown Energy Facility	**Dominion Energy NUGs**	**Power**	**Monongahela**	**448,840**
Alloy Steam Station	**Elkem Metals Co.**	**Power**	**Fayette**	**297,990**
West Union		**Gas Processing**	**Doddridge**	**200,973**
Schultz		**Gas Processing**	**Pleasants**	**111,653**
Ergon Refining		**Refining**	**Newell**	**110,780**
Cobb[2]	**MarkWest Hydrocarbon Inc.**	**Gas Processing**	**Kanawha**	**101,290**
Total Annual Emissions				**102,011,474**

1 - Kentucky Power Co. Big Sandy plant is on the Kentucky side of the Big Sandy River.

2 – Cobb Gas Processing plant is listed twice

carbon dioxide in a year.[105] On a daily basis for sequestration, this is about 100,000 barrels of CO_2 per day for injection. In 2009, West Virginia oil production averaged about 155,000 barrels of oil per month or 5,000 barrels of oil per day.[106] If this 1,000 MW plant has a 50 year project life, then about 1.8 billion barrels of CO_2 will need to be sequestered. In the world of oil & gas production, this is a giant field (>500 million barrels recoverable) and they are not commonly found.

In the second edition of the Sequestration Atlas, 29 sources in West Virginia emit about 102.0 million tonnes (597 million barrels) of CO_2 per year (Table 4B2). The table was assembled by the MRCSP. Two interesting points to make regarding the plant list: 1) the Big Sandy power plant is across the Big Sandy River from West Virginia in Kentucky and 2) the Cobb Gas Processing plant was listed twice while the owner, MarkWest, only mentions on site on their company web site. With an estimate storage resource potential between 4,873 and 14,994 million tonnes, West Virginia has between 47 and 147 years of injectivity.

Including Kentucky Power Company's Big Sandy power plant on a list of emissions for West Virginia highlights an important consideration regarding CCS. Emissions do not respect political boundaries and neither will CO_2 plumes in the subsurface. There are several power plants on the West Virginia side of the Ohio River. West Virginia can only address what it can control but it will be important to work with adjoining states.

The area needed for storage

Estimating the area needed for a storage field is difficult. Because of the buoyancy of CO_2 relative to saline formation fluids, the standard model used in modeling CO_2 injection displays an inverted cone with the accumulation of the CO_2 gathering at the top of the reservoir against the seal (Figure 4B4). This simple model assumes a homogeneous reservoir that ignores geologic variability of reservoir architecture.

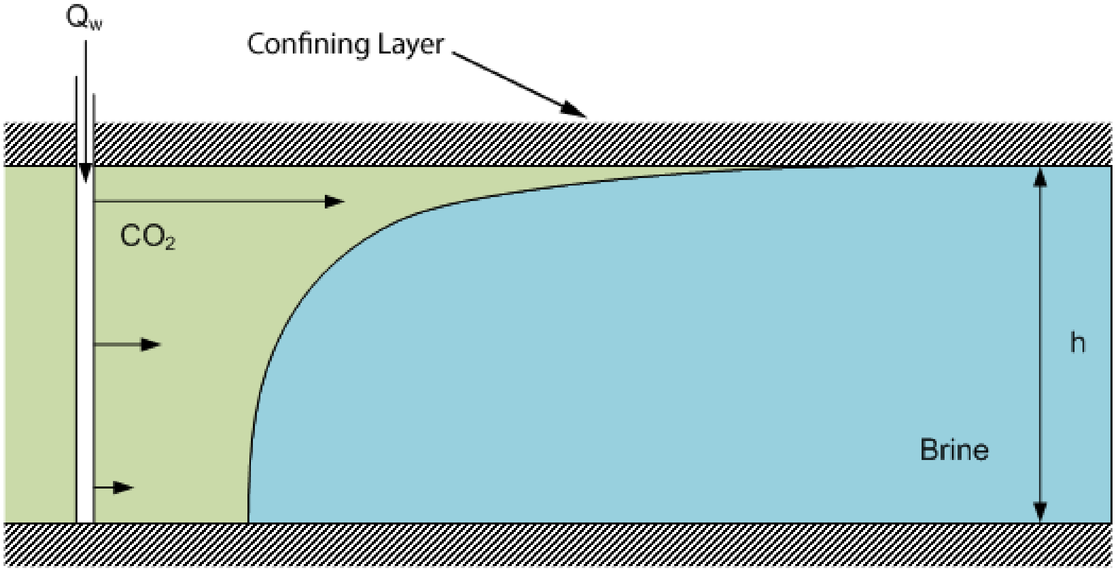


Figure 4B4. Simple model of CO_2 injection into a storage reservoir.(unknown source) (Q_w = injection rate, h = height of reservoir interval)

---

[105] MIT, 2007, The Future of Coal. Found at: http://web.mit.edu/coal/

[106] EIA: http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPWV1&f=M

A simple model as illustrated in Figure 4B4 will require more acreage to secure the rights to the pore space for the top of the plume than the base of the plume. Any reservoir will have internal permeability barriers that will compartmentalize the porous and permeable space available for storage. If the simple model in Figure 4B4 included several permeable barriers acting as internal traps within the reservoir then the area of the plume would be reduced. Modeling done by Advanced Resources International suggests that the plume area could be reduced by 60% from that of the simple model in Figure 4B4.[107]

An important consideration here is that the stratigraphic section present in West Virginia has multiple horizons with storage potential. Utilizing each of these horizons for sequestration of captured CO_2 will create a stacking of storage reservoirs, one above the other or overlapping to some extent. This is true for oil and gas fields, especially for structurally trapped hydrocarbons. Discoveries on structure are first made in the shallow reservoir but upon drilling deeper, oil and gas is often encountered in lower reservoirs. Stacked and/or overlapping reservoirs will help reduce the areal extent of sequestered CO_2 plumes has measured at the surface. Important considerations here will be the location of surface facilities, wells and monitoring sites as these plumes expand with injection.

The Carbon Sequestration Working Group (CSWG) in Wyoming did some modeling utilizing a value of so many million tonnes of CO_2 sequestered per square mile.[108]. Modeling done by the Wyoming State Geological Survey suggested a plume area factor of 0.133 mi^2 per million tonnes CO_2 injected. The CSWG cited a NETL value of 0.75 mi^2 per million tonnes of CO_2 injected but they thought that this was too conservative for their purposes and adopted a value of 0.15 mi^2 per million tonnes injected, an 80 percent reduction in area needed to cover the plume in the subsurface. As noted above, modeling done by ARI shows that multiple permeability barriers within the reservoir can reduce the areal extend of a CO_2 plume by 60 percent. How many tonnes of CO_2 will be stored per square mile will end up being formation specific. However, until these hard values are determined, the above mentioned values will be used to do ‘back of the envelop’ estimates and evaluate prospective areas for further site characterization. Which value or what value to use will be up to whoever is conducting the evaluation.

Combining some factors already presented, one well evaluating 25 mi^2 and storage factors of either one million metric tons per 0.15 mi^2 or 0.75 mi^2, one can see how well the storage needs are met for three power plants of different output and emissions (Table 4B3). The two storage factors, one million metric tons (1Mt) per 0.15 mi^2 or 0.75 mi^2, can reflect either a change in porosity or change in height or thickness of the injection-storage interval or even a change in storage efficiency. Looking at a potential storage field covering 25 mi^2; if this field had a storage factor of 1Mt per 0.15 mi^2 it will hold 166 Mt but only 33 Mt with a storage factor of 0.75 mi^2. The difference between these two storage factors is eight years of injection activity for the John Amos plant. For the Willow Island plant, the 0.15 mi^2 storage factor over 25 mi^2 can easily accommodate the emissions of for a 30 year plant life; for the 0.75 mi^2factor a second storage field will be required to sequester the 42 Mt of emissions. Plant output for the Willow Island plant is about the same as the average boiler size for the coal fired electric power fleet.[109] It was mentioned earlier that it will cost a little over seven million dollars for one evaluation well

---

[107] Kuuskraa, V., 2009, Using Reservoir Architecture to Maximize CO2 Storage Capacity at SECARB’s Mississippi Test Site; presented at GHGT-9, Washington, D.C., November 2009.

[108] Report and Recommendations of The Carbon sequestration Working Group to the Joint Minerals, Business and Economic Development Committee and the Joint Judicial Committee of the Wyoming State Legislature, September, 2009. Found at: http://deq.state.wy.us/out/downloads/1%20FinalReport081909.pdf

[109] Across the United States, there are 1,445 coal fired boilers for electric power generation with a combined nameplate capacity of 337,300 MW[109], an average of about 233 MW per boiler. EIA: http://www.eia.doe.gov/cneaf/electricity/epa/epat1p2.html

and 3-D seismic to cover 25 mi^2. For the Phil Sporn plant, this should just cover site characterization if the storage factor is 1 Mt per 0.15 mi^2. With the smaller storage factor site characterization cost increase five times for the Phil Sporn plant.

Table 4B3: Years of injection for emissions of various plants**.**

Plant Name	**Power MW**	**CO_2 Emissions Mt/yr**	**CO_2 Emission 30 yr Plant Life Mt**	**Years injection – 25 mi^2 area**	
				[0.15mi^2] [166Mt]	**[0.75mi^2] [33 Mt]**
John Amos	2,932	15.2	456	10.9	2.2
Phil Sporn	1,105	5.4	162	30.7	6.1
Willow Island	213	1.4	42	118.5	23.5

Data needed for better estimates of potential storage capacity

The challenge here is to estimate the amount of square area that will need to be characterized and permitted in order to secure the rights to the pore space for sequestration over the life of a particular project. The position and stability of a three dimensional plume of CO_2 in the subsurface is related back to two dimensional surface area. The best set of data that any CO_2 storage field operator will have will be at the end of operations when injection is completed and the field is decommissioned. At this point in time, one know for certain how much CO_2 is sequestered and its areal extent. Thirty or fifth years earlier, the level of certainty for both was much less yet projections were made based on modeling incorporating data on hand at the time. This early information was presented to a regulatory body in order to gain a permit to develop and operate a CO_2 storage field.

Essential data necessary for better storage calculations is porosity, permeability, height of injection interval, areal extend of porosity and permeability and how much pore space will the CO_2 occupy, the efficiency factor. As noted earlier, initial data sources will include the USGS and state geological databases, academic studies and publication, and professional publications. Saline formations are estimated to provide for most of the sequestration yet these formations will have the smallest database. Except for the CO_2 efficiency factor, much to most of this data can be found for oil & gas reservoirs. For saline formations this data will be more difficult to assemble.

Key information is porosity and permeability. Porosity can be calculated from well logs but permeability measurement requires a rock sample in the form of a core. Both require a well to have been drilled or to be drilled. If this information doesn’t exist then a well will have tgo be drilled. Drilling a well requires a permit which requires a drilling unit which requires acreage or leases. Is it worth drilling the well before committing to site characterization? Is there any seismic data to support further work on the prospect? An important step here is moving from initial assessment to site characterization as this step will require an investment of millions to tens of millions of dollars. Making an investment in a subsurface resource requires sufficient data and information to assure investors that the risk is acceptable, that there is an acceptable probability that the project will go forward.

It is widely considered that a CO_2 storage field developer will have to secure the rights to utilize subsurface pore space for sequestration per state regulation. Securing this right is a strategic decision upon which to make an investment. How much area to secure to establish rights to pore space is problematic because the actual extent of the subsurface saline reservoir is unknown. A right of access will have to be established for site characterization to provide access for seismic data acquisition, drilling of a well or wells and initial MVA activity. Some seismic

Vibroseis coverage can be acquired along public highways. Knowing how much area for which to secure pore space rights at the beginning of the process of developing a CO_2 storage field may come down to individual “rule of thumb,” the storage factor (see Table 4B3). The ability to assess economic potential for CO_2 sequestration and proceed with site characterization and securing the rights to subsurface pore space over a broad areal extent will depend on the quality of geologic data available for initial assessment of subsurface potential.

Reservoir assumptions impact estimates of potential storage capacity. Dominant reservoir modeling to date assumes an open reservoir where the CO_2 pressure front does not encounter a boundary resulting in increasing injection pressures. The formations utilized for injection at Sleipner and at In Salah are considered open reservoirs. While some consider most reservoirs closed, many believe reservoir have more open than closed characteristics.[110] A solution to maintaining constant injection pressure is the co-production of formation waters during injection, providing pressure relief and creating an open reservoir. The Wyoming State Geological Survey (WSGS) modeled co-production of formation waters during sequestration operations.[111] WSGS model was able to render about 80 percent of the produced water potable, injecting the reaming 20 percent into the subsurface. They noted this potable water has agricultural or residential potential or can possibly be released to streams or rivers. Co-production of formation waters adds another level to operations requiring additional capital, raising operating expenses and requiring additional permits.

IV.B.3. Possible Failure of Sequestration

IV.B.3.a. Mechanisms of failure

Carbon dioxide could escape from the subsurface through a well casing failure, a well cement failure, a failure at the well head, a well blowout, improperly reworked (workover) wells, improperly abandoned or unmarked wells or a geologic path such as a fault or fractures or a combination. A well failure appears to be one of the more likely causes of a release of CO_2 from underground storage. Pipeline failure presents another possibility of release of CO_2 to the atmosphere. CO_2 pipelines will deliver the CO_2 to the storage field and a field pipeline network will distribute the CO_2 to the injection wells. Inadvertent release of captured CO_2 can range from minimal and possibly undetectable to catastrophic. The ability to detect leakage from a storage reservoir will depend on the level of resolution of the MVA technology and vigilance of the operator. Preventing catastrophic release from pipelines or wells will depend mostly on the quality of the trained personnel operating these facilities.

---

[110] Economides, M.J. and Ehlig-Economides, C.A., 2009, Sequestering Carbon Dioxide in a Closed Underground Volume, SPE Paper 124430, Presented at SPE ATCE meeting in New Orleans, October 2009.
Dooley, J.J. and Davidson, C.L., 2010, A Brief Technical Critique of Ehlig-Economides and Economides 2010: “Sequestering Carbno Dioxide in a Closed Underground Volume”, PPNL-19249

[111] Surdam, R.C., Zunsheng, J., Stauffer, P., and Miller, T., 2010, An integrated strategy for carbon management combining geological CO_2 sequestration, displaced fluid production, and water treatment. Challenges in Geologic Resource Development No. 8, Wyoming State Geological Survey.

Pipelines

Table 4B4: Pipeline Incidents Statistics for the United States from 1994-2006

Pipelines	**Natural Gas**		**Hazardous Liquids**	**CO_2**
	Transmission	**Grid**		
Number of Incidents	1,241	1,707	2,048 (1)	18
Number of Fatalities	29	223	24	0
Number of Injuries	112	765	101 (2)	0
Property Damage	$745 million	$780.9 million	$1,006 million	$1.15 million
2006 Mileage (3)	320,073	1,214,439	160,873	3,769

Source: *PHMSA Annual and HL Accident and Gas Incident Reports as of October 15, 2007.*

(1) The reporting criteria changed on February 7, 2002, adding small spills down to five gallons. For continuity with past trending, the data from accidents used in our statistical summary occurring after this date includes only accidents meeting the reporting criteria: accidents with gross loss greater than or equal to 50 barrels; those involving any fatality or injury; fire/explosion not intentionally set; highly volatile liquid releases with gross loss of five or more barrels; or those involving total costs greater than or equal to $50,000.

(2) Does not include 1,851 injuries that required medical treatment reported for the October 1994 accidents that were caused by severe flooding near Houston, Texas.

