

# CRS Report for Congress

## Pipelines for Carbon Dioxide (CO<sub>2</sub>) Control: Network Needs and Cost Uncertainties

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# Pipelines for Carbon Dioxide (CO<sub>2</sub>) Control: Network Needs and Cost Uncertainties

## Summary

Congress is considering policies promoting the capture and sequestration of carbon dioxide (CO<sub>2</sub>) from sources such as electric power plants. Carbon capture and sequestration (CCS) is a process involving a CO<sub>2</sub> source facility, a long-term CO<sub>2</sub> sequestration site, and CO<sub>2</sub> pipelines. There is an increasing perception in Congress that a national CCS program could require the construction of a substantial network of interstate CO<sub>2</sub> pipelines. However, divergent views on CO<sub>2</sub> pipeline requirements introduce significant uncertainty into overall CCS cost estimates and may complicate the federal role, if any, in CO<sub>2</sub> pipeline development. S. 2144 and S. 2191 would require the Secretary of Energy to study the feasibility of constructing and operating such a network of pipelines. S. 2323 would require carbon sequestration projects to evaluate the most cost-efficient ways to integrate CO<sub>2</sub> sequestration, capture, and transportation. P.L. 110-140, signed by President Bush on December 19, 2007, requires the Secretary of the Interior to recommend legislation to clarify the issuance of CO<sub>2</sub> pipeline rights-of-way on public land.

The cost of CO<sub>2</sub> transportation is a function of pipeline length and other factors. This report examines key uncertainties in CO<sub>2</sub> pipeline requirements for CCS by contrasting hypothetical pipeline scenarios for 11 major coal-fired power plants in the Midwest Regional Carbon Sequestration Partnership region. The scenarios illustrate how different assumptions about sequestration site viability can lead to a 20-fold difference in CO<sub>2</sub> pipeline lengths, and, therefore, similarly large differences in capital costs. From the perspective of individual power plants, or other CO<sub>2</sub> sources, variable costs for CO<sub>2</sub> pipelines may have significant ramifications. If CO<sub>2</sub> pipeline costs for specific regions reach tens, or even hundreds, of millions of dollars per plant, then power companies may have difficulty securing the capital financing or regulatory approval needed to construct or retrofit fossil fuel-powered plants in these regions. High CO<sub>2</sub> transportation costs also could increase electricity prices in “sequestration-poor” regions relative to regions able to sequester CO<sub>2</sub> more locally.

As CO<sub>2</sub> pipelines get longer, the state-by-state siting approval process may become complex and protracted, and may face public opposition. Because CO<sub>2</sub> pipeline requirements in a CCS scheme are driven by the relative locations of CO<sub>2</sub> sources and sequestration sites, identification and validation of such sites must explicitly account for CO<sub>2</sub> pipeline costs if the economics of those sites are to be fully understood. Since transporting CO<sub>2</sub> to distant locations can impose significant additional costs to a facility’s carbon control infrastructure, facility owners may seek regulatory approval for as many sequestration sites as possible and near to as many facilities as possible. If CCS moves to widespread implementation, government agencies and private companies may face challenges in identifying, permitting, developing, and monitoring the large number of localized sequestration reservoirs that may be proposed. However, even as viable sequestration reservoirs are being identified, it is unclear which CO<sub>2</sub> source facilities will have access to them, under what time frame, and under what conditions. Given the potential size of a national CO<sub>2</sub> pipelines network, many billions of dollars of capital investment may be affected by policy decisions made today.

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# Pipelines for Carbon Dioxide (CO<sub>2</sub>) Control: Network Needs and Cost Uncertainties

## Introduction

Congress is considering policies to reduce U.S. emissions of greenhouse gases. Prominent among these policies are those promoting the capture and direct sequestration of carbon dioxide (CO<sub>2</sub>) from manmade sources such as electric power plants and manufacturing facilities. Carbon capture and sequestration is of great interest because potentially large amounts of CO<sub>2</sub> produced by the industrial burning of fossil fuels could be sequestered. Although they are still under development, carbon capture technologies may be able to remove up to 95% of CO<sub>2</sub> emitted from an electric power plant or other industrial source.