(3) Transmission mileage includes transmission and gathering miles. Distribution miles include distribution main miles only.

The total miles of CO_2 pipelines is 0.25 percent of the total natural gas pipeline miles, both transmission and grid pipelines. Natural gas grid pipelines are the distribution segment of the system, found in areas of higher population density than transmission lines which are cross-country. The higher number of injuries and fatalities for grid natural gas pipeline reflect their proximity to more urban areas. Natural gas pipelines are designed to bring their product from the reservoir to the consumer. The conceptual framework of a CO_2 pipeline network is opposite that of the natural gas pipeline network. Carbon dioxide pipelines will transport their product from a source that may or may not be in an urban area to a storage field located in areas of low population density. The grid portion of the CO_2 pipeline network will be in the storage field or among the storage fields. The captured CO_2 will be removed from the 'market' area and returned to the field.

To accomplish the task of significantly reducing CO_2 emissions envisioned for CCS technology, the present CO_2 pipeline network will be greatly expanded. Simple modeling studies done to date suggest a pipeline network of between 6,000 and 36,000 miles transporting as much as 54 Gt of captured CO_2.[112] The actual CO_2 pipeline network could be double the mileage estimate of these studies, even triple yet still be less that the overall network of that for hazardous liquids and still only a fraction of the natural gas pipeline network. Unlike natural gas, CO_2 is not flammable and does not represent an explosive risk, an important point that should reduce the level of risk associated with these pipelines. Carbon dioxide will be transported under higher pressures than that for natural gas to maintain the supercritical or dense phase state. A common accident for pipelines is a puncture due to construction activity. The sudden release of pressure due to puncture of a CO_2 pipeline will be 'explosive' in character but not flammable. There is considerable potential of harm for those in the immediate area. However, the potential for injuries associated with a much longer CO_2 pipeline network should

---

[112] Carbon Sequestration & Storage: Developing a Transportation Infrastructure. Prepared for the INGAA Foundation, Inc. by ICF International. February 2009. Available at: http://www.ingaa.org/cms/31/7306/7626/8230.aspx.
Dooley, JJ, RT Dahowski, and CL Davidson. "Comparing Existing Pipeline Networks with the Potential Scale of Future U.S. CO_2 Pipeline Networks." Presented at 9th International Conference on Greenhouse Gas Control Technologies on November 16-18, 2008, at the Omni Shoreham Hotel in Washington DC. Available at: http://www.sciencedirect.com/science/article/B984K-4W0SFYG-7D/2/a0db295a18b4fe6099846c2ab2738bb0.

not appreciably increase, the possibility for incidents and an increase in fatalities even less. This will depend on urban proximity to the greatly expanded CO_2 pipeline network yet the non-flammable nature of CO_2 should keep the potential for fatalities lower than that for natural gas pipeline incidents.

In testimony before the House Subcommittee on Energy and the Environment, Ian Duncan of the Texas Bureau of Economic Geology stated "It has been suggested in the literature that the incident rate CO_2 pipelines can be estimated from that for natural gas pipelines. USDOT statistics recorded ten incidents of CO_2 pipelines failures. The DOT data suggest that these incidents were caused by: relief valve failure (four incidents); weld, gasket, valve packing failure (three); corrosion (two); and outside force (one). Similar DOT statistics for a very large data set of natural gas pipelines in the US showed the reasons for failure as: outside force, including damage by contractors, farmers and utility workers (35%); corrosion (32%); other, such as vandalism, train derailment and improper operation of manual valves (17%); weld and pipe failures (13%); and operator error (3%). There is good reason to believe that the rate of incidents (rupture, puncture etc) for CO_2 and natural gas pipelines should be the same if CO_2 sequestration is implemented on a large scale. It is important to note that even if the rates of incidents for CO_2 and natural gas pipelines begin to look the same in the future; my judgment is that the risk will still be lower for CO_2 pipelines (a conclusion that appears to be increasingly supported by governmental reports and academic studies). I also believe that the risk from rupture of CO_2 pipelines is the largest risk facing a future CO_2 sequestration industry. If this conclusion proves correct then this places strong bounds on the risks of geologic CO_2 sequestration. Ultimately the risk from pipelines depends on: siting of the pipelines (risks are site specific); operation of the pipelines to minimize possible corrosion (particularly the current industry focus on keeping the water levels in the CO_2 below saturation); and implementation of effective risk management and mitigation plans."[113] Note that in the testimony, there is only one incident of outside force rupturing a CO_2 pipeline while this category accounts for 35 percent of natural gas pipeline failures. Although it may be more rural relative to the natural gas pipeline network, expanding the CO_2 pipeline network will expose it to more opportunities of outside force rupturing.

The Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) has had, since 1988, oversight authority of transportation of CO_2 by pipeline.[114] Carbon dioxide is non-combustible and non-toxic. It is heavier than air. When concentrated it can pool near the ground, displacing oxygen. With time it dissipates, forming a cloud. Because of these properties and the fact that CO_2 is transported as a compressed gas and/or in high concentrations, it is classified as a hazardous material and subject to the Hazardous Material Transportation Laws and DOT's implementing laws. Pursuant to legislation establishing DOT's oversight of CO_2 pipeline, the Department extended its existing hazardous liquids pipeline rules to CO_2 pipeline operations.[115]

PHMSA works closely with certain state agencies to provide oversight of CO_2 pipeline network. Their "integrity management regulations, which currently apply to transmission pipelines (liquid and gas), require operators to conduct risk assessments of the condition of their pipelines; develop and implement risk control measures to remedy safety problems, worst first; and evaluate and report on program progress and effectiveness. Under integrity management

---

[113] Ian Duncan, 2009, Regarding The Future of Coal under Climate Legislation; Carbon Sequestration Risks, Opportunities, and Learning from the CO2-EOR Industry. Testimony before the The U.S. House Committee on Energy and Commerce, Subcommittee on Energy and the Environment, March 10, 2009.

[114] Krista L. Edwards, Deputy Administrator, Pipeline and Hazardous Materials Safety Administration, Department of Transportation, testimony before the Committee on Energy and Natural Resources, United States Senate, January 31, 2007.

[115] Ibid

programs, operators are identifying and repairing pipeline defects before they grow to failure, producing steady declines in the numbers of serious incidents."[116]

PHMSA "operates five regional pipeline safety offices and is authorized to employ 111 inspection and enforcement professionals for fiscal year 2008. In addition to compliance monitoring and enforcement, PHMSA's regional offices respond to and investigate pipeline incidents and participate in the development of pipeline safety rules and technical standards. Our regional offices also work closely with PHMSA's State program partners, which employ approximately 400 pipeline inspectors and directly oversee the largest share of the U.S. pipeline network, including most intrastate pipelines. Under our Congressionally-authorized Community Assistance and Technical Services (CATS) program, PHMSA's regional offices provide safety-focused community outreach and education. With the current wave of pipeline expansion, and increasing commercial and residential development around existing pipelines, the CATS program is serving a vital role in educating the public about pipeline safety and encouraging risk-informed land use planning and safe excavation practices."[117]

The WVDEP or another agency may want to coordinate CO_2 pipeline oversight efforts with the Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). PHMSA already has oversight relationships with states where CO_2 pipelines are in operation.

Well failure

Well failure, either leakage behind casing or an actual blowout, is a second avenue of release of CO_2 to the atmosphere. A change in pressure in the well annulus will alert the operator to a potential leak requiring a closer examination of the well and possibly a well workover. A workover is when a well is opened for repairs and for wells open to high pressure reservoirs this presents the possibility of a well blowout. Carbon dioxide injection wells are high pressure wells. Several blowouts have occurred during operations of West Texas EOR fields from production and injection wells.[118] Release of CO_2 from these blowouts is estimated to range from less than 1 mmcf per day to 10 mmcf per day (~53 to 530 metric tons per day).[119] Cause of these blowouts range from corrosion, leaking gaskets, valves left open or mechanical failure. No injuries of fatalities occurred due to these well blowouts. A carbon dioxide well blowout presents unique challenges. These are high pressure wells and the sudden release of pressure is a high velocity phenomenon that quickly clears out the well. The sharp drop in pressure and gas expansion results in adiabatic cooling. The released CO_2 quickly drops below its triple point providing for the formation of dry ice particles.[120] With anticipate growth of the CO_2 injection business, proper training of CO_2 storage field personnel as well as well workover and well drilling crews is critical for safe operations as well as preventing inadvertent release of CO_2.

The USEPA has published a Technical Support Document: *Vulnerability Evaluation Framework for Geologic Sequestration of Carbon Dioxide*. This document provides a series of evaluation matrixes covering all aspects involved in developing a storage field prospect with the goal of minimizing risk, the probability of sequestered CO_2 migrating beyond its intended boundaries. The USEPA's proposed Class VI injection rules will support this effort. NETL is publishing a series of 'best practices' manuals covering all aspects of CO_2 sequestration. The

---

[116] Ibid
[117] Ibid
[118] Duncan, I.J., Nicot, J-P., and Choi, J-W, 2008, Risk Assessment for future CO2 Sequestration Projects Based CO_2 Enhanced Oil Recovery in the U.S. Elsevier. Available online at www.sciencedirect.com
[119] Skinner, L., 2003, CO_2 blowouts: An emerging problem. World Oil, January 2003, p. 38 - 42
[120] Ibid

USEPA will also develop 12 Technical Guidance documents to inform potential operators, regulators and the public on the various aspects of CO_2 sequestration. West Virginia has established primacy for issuance of permits under USEPA's UIC program. This will most likely continue for Class VI permits. This permit will require construction standards for injection wells.

Other failure mechanisms

Release of CO_2 to the atmosphere by means other than via a well or pipeline failure is an important consideration. An often cited incident is the loss of life associated with large release of CO_2 from Lake Nyos in Cameroon, Africa. In August of 1986, a large volume of CO_2 was released from the lake. This cloud of CO_2 moved downhill from the lake, suffocating about 1,700 people. To the southeast, Lake Monoun had a smaller release resulting in 37 fatalities.[121] Both lakes are in the volcanic region of Cameroon. The CO_2 is from the magma beneath the lakes. This situation is not characteristic of West Virginia or Appalachian Basin geology.

Other potential migratory pathways for CO_2 are old well bores, faults that cut to or near the surface or fracture patterns. A potential danger here is that CO_2 may migrate along these pathways and accumulate in confined space, for example the cellar of near-by house or a structure in or near the storage field. A leak from a Kansas natural gas storage field migrated via an old well bore through the vadose zone (shallow subsurface above the water table) into the cellars of buildings in near-by town.[122] With sufficient accumulation, the natural gas was ignited resulting in several fatalities and destruction of the building. Although non-flammable, CO_2 in sufficient concentration will cause asphyxiation as occurred at Lake Nyos.

Out in the open, it may be difficult for CO_2 to build up to dangerous levels. Monitoring of one of the well blowouts mentioned above recorded CO_2 levels of approximately 4750 ppm (0.475%) 200 feet away and these accumulations dissipated in about 30 minutes.[123] In Utah, the Crystal Geyser is a CO_2 charged eruption of cold waters via an old wellbore. The well was drilled in 1935 for oil exploration. While this well represents an example of poor oversight of a well permit and improper plugging of an abandoned well, it is a tourist attraction and presents no apparent danger.[124]

Natural gas storage in aquifers provides examples on the challenges and potential failure of these types of reservoirs. In 2008, there were 401 active natural gas storage fields: 34 salt caverns, 43 aquifer and 324 depleted oil & gas fields.[125] Total amount of gas in storage, 5.9 TCF, represents about 120 million metric tons (assuming pure methane)[126], slightly more than the 102 million metric tons of annual CO_2 emissions for West Virginia. As the numbers suggest, aquifer natural gas storage is much less desirable than depleted oil & gas reservoir storage. Depleted oil & gas reservoirs are known traps. Development of aquifer natural gas storage has a few drawbacks. Its geological characteristics are not as thoroughly known, as with depleted reservoirs. Some exploratory wells may need to be drilled to gather rock data (wireline logs and core samples), seismic data may be required to confirm the structural configuration of the trap

---

[121] Trying to Tame the Roar of Deadly Lakes, Marguerite Holoway, New York Times, February 27, 2001. Found at: http://www.nytimes.com/2001/02/27/science/trying-to-tame-the-roar-of-deadly-lakes.html?sec=&spon=&partner=permalink&exprod=permalink. Retrieved April 17, 2010

[122] Fredlund, D.F., 2008, The Evolving Regulatory Freamework to Govern Carbon Sequestration, presented at the 7th Annual Conference on Carbon Capture & Sequestration, Pittsburg, Pa.

[123] Ibid, 132

[124] Crystal Geyser, Wikipedia: http://en.wikipedia.org/wiki/Crystal_Geyser. Retrieved April 18, 2010.

[125] EIA, Underground Natural Gas Storage Capacity: http://www.eia.doe.gov/dnav/ng/ng_stor_cap_dcu_nus_a.htm

[126] Lawrence Berkeley National Laboratory article on "Relevance of Underground Natural Gas Storage to Geologic Sequestration of Carbon Dioxide" by Marcelo J. Lippmann and Sally M. Benson.

and injectivity test may be necessary.[127,128] It can take up to four years to develop an aquifer natural gas storage field, twice the time needed of a depleted reservoir,[129] and a further ten or more years before the full extent of storage capacity is realized as the natural gas bubble is increased in area. Development of aquifer storage is a more exploratory procedure than for depleted reservoirs which impacts the economics for these particular projects.

Aquifer natural gas storage is a high pressure operation, exceeding hydrostatic but not fracture gradient pressures, required to displace formation waters and represents a much higher storage efficient, approaching 100 percent, than what is expected for CO_2 storage (Table 4B1). This is necessary to create the bubble and provide for high delivery rates when the stored gas is produced and shipped to market. The high pressure nature of natural gas storage is the main cause of leakage.[130] Most of the leakage is through well failure although some natural gas may be lost at the margins of the bubble. Some operations will drill collector wells to recover natural gas that has escaped the reservoir.[131]

Natural gas storage in aquifers typically is done at a site that appears to have appropriate structure and a trap to contain hydrocarbons. However, since no hydrocarbons were initially discovered in the formation, the nature and quality of the trapping mechanism is not well established. It raises questions about the containment and sealing capability of the apparent trap and the integrity and tightness of the caprock. The Manlove Storage Field in Champaign County, Illinois initially injected natural gas into a St. Peter sandstone reservoir. Natural gas was discovered in the overlying glacial drift shortly after injection began. Natural gas was then injected into the deeper Galesville sandstone but leakage was also detected. Drilling deeper, injection of natural gas was finally secured in the Mt. Simon sandstone because the overlying Eau Clair formation provided a suitable seal.[132]

IV.B.4. Kinds of impacts

IV.B.4.a Groundwater contamination

Regulations Protecting Groundwater

The protection of groundwater throughout a CCS project is vital to the water resources in West Virginia. The current regulations that govern the protection of groundwater include: West Virginia Code, Chapter 22, Article 11 (Water Pollution Control Act) Section 8, Chapter 22 Article 12 (Groundwater Protection Act), and Legislative Rules, Title 47, Series 13 (Underground Injection Control) Sections 12 and 13. The priority for all of these rules is the protection of groundwater.

Risks to Groundwater via CCS

Risks to groundwater quality arise from the potential for CO_2 to mobilize organic or inorganic compounds, acidification and contamination by trace compounds in the CO_2 stream, intrusion of native saline groundwater into drinking water aquifers, and the potential for the CO_2 to displace subsurface fluids. The probability of many of these risks occurring may be decreased by a thorough site characterization, sound injection well construction and sufficient monitoring.