Carbon capture and sequestration (CCS) is a three-part process involving a CO<sub>2</sub> source facility, a long-term CO<sub>2</sub> sequestration site, and an intermediate mode of CO<sub>2</sub> transportation — typically pipelines. Some studies have been optimistic about pipeline requirements for CO<sub>2</sub> sequestration. They conclude that the pipeline technology is mature, and that most major CO<sub>2</sub> sources in the United States are, or will be, located near likely sequestration sites, so that large investments in CO<sub>2</sub> pipeline infrastructure will probably not be needed.<sup>1</sup> Other studies express greater uncertainty about the required size and configuration of CCS pipeline networks.<sup>2</sup> A handful of regionally-focused studies have concluded that CO<sub>2</sub> pipeline requirements for CO<sub>2</sub> sources could be substantial, and thus present a greater challenge for CCS than is commonly presumed, at least in parts of the United States.<sup>3</sup>

Divergent views on CO<sub>2</sub> pipeline requirements introduce significant uncertainty into overall CCS cost estimates and may complicate the federal role, if any, in CO<sub>2</sub> pipeline regulation. They are also a concern because uncertainty about CO<sub>2</sub> pipeline requirements may impede near-term capital investment in electricity generation, with important implications for power plant owners seeking to reduce their CO<sub>2</sub> emissions.

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<sup>1</sup> See, for example: John Deutch, Ernest J. Moniz, et al., *The Future of Coal*. (Cambridge, MA: Massachusetts Institute of Technology: 2007): 58. (Hereafter referred to as MIT 2007.)

<sup>2</sup> Intergovernmental Panel on Climate Change, Special Report: *Carbon Dioxide Capture and Storage, 2005* (2005): 190. (Hereafter referred to as IPCC 2005.)

<sup>3</sup> Eric Williams, Nora Greenglass, and Rebecca Ryals, “Carbon Capture, Pipeline and Storage: A Viable Option for North Carolina Utilities?” Working paper prepared by the Nicholas Institute for Environmental Policy Solutions and the Center on Global Change, Duke University (Durham, NC: March 8, 2007): 4.

In the 110<sup>th</sup> Congress, there has been considerable debate on the capture and sequestration aspects of carbon sequestration, while there has been relatively less focus on transportation. Nonetheless, there is an increasing perception in Congress that a national CCS program could require the construction of a substantial network of interstate CO<sub>2</sub> pipelines. The Carbon Dioxide Pipeline Study Act of 2007 (S. 2144), introduced by Senator Norm Coleman and nine cosponsors on October 4, 2007, would require the Secretary of Energy to study the feasibility of constructing and operating such a network of CO<sub>2</sub> pipelines. The America's Climate Security Act of 2007 (S. 2191), introduced by Senator Joseph Lieberman and nine cosponsors on October 18, 2007, and reported out of the Senate Environment and Public Works Committee in amended form on December 5, 2007, contains similar provisions (Sec. 8003). The Carbon Capture and Storage Technology Act of 2007 (S. 2323), introduced by Senator John Kerry and one cosponsor on November 7, 2007, would require carbon sequestration projects authorized by the act to evaluate the most cost-efficient ways to integrate CO<sub>2</sub> sequestration, capture, and transportation (Sec. 3(b)(5)). The Energy Independence and Security Act of 2007 (P.L. 110-140), signed by President Bush, as amended, on December 19, 2007, requires the Secretary of the Interior to recommend legislation to clarify the appropriate framework for issuing CO<sub>2</sub> pipeline rights-of-way on public land (Sec. 714(7)).