---

[127] Ibid

[128] Storage of Natural Gas, found at: http://www.naturalgas.org/naturalgas/storage.**asp**

[129] Ibid 140, 141

[130] Ibid 140

[131] Ibid 141

[132] Midwest Geological Sequestration Consortium, 2005, An assessment of Geological Carbon Sequestration Options in the Illinois Basin, Phase I Final Report. Found at: http://sequestration.org/publish/phase1_final_rpt.pdf

IV.B.4.b. Permit Requirements

In addition to the rules and regulations which protect groundwater, there are other factors that CCS permits will utilize to protect groundwater. A thorough characterization of the injection site and a geological investigation of the injection formations will aid in the identification of potential avenues for groundwater contamination. Adequate confining zone formations are also necessary to limit the possibility of CO_2 migration into the lower most drinking water aquifer.

Each proposed CCS site should be considered on an individual basis. For instance, the AEP Mountaineer Project has over a thousand feet of confining zone formations between the injection zone and the lower most aquifer. At another site there may only be 500 feet of confining zone formations and be equally capable of protecting groundwater. Using the site characterization and the geological investigation a decision will be made to determine if the vertical separation is sufficient.

Groundwater Quality

USDW is an aquifer that "supplies any public water system, or contains a sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption or contains fewer than 10,000 milligrams/liter of total dissolved solids (TDS)"[133]

Table 4B5: Classification of Water based on Total Dissolved Solids[134]

Water Classification	TDS milligram per liter
Fresh	0 – 1,000
Brackish	1,000 – 10,000
Saline	10,000 – 100,000
Brine	➢ 100,000

Prior to any injection activities, the present USDW groundwater quality at the site must be determined. This may be completed by sampling via groundwater monitoring wells at locations approved by the CCS permit. A minimum of four quarters of monitoring should be completed before injection activities begin. This will enable the facility to compare background groundwater results to the results after injection has begun and throughout the closure and post-closure periods. A change in the groundwater quality parameters may give an indication of contamination.

IV.B.4.c. CO_2 Injection Well Construction

Under the Class V UIC regulations, the CO_2 injection wells must adhere to the construction requirements for a Class I hazardous waste injection well. These requirements are meant to ensure the protection of groundwater resources. If these rules and regulations are met, the probability for groundwater contamination via the injection well is at a minimum.

The USEPA proposed Class VI injection well rules closely follow those established for Class I injection wells. Surface casing for the well is to be set deep enough to place the ground water horizons behind pipe. Surface casing is to be cemented back to surface. Long casing set to total depth or through the injection zone is to be cemented back to surface casing. Injection of CO_2 will be through tubing set inside the long casing string and tied to a packer set just above the injection zone. The packer set point in the casing will have cement on the backside of the casing.

---

[133] EPA, Glossary if Underground Injection Control Terms. Found at: http://www.epa.gov/r5water/uic/glossary.htm#usdw

[134] Fetter, C.W., 2001, Applied Hydrogeology, Prentice-Hall, Inc., Upper Saddle River, NJ. Table 10.1, p. 386.

Through the ground water horizons, CO_2 will be transported to the injection zone via tubing set inside the long casing string that is cemented back to surface and is itself set inside the surface casing that is also cemented back to surface casing.[135]

Also the proposed Class VI rule, the area between the tubing and long-string casing, the annulus, is to be filled with a non-corrosive fluid to protect the casing and tubing. Pressure in the annulus is to be monitored continually for any changes that can indicate a leak. Automatic shut-off valves are to be place downhole as part of the tubing and at the surface as part of the wellhead. Injection pressures are to be limited at 90% of fracture gradient pressure[136]. Many states limit injection pressures for Class II wells to 80% of fracture gradient pressures.

Regulations in West Virginia require surface casing to be set through the lowest ground water horizon or coal seam, whichever one is deeper.

IV.B.4.d. Induced Seismicity

Sequestration of captured CO_2 will result in an increase of subsurface pressures in the storage reservoir. There are three important pressure gradients in the subsurface, hydrostatic, fracture, and lithostatic. Now, as a method to stimulate production, high injection pressures are used to induce a hydraulic fracture in the reservoir. High injection pressure here is sustained only long enough to create the length of fracture desired and designed. This technique may be utilized during the completion process of a CO_2 injection well prior to injection operations. To avoid damaging the storage reservoir or the overlying seal, injection pressures over a longer period of time than used for completion stimulation must be less than the fracture gradient (Fig. 4).

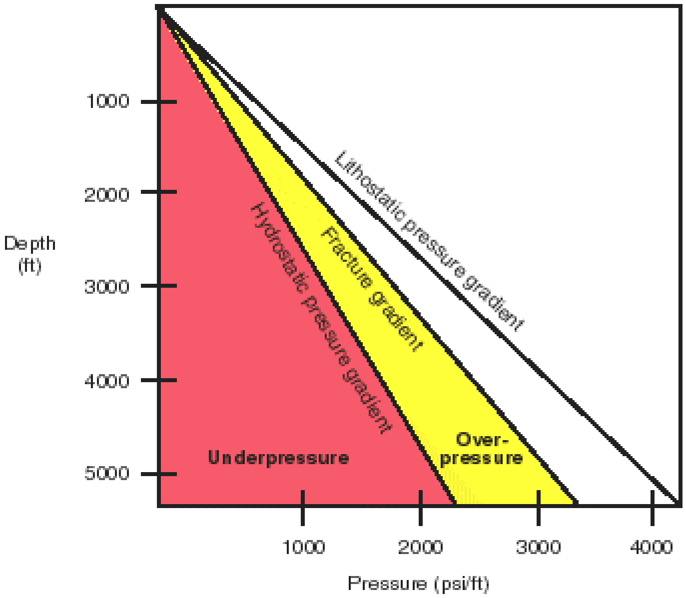


Figure 4B5: Subsurface pressure gradients[137]

In depleted oil & gas reservoirs, the reservoir pressure will be less than the hydrostatic pressure. For saline reservoirs, reservoir pressure will, in most situations, be at hydrostatic pressure. Hydraulic fracturing of an oil & gas reservoir is a production stimulation technique that momentarily exceeds fracture gradient pressures. For situations of induced seismicity,

---

[135] Ibid 95

[136] Ibid 95

[137] Found at: http://www.glossary.oilfield.slb.com/DisplayImage.cfm?ID=159

injection pressures are greater than fracture gradient pressure for either a sustained period of time or in an abnormal subsurface stress environment.

The most widely know incident of induced seismicity occurred at the Rocky Mountain Arsenal near Denver, Colorado between 1962 and 1965. An injection well was drilled to 12,054 feet in the granitic basement rock of the Rocky Mountain front. Formation pressure was measured at 4,133 psi. Injection began at 4,403 barrels per day at 6,033 psi, 1,900 psi over hydrostatic pressure. If fracture gradient was 1.0 psi per foot, this injection pressure should have been reasonable, but the injection zone was granite and the only available porosity was fracture porosity; matrix or intergranular porosity was absent. The first earthquakes occurred within weeks of injection. USGS set up a monitoring system and recorded a total of 710 earthquakes . Injection ceased in 1965. Shortly thereafter final three earthquakes of magnitude 5.0 to 5.2 occurred.[138]

To the north in Rangely Oil Field, waterflooding of the reservoir for secondary recovery began in 1957. This waterflooding triggered earthquakes. A study done by USGS showed that the epicenter of these earthquakes centered in the reservoir and that fluid pressures greater than 4,061 psi in the reservoir "would increase the number of earthquakes from one or two to thirty or forty per month."[139] Subsequently, Stanford University conducted large scale water injections into a fault in Rangely Field that was considered to be near failure. A magnitude 3.1 earthquake was created but the vast majority of induced seismic events were less than a 1 magnitude. Rangely Field is now under active CO_2 injection for tertiary recovery (EOR).[140]

Geomechanical considerations in evaluating a potential CO_2 storage reservoir include:

- Avoid regional tectonic stress near breaking strength of rock
- Avoid potential reservoir where fracture porosity is dominant
- Avoid low permeability reservoirs
- Avoid injection rates that can significantly increase pore pressure over a wide area.

The first two geomechanical considerations listed above are self evident. The next two are somewhat elusive and are tied to rates of injection. Permeability essentially dictates injectivity. High rates of injection require good permeability and/or a thick zone for injection, characteristics unique for each reservoir and injection well. Low permeability means more injection wells to achieve the same rate of injection that fewer wells with better permeability can accomplish. Avoiding increased reservoir pressure over a wide area relates to internal barriers within the reservoir. These barriers can be a change in porosity and/or permeability, faults, or resistance in the displacement of formation fluids, due in part to the first two items. Maintaining a constant rate of injection at this point will increase pressure. Lowering the rate of injection will allow a constant, yet lower, injection pressure. As noted earlier, one way to relieve this situation is to produce the formation waters at some distance from the injection wells, lowering the reservoir pressure and allowing for higher rates of injection. However, handling produced waters adds another level to operations.

Earthquakes that have impacted West Virginia over the last century or more are listed in Table 2. Four of these earthquakes (1897, 1959, 1969, and 1974) have occurred in the Giles County vicinity of the state boundary between SE West Virginia and western Virginia.

---

[138] Rahn, P.H., 1996, Engineering Geology: An Environmental Approach. Second Edition, Prentice-Hall, Upper Saddle River, N.J., 657 p.

[139] Ibid

[140] World Resources Institute (WRI), 2006, CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage. Washington, DC: WRI.

Earthquakes occur in West Virginia more frequently than suggested by Table 2. Since 1974, the USGS has recorded 48 earthquakes ranging in magnitude of 2.1 to 4.5. Of the 48 events, 24 were between 2.0 and 2.9, 19 were between 3.0 and 3.9 and 5 were between 4.0 and 4.9. Earthquake magnitude, based on the Richter scale,[141] is logarithmic and measures the energy released by an event. The Modified Mercalli (MM) scale[142] measures the severity of the event and is expressed in Roman numerals.

On the Richter scale, a 3.5 magnitude represent the value below which an earthquake is generally not felt but recorded. Between 3.5 and 5.4, an earthquake is often felt but rarely causes damages. Only 12 of the earthquakes recorded since 1974 have been greater than 3.5.

On the MM scale, at a value of III, people inside a building may feel the earthquake but those outside most likely will not. At a value of V, people inside and outside will realize an earthquake has occurred and minor damage will occur such has broken dishes and spilled fluids. Only four earthquake events with a MM value of V have affected West Virginia between 1897 and 1974 (Table 4B6).

USGS also records seismic events resulting from mining explosions. Between 1997 and 2000, 155 mining explosion events were recorded. None of these events were greater than 3.5. Of the 155 recorded events, 108 were between 2.0 and 2.9 and 45 were between 3.0 and 3.5.[143]

---

[141] http://www.seismo.unr.edu/ftp/pub/louie/class/100/magnitude.html

[142] http://www.seismo.unr.edu/ftp/pub/louie/class/100/mercalli.html

[143] http://earthquake.usgs.gov/earthquakes/eqarchives/mineblast/

Table 4B6: Earthquakes affecting West Virginia (USGS)[144]

Year	Location	Where Felt	Magnitude	MM Scale Where Felt in WV[2]
1897	Giles Co., Virginia		5.9[1]	VIII
1909	Charles Town - Martinsburg			V - VI
1935	Timiskaming, Quebec	Moundsville – Wheeling	6.25	IV
		Charleston, Fairmont, Parkersburg, Ravenswood, Sutton, Wellsburg		I - III
1937	Anna, Ohio	Huntington	5.4[1]	I – III
1943	Ohio	Wheeling		I – III
1944	Cornwall, Ontario / Massena, New York	Parkersburg	5.8[1]	I - III
1959	Virginia – West Virginia border	Lindside		IV
		Rock Camp		I - III
1968	Southern Illinois	Hamlin, Huntington, Parkersburg, Point Pleasant, Wayne, Williamson	5.4[1]	I - III
1969	SE West Virginia	Athens, Lerona, Elgood	4.5[1]	VI
		Itmann, Logan, Pipestem, Ramp		V
1970	West Virginia (west central portion)	Charleston, Eskdale, Hamlin, Hurricane, Saint Albans		IV
1972	Morgantown	Morgantown: recorded on WVU seismograph		
1974	Giles Co., Virginia	Gap Mills, Pickaway		V
1974	NW West Virginia / SE Ohio	Parkersburg, Ravenswood,		V
		Belleville, Cottageville, New Haven, Morgantown		IV

1 Largest earthquake to occur in this state
2 Modified Mercalli scale

---

[144] US Earthquake History by State. Found at: http://earthquake.usgs.gov/earthquakes/states/

The Nagaoka CO_2 injection project in Japan injected 10,400 tons of CO_2 into a saline aquifer at 1,100 meters between 2000 and 2005. Monitoring was conducted between 2005 and 2007. The Niigata earthquake of 6.6 magnitude struck in July 2007 and "No CO_2 leakage has been observed."[145]

IV.B.5. Risks Assessment

The capture, transportation, and geologic storage of carbon dioxide present environmental and safety risks. What these risks are, and whether they are manageable, are critical questions for the future of carbon sequestration. Identification and estimation of the magnitude of the various risks associated with pipeline transportation and sequestration of captured CO_2 is also important to site selection, permitting, and liability issues. Not understanding and managing the risks of carbon dioxide transportation and geologic storage could invite failure of an environmentally critical program.

What is risk? USEPA defines risk as "the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor." A stressor is "any physical, chemical, or biological entity that can induce an adverse response. Stressors may adversely affect specific natural resources or entire ecosystems, including plants and animals, as well as the environment with which they interact." [146]

Risk has been defined in the context of CO_2 sequestration as:

> "two factors - the probability (frequency) of a specified hazardous event and the severity of the consequences from that event. Risk can be defined as the product of these two factors:
>
> Risk = Frequency x Consequences
>
> Thus, one can have the same level of risk for a frequent event with a low level of damage as for a rare event with a very high level of damage. Therefore, in developing a risk assessment, one must evaluate both frequency and potential damage from an event."[147]

Risk assessment has been described as "the process leading to the characterization of a risk."[148] A risk assessment typically has four components: hazard identification, dose response assessment, exposure assessment, and risk characterization. Risk assessments can range from qualitative, through semi-quantitative, to highly quantitative. The literature of risk assessment is enormous.

---

[145] Gassnova, 2010, International CCS Technology Survey. Issue 6. February 2010. Found at: www.gassnova.no

[146] www.epa.gov/risk/basicinformation.htm Reference to or quotation from particular sources should not be taken as approval of the views expressed by the source.

[147] Risk Assessment and Management For Long-Term Storage of CO_2 In Geologic Formations, Dawn Deel, Kanwal Mahajan, Christopher R. Mahoney, Howard G. McIlvried, and Rameshwar D. Srivastava. Systemic, Cybernetics and Informatics volume 5 number one, page 79.

[148] Footnote 1, page 15, Science and Decisions: Advancing Risk Assessment (2009), The National Academies Press.

The field of risk assessment continues to evolve. The first major work on risk assessment the so-called Red Book was published in 1983.[149] In 2006 the federal Office of Management and Budget proposed a Risk Assessment Bulletin to guide federal agencies in risk assessments.[150] Recently the National Research Council was asked by USEPA to form a committee to develop scientific and technical recommendations to improve the risk analysis used by USEPA. The result was a publication titled "Science and Decisions: Advancing Risk Assessment."