This report examines key uncertainties in CO<sub>2</sub> pipeline requirements for CCS by contrasting hypothetical pipeline scenarios in one region of the United States. The report summarizes the key factors influencing CO<sub>2</sub> pipeline configuration for major power plants in the region, and illustrates how the viability of different sequestration sites may lead to enormous differences in pipeline costs. Power plants, particularly coal-fired plants, are the most likely initial candidates for CCS because they are predominantly large, single-point sources, and they contribute approximately one-third of U.S. CO<sub>2</sub> emissions from fossil fuels. The report discusses the implications of uncertain CO<sub>2</sub> pipeline requirements for CCS as they relate to evolving federal policies for carbon control.

## Scenarios for CO<sub>2</sub> Pipeline Development

Under a national CCS policy, a key question is how to establish a CO<sub>2</sub> pipeline network at the lowest social and economic cost given the current locations of existing CO<sub>2</sub> source facilities and the locations of future sequestration sites. On its face, this may appear to be a straightforward analytic problem of the type regularly addressed in other network industries. The oil and gas industry, among others, employs myriad analytic techniques to identify and optimize potential routes for new fuel pipelines.<sup>4</sup> In the context of CCS, however, predicting pipeline routes is more challenging because there is considerable uncertainty about the suitability of geological formations to sequester captured CO<sub>2</sub> and the proximity of suitable formations to specific sources of CO<sub>2</sub>. One recent analysis, for example, concluded that 77% of the total annual CO<sub>2</sub> captured from the major North American sources could be stored in reservoirs directly underlying these sources, and that an additional 18% could be

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<sup>4</sup> See, for example: BP, "Right on the Route," *Frontiers*, Issue 19 (August, 2007). [http://www.bp.com/sectiongenericarticle.do?categoryId=9019307&contentId=7035194]

stored within 100 miles of the original sources.<sup>5</sup> Other analysts suggest that captured CO<sub>2</sub> may need to be sequestered, at least initially, in more centralized reservoirs to reduce potential risks associated with CO<sub>2</sub> leaks.<sup>6</sup> They suggest that, given current uncertainty about the suitability of various on-site geological formations for long-term CO<sub>2</sub> sequestration, certain specific types of formations (e.g., saline aquifers) may be preferred as CO<sub>2</sub> repositories because they have adequate capacity and are most likely to retain sequestered CO<sub>2</sub> indefinitely.

The Department of Energy estimates that the United States has enough capacity to store CO<sub>2</sub> for tens to hundreds of years.<sup>7</sup> However, the large-scale CO<sub>2</sub> experiments needed to acquire detailed data about potential sequestration reservoirs have only just begun. Given current uncertainty about potential sequestration sites, policy discussions about CCS envision various possible scenarios for the development of a CO<sub>2</sub> pipeline network. If CO<sub>2</sub> can be sequestered near where it is produced then CO<sub>2</sub> pipelines might evolve in a decentralized way, with individual facilities developing direct pipeline connections to nearby sequestration sites largely independent of other companies' pipelines. The resulting network might then consist of many relatively short and unconnected pipelines with a small number of longer pipelines for facilities with no sequestration sites nearby. Alternatively, if only very large, centralized sequestration sites are permitted, the result might be a network of interconnected long distance pipelines, perhaps including high-capacity trunk lines serving a multitude of feeder pipelines from individual facilities. A third scenario envisions CO<sub>2</sub> sequestration, at least initially, at active oil fields where injection of CO<sub>2</sub> may be profitably employed for enhanced oil recovery (EOR). Indeed, a CO<sub>2</sub> pipeline network already exists for EOR purposes in the southwestern United States, although it is limited in geographic reach. Whether CCS policies ultimately lead to one or more of these scenarios remains to be seen; however, the configuration of the resulting CO<sub>2</sub> pipeline network, and its associated costs, may have a significant bearing on which CCS policies best serve the public interest.

## Hypothetical CO<sub>2</sub> Pipelines in the Midwest

Infrastructure requirements and policy implications related to CO<sub>2</sub> pipelines become clearer when considering what actual pipeline projects might look like. This section outlines contrasting scenarios for hypothetical CO<sub>2</sub> pipeline development in the region covered by the Midwest Regional Carbon Sequestration Partnership

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<sup>5</sup> R.T. Dahowski, J.J. Dooley, C.L. Davidson, S. Bachu, N. Gupta, and J. Gale, "A North American CO<sub>2</sub> Storage Supply Curve: Key Findings and Implications for the Cost of CCS Deployment," *Proceedings of the Fourth Annual Conference on Carbon Capture and Sequestration* (Alexandria, VA: May 2-5, 2005). The study addresses CO<sub>2</sub> capture at 2,082 North American facilities including power plants, natural gas processing plants, refineries, cement kilns, and other industrial plants.

<sup>6</sup> Jennie C. Stevens and Bob Van Der Zwaan, "The Case for Carbon Capture and Storage," *Issues in Science and Technology*, vol. XXII, no. 1 (Fall 2005): 69-76. (See page 15 of this report for a discussion of safety issues.)

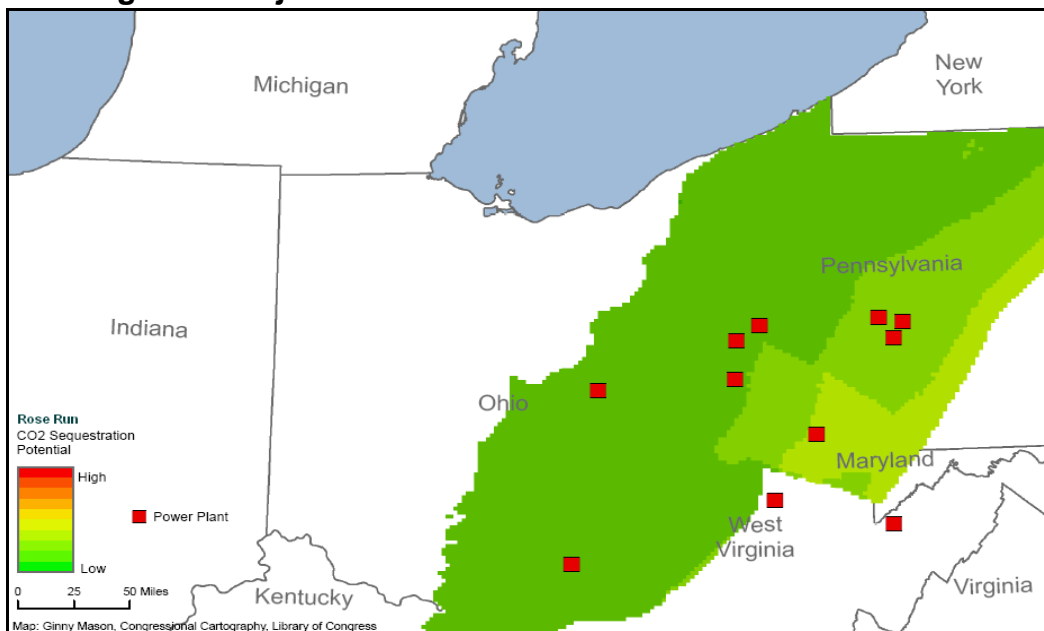
<sup>7</sup> U.S. Dept. of Energy, Office of Fossil Energy, *Carbon Sequestration Atlas of the United States and Canada*, (2007).

(MRCSP). The MRCSP is one of seven regional partnerships of state agencies, universities, private companies, and non-governmental organizations established by the Department of Energy to assess CCS approaches. The MRCSP serves as a good illustration of CO<sub>2</sub> pipeline issues because it has a varied mix of CO<sub>2</sub> sources and potential geologic sequestration sites, and because geologists have completed a number of focused studies relevant to CCS in this region.