The value of risk assessment continues to be debated.[151] A principal concern with risk assessment is scientific uncertainty. The Red Book addressed this concern as follows:

> When scientific uncertainty is encountered in the risk assessment process, inferential bridges are needed to allow the process to continue. The Committee has defined the points in the risk assessment where such inferences must be made as *components*. The judgments made by the scientists/risk assessor for each component of the risk assessment often entail a choice among several scientifically plausible options; the Committee has designated these *inference options*.

Despite the issues raised by risk assessments they are the tool most commonly used in analyzing risk. Understanding risk assessments, and their strengths and limitations is a necessary element of determining the feasibility of carbon dioxide transportation and geologic storage.[152]

IV.B.5.a. Risk Assessment Specific to Carbon Dioxide Transportation and Sequestration

Risk assessment is already occurring in the field of carbon dioxide transportation and sequestration. The literature on this subject is already significant, and is rapidly expanding. There are two sources of information and data to inform risk assessments about carbon dioxide: first, the existing experience in transportation and use of carbon dioxide for enhanced oil recovery (EOR); and second, the experience in analogous areas such as the transportation and storage of natural gas.[153]

---

[149] "Risk Assessment in the Federal Government: Managing the Process". National Research Council. 1983. National Academy Press. This is sometimes known as the Red Book.

[150] Scientific Review Of the Proposed Risk Assessment Bulletin From the Office Of Management And Budget, Committee to Review the 0MB Risk Assessment Bulletin National Research Council (2007).

[151] An Overview of "Science and Decisions: Advancing Risk Assessment", Jonathan Levy et al., Volume 17, Issue 1, Risk in Perspective, Harvard Center for Risk Analysis. www.hcra.harvard.edu

[152] Risk assessment must be accompanied by the companion disciplines of risk management and risk communication. These companion disciplines are equally important.

[153] See generally, "Comparison of risks from carbon dioxide and natural gas pipelines", A. McGillivray & J Wilday, Health and Safety Laboratory, Harpur Hill, Buxton, Derbyshire, SK17 9JN. 2009.

Pipelines

There are presently about 3,800 miles of carbon dioxide pipelines in operation in the United States.[154] These pipelines are regulated by the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration. See generally 49 USC 5101 et seq. and 49 USC 60101 *et. seq*. Department of Transportation regulations in some circumstances require that a pipeline project perform a risk assessment. 49 CFR Part 195.

The principal risks in the pipeline transportation of carbon dioxide are leaks or ruptures.[155] These can occur in various ways. Once a leak or rupture occurs its impact depends on the material released, the magnitude of the release, the local conditions, and the immediate population in the vicinity of the leak. While carbon dioxide is not flammable, it is heavier than air and can settle into depressions creating a risk of asphyxiation.[156] An unfortunate example of this occurred at Lake Nyos in Cameroon[157] yet there is evidence that accumulations of CO_2 will disperse in a safe and reasonable amount of time.[158] It is a risk that must be recognized.

An example of a risk assessment for a carbon dioxide pipeline is found in Appendix E Carbon Dioxide Pipeline Risk Analysis HECA Project Site Kern County, California, Prepared for Hydrogen Energy International LLC, May 19, 2009.[159] This particular pipeline is about 4 miles long and is for EOR.

This particular risk assessment begins by defining risk as “a combination of the probability of a scenario versus the severity of its consequences.” [p. 1-3]. The risk analysis is described as a semi-quantitative analysis based on historical data. It identifies scenarios with adverse consequences that may occur, estimates potential consequences, estimates the likelihood of occurrence, and evaluates the risk.

The risk analysis develops frequencies of occurrence estimates and potential consequences, and establishes a risk index. Particular kinds of failure are considered. Perhaps the most significant part of the analysis is a consideration of the historical failure rate of carbon dioxide pipelines. [p.2-1, Table 4B4]. The accident/spill records of carbon dioxide pipelines were obtained from data provided by the Office of Pipeline Safety of the DOT. A historical failure rate for carbon dioxide pipelines was created. Air modeling was done to estimate the potential impacts from a hypothetical accidental release. Finally, worst-case scenarios are evaluated. The result of this analysis is a projected failure rate for each failure mode [for example equipment failure, corrosion, operator error etc.]. The projected failure rate is determined by multiplying the historic failure rate per mile of carbon dioxide pipeline per year times the total length of

---

[154] Kadnar, J.O. Experience in the CO2 Transportation via Pipeline, in CCS Web Conference on CO_2 Transport, Health And Safety Issues, [US Department of Transportation], 2008 International Energy Agency: Paris.

[155] See generally, "Carbon Dioxide Pipelines: A Preliminary Review Of Design and Risks", J. Barrie et al.,

[156] Some authors express the view that pipeline transportation of carbon dioxide is safe. "Years of experience have led to a regulatory regime and operating procedures that make the operational subsystem [pipeline transportation] a safe, reliable and time-tested component of a CO2 storage system." Environmental Assessment of Geologic Storage of CO_2. Jason J. Heinrich et al., Laboratory for Energy and the Environment, Massachusetts Institute of Technology, Presented at the Second National Conference on Carbon Sequestration, Washington, DC, May 5-8, 2003.

[157] Ibid 135

[158] Ibid 137,

[159] Available at http://www.energy.ca.gov/sitingcases/hydrogen_energy/documents/applicant/revised_afc/Volume_II/Appendix%20E.pdf. The subcommittee expresses no view about whether this risk assessment is legally sufficient, complies with any particular requirement, is technically sufficient, or appropriate to the circumstances. It is given simply as an example of a recent carbon dioxide pipeline risk assessment.

carbon dioxide pipeline. The report concludes with a risk evaluation which is principally presented through a Project Risk Matrix. Mitigation measures are then described. The risk probability calculation concludes that the failure rate for the 4 mile carbon dioxide pipeline is estimated to be about 0.0007 failures per year.

Earlier testimony was presented citing the low incident rate for CO_2 pipelines which is supported by information in Table 4Bxx. This data shows that 18 incidents occurred over a 3,769 mile network over more than 30 years of operations, less than one incident per year across the whole network. On a per mile basis, this is 0.0002 incidents per year. There were no injuries or fatalities due to any of these incidents. This kind of analysis is typical of risk assessment. Its advantage is that it provides a quantitative, or in this case a semi-quantitative assessment of the risks involved. This is very useful. The disadvantage is that it contains a number of assumptions and estimates, not all of which are readily apparent. The value of the risk assessment depends as much on the validity of the data as it does on the validity of the model.

Geologic Sequestration

Geologic storage of carbon dioxide presents the risk of escape of carbon dioxide to the surface presenting a potentially hazardous situation to human health and the environment.[160] In addition, there are risks of: contamination of water supplies and potentially usable groundwater supplies; mobilization of contaminates in underground formations; and potentially increasing the expense of production of coal, gas and other mineral resources in the vicinity of sequestration operations. Finally, there is a risk of triggering a seismic event.

There is limited experience with projects that are only geologic storage of carbon dioxide. This limited experience requires consideration of analogous situations. Injection and storage of carbon dioxide underground has similarities to, and significant differences from, underground injection of brine wastes from oil and gas development, underground injection of wastes, injection of carbon dioxide for enhanced oil recovery, and the storage of natural gas. This experience can be used to assess the risks of geologic storage, and also to identify areas where the existing geologic information is inadequate.[161] In general it is believed that the risks of geologic storage of carbon dioxide change over time. The risks are greatest during and immediately after active injection. Thereafter, with the decline of reservoir pressure towards earlier in situ levels the risks decline.[162] Since long-term storage of carbon dioxide is measured in hundreds of years or longer, the potential long-term risks must be carefully considered. There is a significant and growing body of risk assessment literature directed at the geologic storage of

---

[160] "The amount of CO2 that would need to be injected into geologic storage reservoirs to achieve a significant reduction of atmospheric emissions are very large. A 1000 MW coal-fired power plant emits approximately 30,000 tonnes of CO2 per day, 10 Mt per year (Hitchon, 1996). When injected underground over a typical lifetime of 30 years of such a plant, the CO2 plume may occupy a large area of order 100 km² or more, and fluid pressure increase in excess of one bar (corresponding to 10 m water head) may extend over an area of more than 2, 500 km² (Pruess, et al. 2003). *On CO2 Behavior in the Subsurface, Following Leakage from a Geologic Storage Reservoir, Pruess, Karsten, Lawrence Berkeley National Laboratory. 2006.*

[161] How analogous situations can be used to estimate risks associated with geologic storage of carbon dioxide is discussed in greater detail in table 5.5 of Underground Geologic Storage in Carbon Dioxide Capture and Storage, IPCC Special Report, 2005. Found at: http://www.ipcc.ch/publications_and_data/publications_and_data_reports_carbon_dioxide.htm

[162] "It is an important technical consideration that "risk" associated with injected CO2 is not constant with time. The probability of an unexpected event increases as injection volumes and subsurface pressure ramp up and this requires close monitoring during the operations phase. After injection stops, as pressure equilibriates, and natural trapping mechanisms take effect, the injected CO2 becomes progressively more in mobile." A Technical Basis for Carbon Dioxide Storage; CO2 Capture Project, 2009. The CO2 Capture Project is an effort funded by a consortium of energy companies.

carbon dioxide.[163,164] Of particular interest is the development of modeling techniques for carbon dioxide storage. These risk assessments will generally consider two kinds of scenarios: (1) the general risk of escape of carbon dioxide to the atmosphere, i.e., that the long-term storage of carbon dioxide will not be achieved; and (2) more specific risks of injury to human health and the environment. There are also models for specific subparts of geologic storage such as models for leaks associated with well integrity.[165] As particular projects go forward there will be site-specific risk assessments. The ultimate risk assessment will be done by those who finance sequestration projects.

Two authors, quoted below, conclude that the risks of geologic storage of carbon dioxide are manageable. These authors rely upon the experience in similar fields such as natural gas storage and enhanced oil recovery for their views.[166]

> With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety and environmental risks of geologic storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas. *Carbon Dioxide Capture and Storage, Summary for Policymakers And Technical Summary, Intergovernmental Panel on Climate Change, p. 11.*
>
> On a project –by- project basis, the risks of geologic storage of CO_2 are expected to be no greater than the risks associated with analogous industrial activities that are under way today. Oil and gas production operations, natural gas storage, and disposal of liquid and hazardous waste have provided experience with underground injection of fluids and gases on a massive scale. The injection volume of an individual storage project will be comparable to large-scale CO_2 EOR projects taking place in the U. S. today. Because the technology for characterizing potential CO_2 storage sites, drilling injection wells, safely operating injection facilities, and monitoring will be adapted and fine-tuned from these mature industrial practices taking place today, it is reasonable to infer that the level of risk will be similar. *Carbon Dioxide Capture and Storage, Assessment of Risks from Storage of Carbon Dioxide in Deep Underground Geological Formations, Sally M. Benson Earth Sciences Division, Lawrence Berkeley National Laboratory, version 1.0 April 2, 2006 p. 4.*

Risk assessment of the long term storage of carbon dioxide at a particular site is done or assisted by mathematical modeling or simulations. Typical of this approach is the risk assessment done for the Weyburn project in Saskatchewan, Canada. Weyburn is an enhanced oil

---

[163] A very useful companion to the risk assessment literature is "Vulnerability Evaluation Framework For Geologic Sequestration of Carbon Dioxide", July 10, 2008 United States Environmental Protection Agency, EPA 430-R-08-009. US EPA developed the Vulnerability Evaluation Framework to identify those conditions that could increase the potential for adverse impacts from geologic storage of carbon dioxide. It is a non-quantitative assessment.

[164] A comprehensive overview of international risk assessment issues is found in "Phase I Final Report from CSLF Risk Assessment Task Force", October 2009, Carbon Sequestration Leadership Forum.

[165] See for example, "Supercritical CO2 Leakage Modeling For Well Integrity In Geological Storage Project", E. Houdu et al. Excerpt from proceedings of the COSMOL Conference 2008 Hanover.

[166] Again citation to, or quotation from particular sources does not indicate approval of the views cited to or quoted.

recovery project using carbon dioxide.[167] This risk assessment used two different mathematical models to assess the probability that carbon dioxide will remain stored for the foreseeable future. The modeling estimates that "[t]here is a 95% probability that 98.7% to 99.5% of the initial CO_2 in place will remain stored in the geosphere for 5000 years."

The most thorough site-specific risk assessment for geologic storage to date comes from the FutureGen project.[168] Table 6-11 Estimated Range of Failure Probabilities For Each Release Scenario By Candidate FutureGen Site estimates the probabilities of various failures including: upward rapid leakage through caprock; release through induced faults; and leaks due to undocumented deep wells. The time frame for consideration is 1000 to 5000 years.

For each scenario the probability of at least one failure in the time period is estimated, as is the probability of one failure annually. For the Jewett Texas site scenario, upward rapid leakage through caprock, the probability of at least one failure over the life of the project [1000 to 5000 years] is given as 0.003 to 0.14; while the estimated frequency of one failure occurring annually is 0.000001 to 0.00001.

These estimates, and the approach used to arrive at them, are the current state of the art. The value of these estimates is limited by a lack of track record [real-world data] for such projects, the assumptions necessary to make the estimates, and the nascent state of the models used. Nonetheless, for these two examples, and they may not represent the whole population, the risk assessment estimates very low risk.

Only a few conclusions can be drawn about the current state of risk assessment for geologic sequestration of carbon dioxide. First, such risk assessment for geologic storage is still in its infancy. There is very little real-world data on which to base a quantitative risk assessment. Analogous circumstances from other fields suggest, but do not prove, that carbon dioxide geologic storage risks are manageable. Second, the mathematical models used are undergoing rapid development and remain works in progress. Third, refinement of the risk assessments will be an iterative process. Fourth, the risk assessment literature, subject to the limitations expressed, generally supports continuing forward to establish a framework for such projects.

IV.B.6. Conclusion for Geology & Technology Subcommittee

There is storage potential for sequestration of captured CO_2 in West Virginia. Present estimates of between 4,873 and 14,994 million metric tons can provide between 47 and 147 years of injection activity based on an annual statewide emission rate of 102 million metric tons. Storage potential is a resource and like any other natural resource it needs to be proven. This will be accomplished by the site characterization process prior to securing a permit to operate a CO_2 storage field.

The potential for sequestration of CO_2 extends over most of the state of West Virginia. Considering the potential for saline formation sequestration, the potential for sequestration of CO_2 probably exceeds the geographic range of oil & gas production in the state. The state overlies the sedimentary section of a portion of the Appalachian Basin, one of the major sedimentary basins in the continental United States. Thickness of this sedimentary section varies

---

[167] See generally, Theme 4: Long-Term Risk Assessment Of the Storage Site, IEA GHG Weyburn CO2 Monitoring and Storage Project Summary Report 2000-2004, Volume III. From Proceedings of the Seventh International Conference Greenhouse Gas Control Technology, September 5-9, 2004, Vancouver, Canada. See page 212.

[168] Final Risk Assessment Report for the FutureGen project environmental Statement (revision to October 2007). See section 6.

from about 8,000 feet to more than 20,000 feet. Potential for saline formation, depleted oil & gas reservoirs and unmineable coal seams are all present. Research on sequestration mechanisms in shales is continuing and these may present future opportunity. Due to geologic structural complexities along the Allegheny Structural Front, sequestration potential along the eastern boundary of West Virginia is very limited to non-existent.

Technology for a MVA program is available. How this technology will be applied, locations for sensors and/or sampling will depend on the overall geology of any particular storage field. Legislative activity to date has set general standards, one of which is compliance with SDWA and USEPA's UIC program. Legislation delegates responsibility for promulgation of rules to a state agency. The Department of Ecology in Washington is the only state agency to date to develop regulations regarding sequestration of carbon dioxide. The USEPA plans to release their proposed UIC Class VI rules in late 2010 or early 2011. Available technology is that used in oil & gas exploration and production and its ability to differentiate between oil, natural gas and water is well tested. Level of resolution varies from pore scale with cores (subsurface rock samples) to formation scale with wireline logs to 2-D or 3-D seismic which cover wide geographic areas. The regional partnerships assembled by DOE/NETL are conducting research projects that further our understanding in the application of this technology for sequestration of CO_2.

Looking at examples from natural gas storage and EOR suggest, but do not prove conclusively, that carbon dioxide geologic storage risks are manageable. The sheer scale of finding "appropriately selected and managed geological reservoirs" with which to sequester thousands of millions of metric tons of captured CO_2 will be a daunting task. Risks associated with CO_2 pipeline and injection well operations are better understood that storage of CO_2. EOR operations inject, produce and re-cycle their CO_2. This process restricts the extent of the CO_2 in the subsurface. Geologic risks associated with sequestration, the long-term retention of CO_2, are more inferred from current practices. Depleted oil & gas reservoirs present a known reservoir with an effective seal. Saline reservoirs are not as well known and their extent and associated seal need to be discovered and assessed. As with the natural gas storage industry, there will successes and failures.

The process of developing a CO_2 storage reservoir, a regional geologic evaluation, selecting a suitable location for site characterization, securing rights to the pore space, securing permits, installation of injection wells, pipelines and equipment will take three to four years. The rate at which storage reservoirs can be permitted and developed will dictate the rate of deployment of CCS technology. Without storage, there is no need for capture.

Over the next year, information on storage assessment will be published. Phase III, large-scale injection project are underway by the partnerships. These projects will evaluate injectivity and the performance of the reservoir and the MVA program established to track injection activity. Geology & Technology subcommittee will evaluate and incorporate this information n the final report.

Question 4: What legal and liability issues need to be decided before CCS can be pursued in West Virginia?

IV.C. LEGAL SUBCOMMITTEE REPORT

IV.C.1. Background

As climate change is becoming a growing international concern, significant progress is being made by companies and states interested in assuring that there will be a place in the nation's energy future for coal fired electric power generation. Much of this effort is being focused on carbon capture and sequestration ("CCS") technology as holding the promise of being able to store carbon dioxide emissions from power plants and industrial facilities underground in deep storage sites. With several hundreds of years of storage potential at many locations across the nation, CCS is attracting much attention.

Initial CCS legislation was enacted by the West Virginia Legislature in 2009. The legislation created a carbon capture and storage regulatory program and created a working group to assess a variety of issues. CCS facilities are authorized by the legislation to the extent that the owner or operator holds an underground injection control permit authorized by state law for that purpose. W.Va. Code 22-11A-3(b). The Working Group is required to issue a final report to the Legislature by July 1, 2011, which would address such issues as the ownership and acquisition of pore space and responsibility for long-term liability. Resolution of these issues will be critical in order to provide for the development of commercial scale CCS operations in West Virginia.

The effort to assess legal issues began by undertaking a careful review of activities around the country in identifying significant policy, regulatory and legal issues raised by CCS projects. In addition, several guest speakers provided information on program development in other jurisdictions. Among the guest speakers were Mary Throne, a member of the Wyoming legislature, Lynn Helms Director, North Dakota Industrial Commission, Department of Mineral Resources), Sean McCoy and Lee Gresham of CCSReg/Carnegie Mellon University, Sara Smith, Chair of the Kentucky CCS Working Group, and Kurt Waltzer, Clean Air Task Force and contributor to the CCS recommendations of the Midwest Governors Association.

After identifying the universe of issues involved, initial efforts focused on property ownership and acquisition. Research was conducted on activities in other states and by such organizations as the Interstate Oil and Gas Compact Commission, CCSReg and the Midwest Governors Association. In addition, an evaluation was conducted of the consequence of doing nothing more than to allow current legal process to control the acquisition of land to be used for a CCS project. The goal of this effort was to explore all options in order to create a solution tailored to West Virginia legislature's desire to site commercial scale CCS projects.

The discussion of legal issues in this report will begin with a review of some of the more significant state level activities on CCS. The discussion will then turn to the six possible options which have been identified with a statement of the advantages and disadvantages of each option also provided. Next, the report will set forth the independent analysis of the Legal Subcommittee with respect to the law related to the circumstances under which the United States Constitution requires that a property owner be compensated for the use of property. The report will then offer an initial statement of which of the options involved is favored at this time, even though all other options will continue to be evaluated over the remainder of the study period of the Working Group. Specific text is then offered for the several property acquisition matters that have thus far been considered. Finally a list of issues that have not yet been addressed is offered as the starting point for the continued discussion of the Working group for the coming year.

IV.C.2. State-Based CCS Programs

Significant activity is occurring around the country in the development of state-based CCS programs. Among these initiatives are the following:

IV.C.2.a. IOGCC

In 2007 the Interstate Oil and Gas Compact Commission ("IOGCC") issued its model program for the storage of carbon dioxide in geologic formations. Even though the USEPA is applying the Safe Drinking Water Act regulatory program to CCS facilities, the IOGCC model program is premised on the belief that the regulation of CO_2 geological storage should be left to the states. With respect to property rights, the IOGCC model program provides that an applicant should acquire the property rights to use pore space in the geologic formation for storage. While much of the IOGCC's model program addresses the need to acquire property rights through negotiation or eminent domain, the model program specifically states that the IOGCC is less concerned about what mechanism is used to acquire those rights and is more concerned that all necessary property rights be acquired by valid, subsisting and applicable state law. Following completion of the project, an operator would be obligated to monitor the project to assure its integrity. At the completion of that period, title to the facility would be transferred to the state and the operator and all generators of CO_2 injected would be released from all regulatory liability. The program establishes a trust fund that would assess a fee on each ton of CO_2 injected. The trust fund provides the financial resources for the state to take title to the project at the end of its operating life.

IV.C.2.b. Kansas

In 2007, Kansas established the authority to develop rules for CCS facilities. Kan Stat. Ann. §§55-1637 through 1640. Proposed administrative regulations issued in March 2009 address operational requirements for an environmental permitting program. Among those requirements is that the applicant must hold necessary property and mineral rights and own financial instruments that demonstrate financial responsibility. Kansas law does not define who owns pore space, nor does it define the level of financial responsibility required. To obtain a post-closure determination, the facility operators must demonstrate that the plume and storage pressure have stabilized. Upon written approval of post-closure status, the operator would plug the remaining monitor wells at which point the CO_2 storage facility permit would be revoked and any financial assurance instrument would be released. All future remediation or monitoring activities would be performed by the state.

IV.C.2.c. Louisiana

In 2009, the Louisiana Legislature passed new CCS legislation. Louisiana R.S. 30:1101 through 1111. This bill authorizes expropriation by the state or certain corporations engaged in CCS not only for a storage facility but also for pipelines for transportation. Ten years, or any other time frame established by rule, after cessation of injection, a certificate of completion of injection operations would be issued at which time the storage operator, generators of the carbon dioxide, the owners of the carbon dioxide, and all other owners otherwise having an interest will be released from any and all regulatory duties or obligations and any other liability associated with or related to the storage facility. The statute authorizes a storage operator's fee.

IV.C.2.d. Montana

The Montana legislature passed CCS legislation (SB 498) in 2009 which established a CCS regulatory framework and addressed pore space ownership. Unless otherwise documented, the surface owner owns the pore space for geologic carbon sequestration. The bill also protects the existing rights of mineral owners and does not change common law regarding surface and mineral rights. Operators will pay a fee on each ton of CO_2 injected into a storage reservoir based on anticipated actual expenses that will be incurred by agencies implementing the program. Prior to project completion, an operator is liable for the operation and management of the CO_2 injection well, the storage reservoir and the injected or stored CO_2. The completion and transfer of ownership and liability from the operator to the state is a process that takes 30 years: (a) 15 years after injection of CO_2 ends, a certificate of completion will be issued if the operator is in full compliance with all rules and (b) for a period of an additional 15 years after the certificate of completion is issued, the operator must continue adequate monitoring of the wells and reservoir and continue to accept all liability. Following the 15 year period of required monitoring and verification, if the operator has title to the storage reservoir and the stored CO_2, it may transfer the title to the state if the operator meets all requirements. Once the title is transferred to the state, the state is granted all rights and interests in and all responsibilities associated with the geologic storage reservoir and the stored CO_2. The transfer releases the operator from all regulatory requirements and liability associated with the reservoir and the stored CO_2. If the operator does not transfer title to the state, the operator accepts liability indefinitely for the reservoir and the stored CO_2.

IV.C.2.e. North Dakota

In 2009, Senate Bills 2139 (pore space and property issues) and 2095 (carbon dioxide storage operational issues) were enacted into law. This legislation creates a legal and regulatory framework for carbon capture and storage and addresses pore space and property issues relevant to carbon capture and storage, including placing title to pore space in all strata underlying the surface with the owner of the overlying surface estate. If a storage operator does not obtain the consent of all persons who own the storage reservoir's pore space, the state may require that the pore space owned by non-consenting owners be included in a storage facility and subject to geologic storage. This is accomplished through the amalgamating provision, which is similar to unitization, requiring the consent of 60% of the property owners.

Multiple funds are established to defray the expenses incurred by regulatory agencies throughout the carbon sequestration process. The actual fee amount is to be based upon the anticipated expenses that will be incurred in regulating storage facilities during their construction, operation, and pre-closure phases. The storage operator has title to the carbon dioxide injected into and stored in a storage reservoir and holds title until a certificate of project completion has been issued. While the storage operator holds title, the operator is liable for any damage the carbon dioxide may cause, including damage caused by carbon dioxide that escapes from the storage facility.

After project completion and application for closure, consideration will be given to issuing a certificate of project completion. Such certificate may not be issued until at least 10 years after carbon dioxide injections have ended. Once a certificate is issued, title to the storage facility and to the stored carbon dioxide transfers without payment of any compensation to the state and the storage operator and all persons who generated any injected carbon dioxide are released from all regulatory requirements and other liability associated with the storage facility.

IV.C.2.f. Oklahoma

Also in 2009, Oklahoma passed the "Geologic Storage of Carbon Dioxide Act" (S.B. 610). The act provides the legal framework to encourage the long-term geologic storage of carbon dioxide in Oklahoma. The Corporation Commission is granted the authority to grant certificates of public convenience and necessity and to authorize storage facilities which allows the storage operator to initiate the condemnation action necessary to site the facility. The act is almost silent with regard to addressing potential liability associated with CCS activities. However, it provides for the establishment of financial sureties or bonds.

IV.C.2.g. Wyoming

In 2009, Wyoming passed three bills to address ownership and liability issues related to geological storage of carbon dioxide. H.B. 57 clarifies that mining and drilling rights will be prioritized over geologic sequestration activities. H.B. 58 provides that the injector holds the title and liability for sequestered carbon dioxide and all other materials injected during the sequestration process. H.B. 80 establishes a procedure for unitizing geologic sequestration sites, whereby pore space rights from multiple parties would be aggregated for the purposes of a carbon storage project as long as 80 percent of the parties approve the project. This suite of bills complements that which was passed in 2008. H.B. 89 specified ownership of pore space. The 2008 legislation declared that the ownership of all pore space in all strata below the surface lands and waters of the state is declared to be vested in the owners of the surface above the strata. H.B. 90 established an operational regulatory program.

The legislation in the various states is setting the legal and regulatory framework for CCS projects in advance of the development of federal legislation. This work is allowing the current development of experimental CCS projects across the country. If commercial scale CCS projects are to be developed in time to play a meaningful role in framing national policy with respect to global climate change, these efforts to address legal issues must be accelerated. The WVCCS legal subcommittee is working toward resolution of the legal issues associated with the ownership and acquisition of pore space and responsibility for long-term liability.

IV.C.3. Pore Space Acquisition Options

As the result of its survey of proposals by other states and organizations, the subcommittee identified six alternatives related to the nature and extent of the obligation of an operator of a facility engaged in the geologic sequestration of carbon dioxide to acquire the property rights for that purpose. Those six alternatives are as follows:

Option 1. Existing Law

Legislation passed in 2009 provides an initial framework for CCS projects and in doing so relies upon the present state Water Pollution Control Act. While that 2009 legislation does not explicitly address eminent domain, eminent domain provisions do exist elsewhere in statutory law (see W.Va. Code, Chapter 54, Article 2). Even though the legislation requires that "necessary" legal rights to sequester CO_2 be demonstrated as part of the permitting process, the legislation does not define what rights are "necessary."

Advantages:

- Property rights may be acquired under existing property law.
- Existing law does not state what legal rights are necessary to sequester CO_2.
- This process would not require amendments to the current legislation.
- New legislation to begin acquiring the property rights would not be required.
- Current CCS law may allow electric utilities and others, such as the Public Energy Authority and the gas pipeline authority, to exercise eminent domain without further amendment.

Disadvantages:

- Requires a title search of existing property instruments to determine property ownership, which is time-consuming and expensive (there are 19,491 surface parcels and 1,026 mineral tracts in Mason County alone).
    - surface owners, oil and gas owners, coal owners, other mineral owners, and lien holders (deeds of trust, tax liens, judgment liens, other liens) must be identified.
    - A very conservative estimate of the title report costs would be $5,000 per tract.
- In the likely event all the necessary property cannot be acquired through negotiation, a condemnation action must commence.
- All compensation is paid by the condemnor along with the costs (commissioners, jury trial, etc.).
- Eminent domain is not authorized for any party other than utilities already having the power of eminent domain.
- Compensation to land owners would likely be variable.
- Uncertainty exists about the ownership of pore space and the obligation to acquire the right to use that pore space.

Option 2. Streamline Existing Law

Streamline existing law by including some or all of the following suggestions: (1) allow the use of tax records (updated to include transactions occurring in the past year) or other alternative methods to identify pore space ownership; (2) use Administrative Law Judge's ("ALJ") (or create a specific special master) as a first step in setting compensation; (3) expand the scope of existing eminent domain authority (gas pipelines, PEA); (4) expand entities with Certificate of Necessity from DEP/PSC (PSC would likely need to be involved for rates); (5) allow companies other than existing utilities the right to acquire the property rights and operate such facilities; (6) clarify who owns pore space under various scenarios; and (7) protect operators from common law claims (*e.g.* trespass) where CO_2 moves onto property not yet acquired.

Advantages:

- Simplifies the title search.
- Reduces costs and time.

- Might be able to provide some structure for controlling compensation.
- Does not purport to change existing ownership of pore space, but rather it simply creates a presumption of ownership in certain circumstances and allows that presumption to be rebutted, thereby protecting the rights of the owners.
- Allows an expanded group of applications.

Disadvantages:

- Requires changes to existing law.
- Still requires compensation for all property owners.
- Does not address the "windfall" value that may be created for the use of pore space for CO_2 sequestration.

Option 3. Public Use

The Midwest Governors Association has proposed that a state either unitize pore space or declare the subsurface below 2,500 feet not associated with hydrocarbon development to be accessible for public use. A fixed fee per acre will be provided for the use of the pore space. Eminent domain would be authorized. This option has not yet been enacted into law by any state.

Advantages:

- Eliminates the uncertainty associated with determining the identity of the owner of the pore space.
- Simplifies compensation (set at nominal amount).
- Use of police powers may preclude (or minimize) compensation.