## Sequestration in the Rose Run Formation

The MRCSP has identified key CO<sub>2</sub> sources and geologic formations potentially suitable for carbon sequestration within its seven-state region encompassing northeast Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia. **Figure 1** shows the locations of 11 of the largest CO<sub>2</sub> sources located in the MRSCP region — all coal-fired electric power plants emitting over 9 million metric tons of CO<sub>2</sub> annually.<sup>8</sup> There are numerous other CO<sub>2</sub> sources in this region, including many other power plants and large industrial facilities, but the 11 power plants in this analysis include the very largest in terms of annual CO<sub>2</sub> emissions.

**Figure 1. Major Power Plants and the Rose Run Formation**



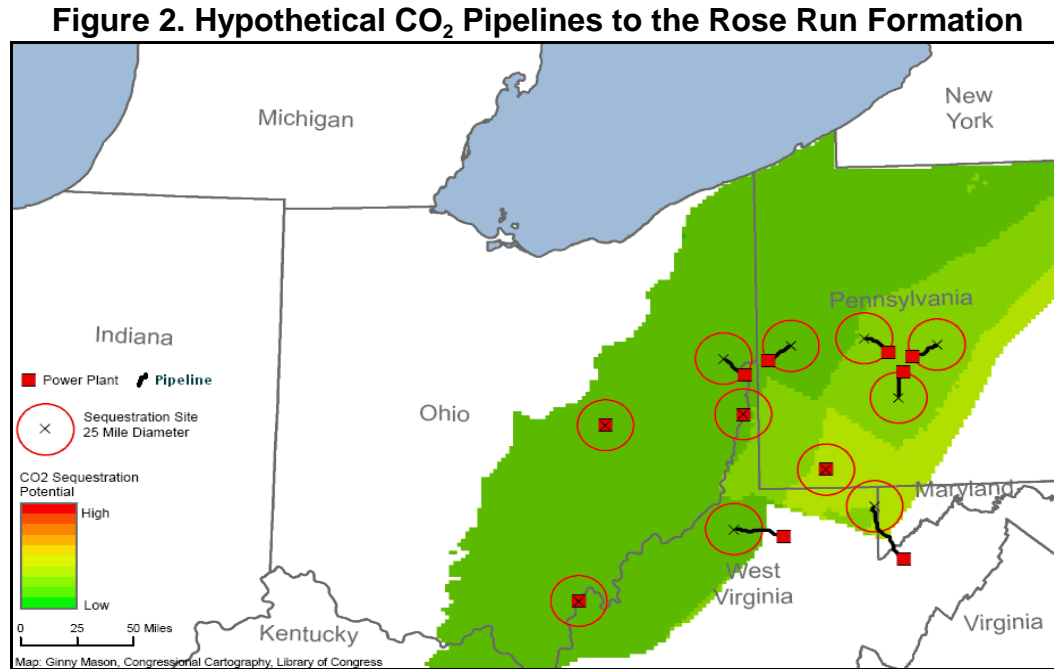
**Source:** MRCSP. Geologic data for NY are not provided by the MRCSP.

**Figure 1** also shows the locations of the Rose Run sandstone, a deep saline formation identified by the MRCSP as a potential carbon sequestration site.<sup>9</sup> As the figure shows, the plants all lie above or near to this formation, so suitable CO<sub>2</sub> injection sites presumably could be located very near to each of these plants. If the

<sup>8</sup> National Energy Technology Laboratory, “NatCarb” online database, March 29, 2007. [[http://drysdale.kgs.ku.edu/natcarb/med\\_view/map.cfm?kid=242&theme\\_kid=3](http://drysdale.kgs.ku.edu/natcarb/med_view/map.cfm?kid=242&theme_kid=3)]

<sup>9</sup> For most of the area shown in **Figure 1**, the Rose Run sandstone lies at depths greater than 2,500 feet — deep enough to make the formation potentially suitable for CO<sub>2</sub> sequestration.

Rose Run formation proves to be viable for large-scale CO<sub>2</sub> sequestration, then some plants may be able to inject CO<sub>2</sub> directly below their facilities, and CCS pipeline requirements for some of the other 11 power plants could be small. If this were the case, then the CCS CO<sub>2</sub> pipeline network for the 11 plants might appear as shown in **Figure 2**.