Disadvantages:

- Creates uncertainty to the extent that compensation is set below "fair market value."
- The issue of whether a legislative declaration of pore space below 2,500 feet constitutes a taking, which would trigger payment of just compensation, has not yet been tested.
- Due to variations in West Virginia's geology, the strata available for carbon dioxide sequestration may dip causing a depth line to pass in and out of a given stratum, potentially complicating the issue.
- Operator would still be required to bear the burden of determining ownership of pore space and of taking the right to use the pore space, even if CO_2 sequestration does not materially impair the pore space owner's use.

Option 4. Unitization

Unitization of pore space rights has been suggested by the Midwest Governors Association and has been enacted into the laws of North Dakota and Wyoming. The concept has not been applied to an actual CCS operation. Unitization would mandate that pore space rights can be used for CCS if a majority of rights are obtained by consent. Compensation for those additional rights is required and must be determined.

Advantages:

- The law could be amended to allow for its expanded use, as has been done in other states (such as Wyoming and North Dakota).
- The taking could occur without reliance upon new eminent domain authority.
- Efficient method.

Disadvantages:

- Current West Virginia law would need to be changed to expand unitization to include CO_2.
- Historically, unitization has assumed continued payment to the property owner.
- With CCS, there is no apparent, continual revenue stream or "product" beyond the operational stage of the project.
- The Wyoming program does not address how the affected property owners will be compensated.
- The price paid for the use of the pore space must be sufficient to entice a majority of the pore space owners to voluntarily relinquish the pore space for this to work effectively.
- It presumes an arms length/fair transaction between the parties, which may not always be the case.

Option 5. Permit Authorization

The Carnegie Mellon CCSReg Project has offered a comprehensive regulatory framework for geologic sequestration ("GS") based upon the balancing of the interests of private property owners with the public benefit of GS, and reducing the possibility of interference with other productive non-GS uses of the subsurface that are also in the public interest. This framework should enable UIC regulators to permit GS projects and allocate use of subsurface pore space under an expanded version of the UIC program. Under this framework, regulators would consider the trade-offs between private interests and the public benefit of a proposed GS project, determining the safest, most efficient and equitable use of the pore space, including non-GS uses. This framework should increase the potential for either avoiding most subsurface property disputes outright, or resolving them at the outset in a stable and predictable environment that is fair and equitable to all affected parties. An approval by UIC regulators to allow the sequestration of CO_2 in that pore space could be challenged as a *per se* physical taking of property that requires compensation. A detailed discussion of the law of "takings" is set forth elsewhere in this report. U.S. Courts have consistently ruled that due to the overarching public benefit of underground disposal of fluid waste, technical trespass claims against waste injection operators properly licensed through the UIC permitting process are compensable only if a material impairment with use of the subsurface or the surface can be demonstrated. This same rationale has been applied to state-authorized enhanced oil and natural gas recovery operations and field unitization—that is, claims for subsurface trespass must yield to the public interest of efficiently producing natural resources. The CCSReg proposal and recommendations are set forth in a policy paper “Governing Access to and Use of Pore Space for Deep Geologic Sequestration” dated July 13, 2009.

Advantages:

- Expedited process and minimize cost.
- Property issues would be addressed during the permit process.
- Eliminating trespass would be very helpful.
- Eliminates the economic windfall that would be created by the passage of legislation mandating that pore space rights be obtained for CO_2 sequestration.

Disadvantages:

- Cutting off unasserted property rights, particularly for minors, may pose a problem.
- May unduly delay the issuance of the permit and without a valid permit it may not be possible to utilize the power of eminent domain needed to acquire the necessary pore space.

Option 6. Reverse Rule of Capture

Based upon the current application of the UIC program, the Ohio federal district court case involving the UIC program and the experience of the State of Florida with the underground injection of treated municipal wastewater, one option would be to establish a program that does not call for the taking of pore space rights. In Florida, property rights are generally not taken in connection with its extensive treated municipal waste disposal via the UIC program nor are they taken in connection with the underground injection of hazardous waste (however this often occurs on public land or offshore).

Advantages:

- Sequestration projects may be able to sequester carbon dioxide into pore space where they have no surface or mineral ownership interests.
- Reverse rule of capture involves acquiring rights to usage as opposed to ownership rights.
- Using the reverse rule of capture would eliminate the need to acquire the property rights to pore space.
- This would save considerable time and money.

Disadvantages:

- This approach might require characterization of this activity more as waste (and not commodity) management, which may create RCRA implications.
- Only a minority of states have adopted the reverse rule of capture rule and it is unclear whether states other than Ohio would follow this rule.
- It may subject the CCS operator to trespass or other common law claims.

Additional Legal Research on Permit Authorization Option

The Subcommittee also considered additional legal research related to the option of allowing the permit in a proper case to authorize the use of pore space. This research addresses implications of the “Takings Clause” of the Fifth Amendment of the Constitution of the United States and of common law tort actions. Many of the cases discussed involve the injection of salt water or waste water into subsurface formations and its migration under properties of adjoining landowners. These cases are therefore analogous to the injection of carbon dioxide into subsurface pore space formations.

As discussed in the attached legal research, the law with respect to “takings” is principally addressed in four decisions of the United States Supreme Court.

Causby v. United States, 328 U.S. at 258 (1946), involved the question of whether the federal government’s frequent and regular flights of aircraft over a property owner’s land at low altitudes constituted a taking. 328 U.S. at 258. While the Supreme Court of the United States held that there was a taking under these circumstances, its holding was premised on the fact that the flights were “so low and so frequent as to be a direct and immediate interference with the enjoyment and use of the land.” *Id*. at 266. Otherwise, the Court recognized, flights over private land are not a taking. *Id*. Specifically, the Court observed:

> [i]t is ancient doctrine that at common law ownership of land extended to the periphery of the universe – *Cujus est solum ejus est usque ad coelum*. But that doctrine has no place in the modern world. The air is a public highway, as Congress has declared. Were that not true, every transcontinental flight would subject the operator to countless trespass suits. Common sense revolts at the idea. To recognize such private claims to airspace would clog these highways, seriously interfere with their control and development in the public interest, and transfer into private ownership that to which only the public has a just claim.

Id. at 260. Thus, the Court recognized that “[t]he airplane is part of the modern environment of life, and the inconveniences which it causes are normally not compensable under the Fifth Amendment. The airspace, apart from the immediate reaches above the land, is part of the public domain.” *Id*. at 266.

In *Penn Central Transportation Company v. City of New York*, the Supreme Court of the United States was faced with the question of whether the designation of a privately owned property as a “landmark” by a city landmark preservation committee, thereby preventing further construction on the property, amounted to a “taking” of the property without just compensation. 438 U.S. 104 (1978). The New York Court of Appeals concluded that there was no taking of the property since the landmark law did not transfer control of the property to the City, but rather, only restricted Penn Central’s exploitation of it. *Id*. Further, the New York Court of Appeals found that Penn Central was not denied due process. The U.S. Supreme Court affirmed the decision of the New York Court of Appeals and identified several factors that have particular significance in resolving such claims. *Id*. These factors included the economic impact of the regulation on the property owner, the extent to which the regulation interfered with “distinct investment backed expectations,” and the character of the government action, i.e., was the interference a physical invasion of the property by government or was the interference a public program adjustment to benefits and burdens of economic life in order to promote the common good. *Id*. In finding that landmark law did not interfere with Penn Central’s present use of the Terminal, that Penn Central was still permitted to profit from its use of the Terminal and to obtain a reasonable return in its investment, and that Penn Central was not denied all use of the pre-existing air rights as they were transferable to other parcels in the vicinity, the Court concluded that the interference with Penn Central's property by the landmark law was not of such a magnitude that required the exercise of eminent domain and payment of compensation. *Id*. at 136.

In *Loretto v. Teleprompter Manhattan CATV Corp.*, the Supreme Court of the United States addressed the question of whether "a minor but permanent physical occupation of an owner's property authorized by government constitutes a 'taking' of property for which just compensation is due under the Fifth and Fourteenth Amendments of the Constitution." 458 U.S. 419, 421 (1982). At issue was a New York statute that required a landlord to permit cable television companies to install cable television facilities, or equipment, on the landlord's property for which the landlord was permitted to demand payment from the company of no more than an amount determined by a State Commission to be reasonable. The State Commission, acting in accordance with the statute, determined that a one-time payment of $1 was a reasonable fee. The Supreme Court of the United States held that the statute constituted a taking of property for which the property owner was entitled to just compensation under the Fifth and Fourteenth Amendments. Syl., *Loretto*, 458 U.S. 419. In arriving at this conclusion, the Supreme Court recognized that "[w]hen the 'character of the governmental action,' *Penn Central Transportation Co. v. New York City*, 438 U.S. 104, 124, 98 S.Ct. 2646, 2659, 57 L.Ed.2d 631, is a permanent physical occupation of real property, there is a taking to the extent of the occupation without regard to whether the action achieves an important public benefit or has only minimal economic impact on the owner." Syl., *Loretto*, 458 U.S. 419. There are, however, some distinguishable facts between those presented in *Loretto* and those involved with carbon sequestration. For instance, *Loretto* involved the installation, or "direct physical attachment," of cable facilities, which included plates, boxes, wires, bolts, and screws, to a building such that the facilities were "completely occupying" space immediately above and on the building's roof and along the building's exterior walls. These areas of the building are readily accessible and usable by its owners and may easily be put to other uses if so desired. Conversely, with respect to carbon sequestration in formations at least 2,500 feet beneath the surface, a property owner, unless already having an existing or reasonably foreseeable use of such a formation, cannot access this portion of his or her property without the expenditure of very significant financial resources and the use of sophisticated and expensive machinery and equipment. Thus, such formations are not even remotely readily accessible or easily put to other uses by the property owner. Further, in *Loretto*, the property to which the cable facilities were directly physically attached was of substantial economic value to its owners (i.e., residential rental property) and was in existing use by its owners (i.e., the property currently was being rented as residential living space by the owners).

The Loretto case was applied in *FPL Farming, Ltd. v. Texas Natural Resource Conservation Commission* in which a neighboring landowner's challenge to a state environmental commission's order allowing an industrial waste injection operator to increase a maximum injection rate of the industrial waste to a saltwater formation beneath the surface. No. 03-02-00477, 2003 WL 247183 (Tex.App.-Austin, Feb. 6, 2003). FPL contended that the permits amounted to an unconstitutional taking by allowing the waste plume to migrate under its property. *Id*. at 5. FPL asserted that it lost its right to possess the subsurface by being denied its ability to exclude the waste plume therefrom. *Id*. FPL also asserted that it lost its right to use the subsurface because the migrating waste plume would prevent FPL from mining the subsurface for brine or constructing its own injection well. *Id*. While the Court acknowledged that a permanent physical occupation occurs with government action that destroys a property owner's right to possess, use, and dispose of its property, the Court cast aside FPL's assertions as speculative. *Id.*, citing *Loretto v. Teleprompter Manhattan CATV Corp.*, 458 U.S. 419, 435 (1982). The Court also found that FPL failed to meet the *Loretto* test for establishing a permanent physical invasion and a public taking in that FPL failed to demonstrate that it was denied an opportunity to apply for a brine mining permit or an injection well permit (i.e., that it was denied its right to possess, use, and enjoy the subsurface of its property) and that it was impaired in its right to sell its land as a result of the amended permits. *Id.* So, the Court concluded that there was no public taking of FPL's property as a result of the Commission's orders.

In *Lucas v. South Carolina Coastal Council*, the Supreme Court of the United States was asked to determine whether a land-use regulation's substantial impact on the economic value of private property constituted a taking under the Fifth and Fourteenth Amendments requiring the payment of just compensation. 505 U.S. 1003, 1007 (1992). Specifically, the State of South Carolina's Beachfront Management Act barred the petitioner, Lucas, from erecting any permanent habitable structures on his beachfront property, which he had purchased for that very purpose prior to the enactment of the Act. The Supreme Court of the United States found that the Act amounted to a taking of Lucas's property, entitling him to just compensation. In finding that the Act constituted a regulatory taking of Lucas's property, the Court held that regulations that deny a property owner of all "economically viable use of his land" amounts to a taking for which payment of just compensation is required. Syl., *Id.* at 1004. It is doubtful that the *Lucas* analysis would be problematic or used to attempt to invalidate a regulation permitting carbon sequestration in formations at least 2,500 feet beneath the surface since the property owner would still be entitled to all other uses of the property, whether economically viable or not.

Based on the foregoing case law, the Subcommittee concluded that the following concepts/provisions should be considered for incorporation into underground carbon sequestration legislation:

- The legislation should elaborate, in detail, on the policy reasons for using subsurface formations for CO_2 sequestration, including public health, climate change, importance of coal industry to the state, recognition of justified limitations on subsurface property rights, and the public interest in the development of subsurface formations for CO_2 sequestration. The legislation should emphasize that subsurface CO_2 sequestration is a necessary and vital part of the modern environment of life in light of the challenges the world faces with climate change and increasing energy demands (echoing language used in *Causby*);
- The legislation should declare that the foregoing public policy concerns warrant the state's use of police power in ensuring that subsurface formations throughout the state can be used for the purpose of CO_2 sequestration;
- The legislation should declare that pore space, non-hydrocarbon bearing formations within the boundaries of the state and (a) 2,500 feet beneath the surface or (b) between 2,500 feet and 12,000 feet beneath the surface ("Formations") that are not under an existing or reasonably foreseeable use by the respective property owner are part of the public domain

(analogous to airspace "apart from the immediate reaches above the land, is part of the public domain" *Causby*);

- The legislation should authorize the West Virginia Department of Environmental Protection (or other state agency) to regulate the access to and use of the Formations for CO_2 sequestration;
- The legislation should authorize the DEP to define, by regulation, a permitting process by which parties may apply for a permit that authorizes the parties to access and use, exclusively for a defined length of time, the specific areas of the Formations defined and approved in the permit applications; the legislation and/or the regulations should require the party seeking the permit to obtain rights to use the surface from the surface owner for the injection well site;
- The legislation and/or the regulations should specify that, once an order granting a permit is issued and the party has secured the required surface rights to construct and operate an injection well, that party may access and use the permitted areas of the Formations for CO_2 sequestration in compliance with all provisions of the permit;
- The legislation and/or regulations should allow a property owner to pursue an inverse condemnation proceeding to recover damages if the property owner can establish that it has suffered actual physical damages to its property caused by the migration of CO_2 into the portion of the Formation beneath the owner's property or that the migration of the CO_2 has actually interfered with the owner's existing or reasonably foreseeable use of its property. Otherwise, the injecting party will not be liable for common law tort claims brought by the property owner, including trespass and nuisance.

IV.C.4. Initial Assessment of Pore Space Acquisition Methodology

The Legislature has requested the Working Group to make recommendations to encourage the development of CCS and to examine factors integral to the construction, maintenance, and operation of CCS facilities, among other things. In response to this request, the Working Group has turned its initial attention to the manner in which pore space rights are to be acquired.

The resulting analysis has focused principally on two overarching factors: (1) the practicality and cost of any approach that required that all owners of pore space be identified and paid for the right to use pore space without regard to the landowners potential for use of the pore space, and (2) the constitutional requirements applicable to the circumstances under which the use of land required compensation as a taking.

With respect to the first of these factors, the Working Group recognizes that in West Virginia and much of the East, the shear number of property owners that could be within the footprint of a CCS project could be extremely large. In Mason County, West Virginia alone, there are nearly 20,000 surface owners and 1,000 mineral owners. On the conservative assumption that a typical title examination could cost $5,000 per tract, the cost to do title searches for a project with a footprint as large as Mason County would be approximately $100 million. Added costs related compensation to landowners and transactional costs related to acquiring the property rights cause the Working Group to conclude that an alternative course of action should be pursued.