**Source:** MRCSP, CRS. Geologic data for NY are not provided by the MRCSP

The hypothetical pipeline layout in **Figure 2** assumes that a 25-mile diameter, non-overlapping reserve area is needed for each plant's sequestration site and that any location within the Rose Run formation is viable for sequestration. **Figure 2** also assumes that each power plant is either located at or is connected to the center of its respective sequestration field by a large trunk pipeline built along existing rights of way and capable of carrying its peak CO<sub>2</sub> output. Smaller pipelines branching from the centrally-located plant or from the trunk line distribute the CO<sub>2</sub> to multiple injection wells in the sequestration site. These smaller pipelines are not considered in detail in this report.

**Figure 2** shows that the longest trunk pipeline for CO<sub>2</sub> transportation is 32 miles long, and the average pipeline is approximately 11 miles long. According to models developed at Carnegie Mellon University (CMU), the capital costs to construct an 11-mile pipeline in the Midwestern United States with a capacity of 10 million tons of CO<sub>2</sub> annually would be approximately \$6 million. The levelized cost would be approximately \$0.10 per ton of transported CO<sub>2</sub>, including costs for operation (e.g., compression) and maintenance.<sup>10</sup>

<sup>10</sup> Model found in: Sean T. McCoy and Edward S. Rubin, "An Engineering-Economic Model of Pipeline Transport of CO<sub>2</sub> with Application to Carbon Capture and Storage," (continued...)



**Potential Barriers to Rose Run Sequestration.** Although the Rose Run formation is identified by the MRCSP as a major potential sequestration site, it has characteristics which may ultimately limit its viability for large-scale CO<sub>2</sub> sequestration. The most important of these is overall sequestration capacity. Because the Rose Run formation has low to moderate permeability and thickness, geologic models show that it is unlikely all of the CO<sub>2</sub> emitted in the Rose Run region can be efficiently sequestered in the Rose Run formation.<sup>11</sup> The Rose Run formation is also relatively fractured.<sup>12</sup> Geologists have concluded that injecting pressurized CO<sub>2</sub> into the Rose Run formation potentially could induce minor earthquakes along certain preexisting (but undetected) faults in otherwise seismically stable areas.<sup>13</sup> Faults and fractures can, in some cases, provide additional sequestration capacity and be beneficial for sequestration. But faults or fractures can also be permeable conduits for leakage and “can be a significant pathway for the loss of sequestered CO<sub>2</sub>.”<sup>14</sup> While studies are not yet available to establish the validity of any of these concerns, future research may conclude that significant parts of the Rose Run formation would be unsuitable for large scale, permanent CO<sub>2</sub> sequestration.<sup>15</sup>

## Alternatives to CO<sub>2</sub> Sequestration in Rose Run

The CO<sub>2</sub> sequestration capacity of the Rose Run formation may turn out to be too limited because of its overall size or integrity. If the policy goal is to sequester CO<sub>2</sub> from all major sources in the region, then at least some of the largest power plants in the MRCSP will need to sequester their carbon emissions elsewhere. The alternative sites for potential CO<sub>2</sub> sequestration nearest to Rose Run are unmineable coal beds, oil and natural gas fields, and another large saline formation — the Mount Simon sandstone.

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<sup>10</sup> (...continued)

*International Journal of Greenhouse Gas Control*, In press (November 19, 2007). Cost estimates were provided by Sean McCoy at the request of CRS.

<sup>11</sup> M.D. Zoback, H. Ross, and A. Lucier, “Geomechanics and CO<sub>2</sub> Sequestration,” *GCEP Technical Report 2006*, Stanford Univ., Global Climate and Energy Project (2006):11. [[http://gcep.stanford.edu/pdfs/QeJ5maLQQrugiSYMF3ATDA/2.4.2.zoback\\_06.pdf](http://gcep.stanford.edu/pdfs/QeJ5maLQQrugiSYMF3ATDA/2.4.2.zoback_06.pdf)]

<sup>12</sup> U.S. Dept of Energy, Office of Fossil Energy, *Carbon Sequestration Atlas of the United States and Canada*, (2007):38.