Turning then to the constitutional requirements related to compensation for the use of land, the Working Group recognizes that not all use of private land result in a compensable taking. The United States Supreme Court and other courts have recognized a number of circumstances in which compensation was not required to be paid for the use of land. These cases have included in certain circumstances airplane over-flights of land and injection of material into underground foundations.

The Working Group carefully assessed the proposal of the Midwest Governors Association to establish as having a public use certain pore space located below 2500 feet.

In addition the Working Group carefully evaluated the recommendation of the Carnegie Mellon CCSReg Project which offered a comprehensive regulatory framework for GS based upon the balancing of the interests of private property owners with the public benefit of GS, and reducing possibility of interference with other productive non-GS uses of the subsurface that are also in the public interest. This framework was based on the premise that UIC regulators shuld be enabled to permit CCS projects and allocate use of subsurface pore space under an expanded version of the UIC program. Under this framework, regulators would consider the trade-offs between private interests and the public benefit of a proposed CCS project, determining the safest, most efficient and equitable use of the pore space, including non-CCS uses. This framework should increase the potential for either avoiding most subsurface property disputes outright, or resolving them at the outset in a stable and predictable environment that is fair and equitable to all affected parties.

By reviewing the facts and circumstances surrounding theses cases, the Working Group has developed a statutory mechanism set forth in the following section that is believed to pass constitutional muster. While the dedication of certain pore space below 2,500 feet to public use is the approach favored by the majority of the Working Group at this time, it will continue to evaluate the public use approach as well as alternative approaches.

IV.C.5. Legislative Elements

The following are elements of a legislative proposal that the Subcommittee has concluded to be appropriate to address several components of the West Virginia Carbon Dioxide Sequestration Act (W. Va. Code 22-11A-1 through 9). Following the statement of each element, specific legislative language is set forth that would implement that element.

Pore Space Acquisition

Before injection begins the applicant would need to demonstrate that is either has (or is expected to have through immediate right of entry in an eminent domain action or otherwise) "necessary" property rights related to a CCS facility.

Existing provision: W. Va. Code 22-11A-5(a)(6):

> A site and facilities description, including a description of the proposed carbon dioxide sequestration facilities and documentation sufficient to demonstrate that the applicant has, or will have prior to the commencement of the operation, all legal rights, including without limitation the right to surface or pore space use, necessary

to sequester carbon dioxide and associated constituents into the proposed carbon dioxide sequestration site;

A “necessary” right would include appropriate rights needed for surface usage (i.e. pipelines, surface facilities, wells locations etc.), appropriate rights needed for the construction of wells (including the rights to drill through any hydrocarbon bearing formations) and appropriate rights to use certain geologic strata for the sequestration of carbon dioxide. The acquisition of these rights would take place in customary fashion utilizing such concepts as voluntary negotiation or condemnation.

A “necessary” right shall not include the right to use a portion of a geologic strata for the purpose of sequestering CO_2 in the event that such geologic strata is located below 2500 feet and does not have a reasonably foreseeable use for a purpose other than the sequestration of carbon dioxide.

Amendment of existing section: W. Va. Code 22-11A-1

(a) The Legislature finds that:

(1) Carbon dioxide is a colorless, odorless gas that can be produced by burning carbon and organic compounds;

(2) Carbon dioxide is emitted into the atmosphere from a number of sources including fossil-fueled power plants, automobiles, certain industrial processes and other naturally occurring sources;

(3) By far, fossil-fueled power plants are the largest source of carbon dioxide emissions. These power plants emit approximately one-third of carbon dioxide emissions worldwide;

(4) On average, the United States generates approximately fifty-one percent of its electricity from coal-burning plants, which are a prominent source of carbon dioxide emissions;

(5) West Virginia’s reliance on electricity produced from coal is even more pronounced, as West Virginia generates approximately ninety-eight percent of its electricity from coal burning power plants;

(6) There is increasing pressure, both nationally and worldwide, to produce electrical power with an ever-decreasing amount of carbon dioxide emissions;

(7) West Virginia is a state rich in natural resources, and its economy depends largely upon the demand for energy produced from materials found within the state, not the least of which is coal;

(8) As demand for energy produced from alternative and renewable resources rises, new technologies are needed to burn coal more cleanly and efficiently if West Virginia is to remain competitive as an energy producing state;

(9) Carbon dioxide capture and sequestration is the capture and secure storage of carbon dioxide that would otherwise be emitted to, or remain in, the atmosphere. This technology is currently being used and tested to reduce the carbon footprint of electricity generated by the combustion of coal;

(10) The science of carbon dioxide capture and sequestration is advancing rapidly, but the environmental effects of large, long-term carbon dioxide sequestration operations are still being studied and evaluated;

(11) Although the state is committed to expanding its portfolio of alternative and renewable energy resources, electricity generated from these resources is insufficient in the near term to meet the rising demand for energy;

(12) It is in the public interest to advance the implementation of carbon dioxide capture and sequestration technologies into the state's energy portfolio;

(13) Inasmuch as the subsurface sequestration of carbon dioxide is a necessary and vital part of the modern environment of life in light of the challenges the world faces with climate change and increasing energy demands, it is appropriate for the state to use its police power to ensure that subsurface formations throughout the state can be used for the purpose of carbon dioxide sequestration in accordance with this article;

(14) It is in the public interest to declare as a public use the use of certain deeper geologic strata for the purpose of carbon dioxide sequestration in accordance with a permit issued pursuant to this article, so long as those geologic strata do not have a current or reasonably foreseeable use for any purpose other than the geologic sequestration of carbon dioxide;

(15) The state should provide for a coordinated statewide program which authorizes the exclusive access to and use of specific areas of the geologic formations and otherwise regulates the injection, storage and withdrawal of carbon dioxide and fulfilling the state's primary responsibility for assuring compliance with the federal Safe Drinking Water Act, including any amendments thereto.

(1~~3~~6) The transportation by pipeline and sequestration of carbon dioxide by a public utility engaged in the generation of electricity may be integral to the construction, maintenance and operation of electric light, heat and power plants operating in the state; and

(1~~4~~7) Therefore, in order to expand more rapidly the generation of electricity with little or no carbon dioxide emissions, it is critical to encourage the development of carbon dioxide capture and

> sequestration technologies; to examine factors that may be integral to the construction, maintenance and operation of carbon dioxide sequestration facilities; and to study the economic and environmental feasibility of large, long-term carbon dioxide sequestration operations.

The subcommittee notes that subsections 2, 3, 4, 5, and 6 of the above findings contain factual statements that should be reviewed for current accuracy.

Proposed new subsection:

> (a) For the purpose of [W. Va. Code 22-11A-5(a)(6) (correct citation to be added later)] a necessary legal right to sequester carbon dioxide and associated constituents into the proposed carbon dioxide sequestration site shall include appropriate rights to utilize the surface of the land involved in addition to the rights to use certain geologic strata for the sequestration of carbon dioxide; however, a necessary legal right shall not include the right to use for that purpose those portions of a geologic strata located at a depth of two thousand five hundred feet or more below the surface of the land which, on the effective date of a permit issued pursuant to this article, do not have a current or reasonably foreseeable use for a qualifying purpose. Such right to use such geologic strata located at a depth of two thousand five hundred feet or more below the surface is hereby dedicated to be a public use and no compensation shall be required to be paid solely for such use.

Proposed new definitions:

> "Qualifying purpose" means the lawful use of geologic strata for any significant purpose, including but not limited to, the storage of natural gas, or the extraction of coal, oil, natural gas, coalbed methane or other minerals in paying quantities utilizing then-current production techniques or technologies that are feasible for use in the region, but does not include the use of such strata for the purpose of storing or sequestering carbon dioxide.
>
> "Permit issued pursuant to this article" means a permit issued by the secretary pursuant to this article for the sequestration of carbon dioxide in geologic strata.

The CCS permit will be the mechanism for determining whether there is an existing use, for seeking to resolve that competing use and for authorizing the use of the geologic strata for the sequestration of carbon dioxide.

Proposed new section:

> (a) Property owners potentially affected by a proposed sequestration facility shall have the opportunity to demonstrate the project will impair a current or reasonably foreseeable use of the geologic strata for a qualifying purpose during the permit

application's public comment period. If impairment is demonstrated, the secretary shall issue a permit for the project upon the condition that the operator:

(1) reach a contractual agreement with such owner resolving the claim of a preexisting interest;

(2) modify the project so that it avoids the impairment; or

(3) initiate condemnation proceedings to acquire the property rights likely to be materially impaired.

(b) In the absence of a showing that the geologic strata proposed for use has a current or reasonably foreseeable use for a qualifying purpose that is likely to be materially impaired by the proposed project, the public interest associated with sequestering carbon dioxide in geologic strata to help mitigate effects of climate change shall prevail over any right of the owners of any rights in such strata to exclude operators who are properly licensed pursuant to this article. Therefore, an operator conducting activity pursuant to a permit issued pursuant to this article for the sequestration of carbon dioxide in such strata shall have the right to inject into and occupy the geologic strata within the boundaries designated by such permit in all areas in which all portions of such geologic strata are located at a depth of two thousand five hundred feet or more below the surface of the land and, which on the effective date of such permit do not have a current or reasonably foreseeable imminent use for a qualifying purpose that is likely to be materially impaired by the proposed project.

[Note: Additional drafting on this provision may be necessary to make it clear that the 2500 feet measurement is the minimum distance between the upper most portion of the reservoir and lower most portion of the surface of the land overlying the projected plume area.]

Restriction on usage of hydrocarbon bearing and other formations

The operator should not be allowed to store CO_2 in geologic strata bearing coal, oil, natural gas, coalbed methane, or other minerals which could be extracted in paying quantities utilizing then current production techniques or technologies that are feasible for use in the region unless that formation is owned by the operator, or has permission of the owner to authorize such a use.

Proposed new section:

(a) The owner or operator of a sequestration facility shall obtain a permit pursuant to this article from the secretary prior to the construction, operation or modification of a sequestration facility. Any entity owning or operating a sequestration facility in existence on the effective date of this article is hereby authorized to continue operating until such time as the secretary has established operational and procedural requirements applicable to such existing sequestration facilities and the entity owning or operating such facility has had a reasonable opportunity to comply with those requirements.

(b) A sequestration facility for carbon dioxide is hereby authorized, provided that the secretary shall first issue a permit authorizing such proposed sequestration of carbon dioxide and designating the horizontal and vertical boundaries of the sequestration facility. In order to authorize a sequestration facility for carbon dioxide, the secretary shall find as follows:

(1) That an applicant has obtained or applied for a certificate of public convenience and necessity from the public service commission pursuant to this article;

(2) That (a) the formation has characteristics suitable for or which can be made suitable for the storing of carbon dioxide through fracturing or other demonstrated techniques, (b) the boundaries of the sequestration facility can be established with reasonable certainty and (c) the sequestration facility is otherwise suitable and feasible for the injection, storage and, if proposed, withdrawal of carbon dioxide;

(3) That the use of the sequestration facility for the sequestration of carbon dioxide will not contaminate other formations containing fresh water, oil, natural gas, coal, coalbed methane, or other minerals that could be extracted in paying quantities utilizing then-current production techniques or technologies that are feasible for use in the region;

(4) That the sequestration facility will not be used to inject carbon dioxide into that part of a geologic strata that is within the certificated boundaries (including the protective area) of an existing natural gas storage field certificated by the federal energy regulatory commission or the public service commission;

(5) That the sequestration facility will not be used to inject carbon dioxide into a geologic strata bearing oil, natural gas, coal, coalbed methane, or other minerals capable of being produced in paying quantities utilizing then-current production techniques or technologies that are feasible for use in the region, unless the proposed operator demonstrates that it owns the affected oil, natural gas, coal, coalbed methane, or other minerals in such geologic strata within the proposed boundaries of the sequestration facilities or has the permission of the owner to authorize such a use,

(6) That the sequestration facility will be operated in such a manner as to protect human health and the environment; and

> (7) That the qualities of the carbon dioxide to be managed will not compromise the safety or structural integrity of the sequestration facility.
>
> (c) In the event one sequestration facility is or may interfere with another sequestration facility, the secretary shall resolve the dispute by taking such remediation actions, enforcement actions or permit modifications as may be necessary to resolve the dispute and to avoid future interference.

Primacy of mineral estate

Statutory and common law regarding primacy of a mineral estate should not be altered, nor should there be a limit on the right of a mineral owner to make reasonable use of the subsurface for mineral exploration or production. The holder of a mineral interest should not be prevented from exercising its lawful rights in a manner that will not compromise the safety or integrity of the CO_2 sequestration project. If such rights cannot be exercised without compromising the sequestration project, such activities should be restricted or precluded to the extent necessary to protect the safety or integrity of the sequestration project, without compensation being required. If the mineral interest owner or holder believes the prohibition amounts to an uncompensated regulatory taking, the interest-holder may, of course, file an inverse condemnation claim.

Proposed amendment to § 22-11A-8:

> (a) Nothing in this article shall be deemed to affect the otherwise lawful right of a ~~mineral owner~~ person to drill or bore through or otherwise exercise rights near a formation in which carbon dioxide is being sequestered ~~sequestration site, if done~~ in accordance with the rules promulgated ~~under~~ pursuant to this article to protect the safety and integrity of ~~for protecting~~ the carbon dioxide sequestration project ~~site~~ against the escape of carbon dioxide.

[Note: Additional editing to the subsection may be needed to address the term “near”.]

> (b) The injection of carbon dioxide for purposes of enhancing the recovery of coal, oil, natural gas, coalbed methane or other minerals pursuant to a project approved by the department shall not be subject to the provisions of this article. Nothing in this article is intended to impede or impair the ability of ~~an oil, natural gas or coalbed methane operator to inject carbon dioxide through an approved enhanced oil, natural gas or coalbed methane recovery project and~~ any party entitled thereto to establish, verify, register and sell emission reduction credits ~~associated with the project~~.
>
> (c) Except as herein specifically provided, nothing in this article shall alter or amend existing state law regarding correlative property rights or the primacy of the coal, oil, natural gas, coalbed

methane or other mineral estate. [Note: Additional research may lead to further changes to this provision.]

(~~c~~d) The Office of Oil and Gas shall have jurisdiction over any subsequent extraction of sequestered carbon dioxide that is intended for commercial or industrial purposes.

(e) Except as herein specifically provided, nothing in this article shall alter, amend, diminish or invalidate rights to use subsurface pore space that were acquired by contract or lease prior to the effective date of this article, including, without limitation, rights acquired for the underground storage of natural gas, or in connection with the extraction or production of coal, oil, natural gas, coalbed methane or other minerals, including, without limitation, rights for the secondary recovery of coal, oil, natural gas, coalbed methane or other minerals by injection of carbon dioxide or water or by other means.

Eminent domain

To the extent that it is necessary for an operator to take an interest in property, the issuance of a permit under this article in conjunction with PSC approval shall be sufficient to authorize the use of eminent domain. Existing powers of eminent domain are to be preserved.

Proposed new section:

(a) Except as provided in subsection (b) of this section, any sequestration operator or pipeline operator is hereby authorized, after obtaining any permit from the secretary required by this article and any certificate of public convenience and necessity from the public service commission required by this article, to exercise the power of eminent domain to acquire surface and subsurface rights and property interests necessary or useful for the purpose of constructing, operating or modifying the sequestration facility or carbon dioxide transmission pipeline, including easements and rights-of-way across lands for pipelines transporting carbon dioxide to and among facilities constituting said sequestration facility.

(b) No sequestration operator or pipeline operator may exercise the power of eminent domain for the purpose set forth in subsection (a) of this section:

(1) to obtain title to coal, oil, gas, coalbed methane, or other minerals which on the effective date of any permit from the secretary required by this article are capable of being produced in paying quantities utilizing then-current production techniques or technologies that are feasible for use in the region, except in accordance with subsection __, or

> (2) to obtain right of way for a pipeline to transport carbon dioxide that is withdrawn from a sequestration facility to a location that is outside the boundaries of the storage facility.
>
> (c) The exercise of the right of eminent domain granted in this article shall not prevent entities from drilling through the sequestration facility in such manner as shall comply with the requirements of the secretary sequestration issued for the purpose of protecting the sequestration facility against pollution or invasion and against the escape or migration of carbon dioxide. Furthermore, the right of eminent domain set out in this article shall not prejudice the rights of the owners of said lands or other rights or interests therein as to all other uses not acquired for the storage facility.
>
> (d) The eminent domain authority authorized under this article shall be in addition to any other power of eminent domain authorized by law.
>
> (e) No rights or interests in sequestration facilities acquired for the injection and sequestration of carbon dioxide by an operator who has obtained a permit pursuant to this act shall be subject to the exercise of the right of eminent domain authorized by this act. The secretary, however, may reopen an earlier permit for the purpose of balancing the interest of two or more projects with competing interests. The secretary shall modify one or more of the original permits to the extent necessary to resolve such competing interests.

Pore space compensation

In determining the amount of compensation to be paid to a property owner for the taking of any necessary property rights related to the use of pore space, no value shall be attributed to the present or future use of that pore space for the sequestration of CO_2.

Proposed new section:

> (a) In any case in which property may lawfully be taken for a public use, application therefore may be made by petition to the circuit court or the judge thereof in vacation, of the county in which the estate is situated. If a tract lies partly in one county and partly in another, the application in relation thereto may be made in either county. Except as provided in section ___, the condemnation proceeding shall be conducted pursuant to the provisions of article two, chapter fifty-four of this code; provided that in determining the amount of compensation to be paid to a property owner for taking of any necessary property rights related to the use of pore space, no value shall be attributed to the present or future use of that pore space for the sequestration of carbon dioxide.

Trespass and Nuisance

If at any time it is determined by a court of competent jurisdiction that an operator is required to own a property right that the operator does not then own, the operator shall be required to obtain that property right, but would not be subject to common law or other claims (i.e. trespass or nuisance) for the failure to have owned that property right.

Proposed new section:

> (a) In the event it is determined by a court of competent jurisdiction that an operator who is operating in compliance with a valid permit issued pursuant to this article is required to obtain a property right that the operator does not then own, the operator shall be required to obtain that property right, but the operator shall not be liable under common law for claims of trespass or nuisance based upon the failure to have owned that property right; provided, however, that such an operator shall not be protected from such claims if the operation involved impedes the recovery of coal, oil, natural gas, coalbed methane, or other minerals capable of being produced in paying quantities utilizing then-current production techniques or technologies that are feasible for use in the region.
>
> (b) In the event the owner of such geologic strata believes such use is a *per se* physical taking of property without just compensation, the aggrieved owner may file an inverse condemnation action.

Property owner identification and notice

One additional option for steam-lining the process of undertaking eminent domain would be to rely upon tax records to determine property ownership. No effort has yet been undertaken to prepare specific provisions related to this possibility.

Role of ALJs

As an alternative to filing an eminent domain action in circuit court, it may be desirable to allow application to be made to a panel of administrative law judges or special board of appraisers which might be empowered to determine compensation to be paid for property rights to be taken (subject, of course, to appeal to an appropriate circuit court). No effort has yet been undertaken to prepare specific provisions related to this possibility.

IV.C.6. Other issues to be addressed by the Legal Subcommittee

Permitting

The operator shall be required to obtain a permit pursuant to the West Virginia Carbon Dioxide Sequestration Act from the DEP prior to the construction, operation or modification of a carbon dioxide sequestration facility. In order to obtain the permit, DEP shall require the applicant to obtain a certificate of public convenience and necessity from the public service commission (“PSC”) in addition to the other requirements. This permit application shall be transparent with the federal Safe Drinking Water Act, relating to the state’s participation in the underground injection control program, and the state’s requirement to obtain a “well work” permit. The operator will be required to demonstrate appropriate financial responsibility throughout the injection process and through closure. The permitting requirements should mandate that construction on the facility begin within a specified period of time following permit issuance.

Groundwater Protection

The Groundwater Protection Act currently contains exemptions for activities that involve direct contact with groundwater. At the time the Groundwater Protection Act was enacted in 1994, the possibility of injecting carbon dioxide in geologic formations was not known to the Legislature. Since carbon sequestration is very similar to the activities that were exempt from coverage under various portions of the Groundwater Protection Act, it is appropriate to expand those exemptions to include carbon dioxide sequestration wells in the same manner that UIC Class 2 and 3 wells are currently exempt.

Administrative Fees

Permit application fees shall be assessed for applications filed with each of the DEP and the PSC. In addition, an administrative trust fund shall be created to offset the cost of administering the remainder of CCS regulatory program.

Interstate Projects

Due to the fact that the geologic basins containing formations suitable for geologic sequestration cross state boundaries creating the likelihood that plumes from the injection formation could cross into another state, it may be necessary to authorize the Secretary to enter into reciprocal agreements with other governments or government entities.

Preemption

All laws should be preempted other than those specifically authorized to regulate carbon dioxide sequestration facilities (in much the same way as those laws are currently preempted under the Groundwater Protection Act).

Report to Legislature

The Secretary shall submit timely reports to the legislature assessing the effectiveness of the carbon dioxide sequestration program.

Liability transfer

Liability transfer should be authorized during the post closure period to promote CCS activities. Ownership of the storage facility including the stored carbon dioxide shall transfer to a quasi-public entity, the state, or the federal government upon the issuance of a certificate of completion by the Secretary of the DEP.

Post Closure Trust Fund

A trust fund should be established to provide funds to maintain the facility in the post closure phase and to purchase insurance and if necessary to respond to claims. Provision should be made for the handling of subsequent sequestration facilities.

PSC Approval

As noted above in 7.a., a certificate of public convenience and necessity shall be required from PSC before beginning construction of the storage facility or carbon dioxide transmission pipeline. The power of eminent domain shall be authorized to any storage operator or pipeline operator who obtains a permit under the West Virginia Carbon Dioxide Sequestration Act and obtains a certificate of public convenience and necessity from the PSC.

Ownership and Value of Stored CO_2

The owners of geologic strata being used for the storage of carbon dioxide need to receive assurances that they will be allowed to participate in any economic value that may be associated with the removal of the carbon dioxide for profit. Such provisions might addresses ownership of the CO_2 underground as well as assuring that the owners of the geologic strata in which CO_2 is stored are not subject to liability related to that storage.

Forced unitization

Forced unitization will continue to be evaluated as an administrative mechanism for obtain necessary rights to use pore space.

Pipelines

Pipelines will be an important part of a successful CCS program. Additional evaluation will be undertaken about pipeline to include their siting and permitting. In addition, attention will need to be given to the acquisition of rights of way for pipelines.

V. MINORITY OPINIONS

V.A. Minority Report on Risk Assessments for Long Term Geologic Storage of Carbon Dioxide.

By John Leeson on June 14, 2010

There have been some risk assessments for long term geologic storage of carbon dioxide. My understanding is that some of the risk assessments have been done or assisted by mathematical modeling or simulations.

I do not have confidence in calculated probabilities of carbon dioxide loss from geologic storage.

In my opinion, there is insufficient current information and carbon dioxide storage history to accurately determine risk probabilities of carbon dioxide loss from geologic storage, particularly from aquifers. Most of the potential carbon dioxide storage capacity in West Virginia is in saline aquifers.

It seems to me that the risk of carbon dioxide loss will likely be different from different geologic formations used for storage such as depleted oil and gas fields, coal beds and aquifers. One general calculated risk probability value is not likely to adequately describe the risks of storage in various types of formations.

V.B. WVCCS Working Group Legal Subcommittee Minority Report.

June 30, 2010

Prepared by David McMahon, J.D.; Surface owners representative.1624 Kenwood Road, Charleston, WV 25301. Voice/VoiceMail 304-415-4288 E-mail: wvdavid@wvdavid.net

This minority report on the work of the Legal Subcommittee will not be lengthy because this is an interim report, and because of constraints on funding for the participation of pubic interest members. It will only be on one of the subjects that the Legal Subcommittee addressed without waiving the right to comment on other aspects of the final report. A comment in an earlier draft of this Minority Report on the issue of ultimate "liability transfer" took the position that the sequestering entity should always retain some liability, like a deductible, for public policy reasons. Since the Legal Subcommittee has not discussed that issue, the comment was removed.

Acquisition of right to use the pore space

The Carbon Dioxide Sequestration Working Group was initiated by Legislation. The introduced version of that legislation included a presumption that the owner of the surface of any tract of land also owned the pore space – meaning that it would need to be purchased or taken the same as any other interest in land before it could be used for carbon sequestration. How far we have come.

That initial universal presumption did go too far, and it was not included in the final legislation. There are circumstances where the fee owner of a tract of land deeds the surface to another owner, and the clear contemplation of the parties is that the purchaser is only getting the surface (and even that surface is subject to the mineral owners rights to use the surface for obtaining the minerals using methods in the contemplation of the partes at the time of the severance deed). That surface owner does not own, and should not be presumed to have, any rights to the pore space in that limited situation.

However, in many, probably most cases, the deeding away of oil and gas, or coal, or minerals, by someone who kept what was not deeded away, did not contemplate the deeding of the right to use pore space. Indeed that has been the working premise of the long established conventional natural gas storage industry in West Virginia for many, many years. So lots of surface owners own pore space even if they do not also own the minerals.

And owners who own the minerals but not the surface are not so concerned about the effects on the surface or the potential harm to groundwater etc. But those mineral owners who do also own the pore space believe that they have something valuable – increasingly valuable it turns out.

The legal subcommittee recognized early on that the subcommittee could provide a number of different options for a legal regime and process for establishing the right to sequester carbon dioxide in the pore space of land owned by others. There are opponents of carbon sequestration who may well sue to stop it. The options will be on a continuum that includes a consideration of the possible law suit to stop it. On one end is a regime and process that will guarantee that there will be no successful legal challenge on basis of taking or trespass, but which require much greater time and effort and expense to accomplish. On the other end of the continuum are regimes and processes which will be quick and cheap, but unlikely to stand up to constitutional and other challenges in the courts.

A distilling of the subcommittee's progress would be that its thinking started almost on one end of the spectrum, but ended up at the other end of the spectrum. The subcommittee learned more and more about how difficult it would be to identify the owners of the pore space and contact them to purchase the right to use it or, in the event they were unwilling to sell it for the price offered, condemn it. Also, the political difficulties of condemnation legislation entered into the analysis. So the subcommittee searched harder and harder for some alternative. Without finding any legal authority that this report believes is solid, it abandoned notice and negotiated purchase/condemnation of individual tracts. While this minority report can only compliment the thoroughness and openness of the effort, the result in the interim report is not fair to the owners of pore space, whoever they may be, or to owners of other interests in the land whether they be surface or gas. And in addition it will not likely stand up to constitutional scrutiny. And the result is certainly not certain enough of its constitutionality to prevent carbon sequestration from being held up by long litigation over its constitutionality. In addition, its apparent unfairness to land interest owners will probably not have a greater likelihood of success in the Legislature than would increasing condemnation rights.

The subcommittee's current recommendation is in essence that,

> "We can pump carbon dioxide under your land at such high pressures that it will not turn to gas. We can do it without your permission unless you get some general notice sent to the public and point out during a permit process that the project will 'impair a current or reasonably foreseeable use of the geologic strata [not strata above and below that strata that may be impaired, but the strata used for sequestration] for a qualifying purpose'. And we do not have to pay you for doing this under your land unless you have a current or reasonably foreseeable economic use utilizing then-current production techniques or technologies that are feasible for use in this region. The reason we can do this is that we need to do this really badly and it is too hard to do it any other way, so we think the courts will say it is not a trespass or a taking. And if we do need to take it from you because you have a current economic use for it, then we will compensate you on what the pore space was worth to you the seller and not to us the buyer."

The report analogizes the sequestering of carbon dioxide to the regime of law for disposal of *treated* municipal waste water in Florida or a court case for salt water disposal in Ohio. This minority report does not think that our courts will find those processes to be analogous to carbon sequestration, or that, our courts would be persuaded by the legal reasoning of those regimes and cases in other states even if the circumstances were analogous.

When we started we were cynical that using someone's property without finding and compensating them was not going to be acceptable. Since we figured out how hard that would be, we have convinced ourselves that it is possible to do it differently. We have figured this out only in the face of the difficulty of doing it otherwise. We have not come to this conclusion based on based on newly discovered law or facts.

What the committee should do is a further investigation of processes and statutory evidentiary, valuation and other presumptions in order to more economically find the owners and compensate them.

One particular problem is that using one formation for carbon sequestration will make it more difficult to drill to gas (or other) resources in lower formations. This could cause producers to want to drill instead on tracts where there is no carbon sequestration, and so lower the value of the tracts underlain by carbon sequestration. A possible avenue of investigation to address that is to keep escrows to compensate owners for the extra cost of drilling through formations used for carbon sequestration in the event the owner ever finds it necessary or convenient to drill through the formation used for carbon sequestration to deeper gas or other resources.

Below is a list of the interests who would oppose the use of their land for carbon sequestration and their rationale. It is supplied both to show some of the legal reasoning to be avoided and show the motivation to oppose carbon sequestration.

1. It's mine and I don't want you doing with it just because its mine and not yours and this is America and you should not be able to take it any more than you should be able to take my guns.
2. It's mine and I do not want it harmed – particularly the surface and groundwater, but all of it really. You say that supercritical carbon dioxide will not get loose and come to the surface, but I do not believe you. You can't prove a negative to my satisfaction – that it will not harm me or my land somehow. Particularly when we have 1) 50,000 active oil and gas wells in the state with un-cemented annular spaces in between the cementing of the surface/coal casing and the cementing of the production pipe at the bottom of the hole near the production formation, and 2) there are 9000, or maybe more, pre-1929 orphaned oil and gas wells that have not been plugged at all and more than 10,000 post-1929 wells that need plugged that the State does not have the resources to make the industry plug. I do not want that carbon sequestered under me.
3. It's mine and you are taking it and you need to pay me. Fundamental fairness. How come those people in New York don't have to pay me for it just because they need it very badly. You can say you can trespass onto me without paying me or "taking" it because I am suffering no harm. But if it has value to you, how come you are now saying it has no value to me.
4. It's mine and you are ruining/diminishing the speculative value of the formation you are using and the formations below it. Just because I am not using it now, or have no immediate plans to drill through it to possible deeper formations right now, does not mean it does not have value to me. No one thought the Marcellus Shale was worth anything three years ago, but new discoveries and technologies have made it the most valuable gas find ever in West Virginia! Some day they will discover deeper gas or some other valuable substance, but it will cost more to get through the formation where the carbon dioxide is sequestered so they will go do it on someone else's land. Don't tell me that speculative value does not mean anything. If that was true, surface owners could buy their minerals back for what they sold it for.

The draft recommendation saying that those objections are not relevant because "It's not yours," will be an inadequate response to these interest groups, and the courts and the Legislature.