<sup>13</sup> Amie Lucier, Mark Zoback, Neeraj Gupta, and T. S. Ramakrishnan, “Geomechanical Aspects of CO<sub>2</sub> Sequestration in a Deep Saline Reservoir in the Ohio River Valley Region,” *Environmental Geosciences* (June 2006), 13(2):85-103.

<sup>14</sup> S. Julio Friedmann, *Site Characterization and Selection Guidelines for Geological Carbon Sequestration*, Lawrence Livermore National Laboratory, UCRL-TR-234408 (September 7, 2007); K. Prasad Saripalli, B. Peter McGrail, and Mark D. White, “Modeling the Sequestration of CO<sub>2</sub> in Deep Geological Formations,” *Proceedings of the First National Conference on Carbon Sequestration*, National Energy Technology Laboratory (May 14-17, 2001):11.

<sup>15</sup> For an example of such research, see: L. Chiamonte, M. Zoback, M., S.J. Friedmann, and V. Stamp, “Seal Integrity and Feasibility of CO<sub>2</sub> Sequestration in the Teapot Dome EOR Pilot: Geomechanical Site Characterization,” *Environmental Geoscience*, v. 53 (2007).

**Unmineable Coal Beds.** The MRCSP region contains unmineable coal beds underlying the same general geographic footprint as the Rose Run formation, but located at different depths underground. Studies suggest that such coal beds may be suitable for sequestration. In some cases injected CO<sub>2</sub> could replace methane trapped in the coal seam, increasing natural gas available for extraction wells in a process similar to EOR known as enhanced coal-bed methane recovery. However, the potential capacity for storing CO<sub>2</sub> in regional coal beds is only about 5% compared to the Rose Run sandstone, and the practicability of storing CO<sub>2</sub> in coal seams is virtually untested.<sup>16</sup> In addition, removing groundwater from coal seams prior to CO<sub>2</sub> injection may create environmental problems related to water disposal, and some studies indicate that coal swelling associated with CO<sub>2</sub> injection may curtail the permeability of the coal seam, limiting its overall capacity to store CO<sub>2</sub>.<sup>17</sup>

**Oil and Natural Gas Fields.** The MRCSP region includes a number of oil and natural gas fields which may offer opportunities for CO<sub>2</sub> sequestration. The region also includes a number of natural gas storage reservoirs, both natural and manmade, which suggest that CO<sub>2</sub> could be similarly stored. However, according to the MRCSP, the ten largest oil and gas fields in the region have an average CO<sub>2</sub> sequestration potential of only 251 million tons.<sup>18</sup> By comparison, the 30-year CO<sub>2</sub> output of the 11 plants in this analysis would range from 270 to 491 million tons at current emission levels. The oil and gas fields in the MRCSP region, therefore, even if they could achieve their stated sequestration potential, may not individually have sufficient capacity to sequester CO<sub>2</sub> from one of the 11 power plants in this analysis operating with current emissions over a 30-year period. Multiple fields possibly could be used by individual power plants to achieve adequate long-term sequestration, but this would require multiple pipeline networks and, consequently, could increase CO<sub>2</sub> transportation costs and complexity.

Oil and gas production fields also present CO<sub>2</sub> sequestration challenges due to numerous boreholes from historical well-drilling activity. Geologists are concerned that old oil and gas wells may be inadequately sealed and that their locations may be uncertain.<sup>19</sup> Increased leakage risks from old wells, as well as associated mitigation and monitoring costs, may reduce the economic CCS sequestration potential in oil or gas fields. Although revenues from CO<sub>2</sub> sales for EOR projects could offset CO<sub>2</sub> transportation and sequestration costs for some source facilities, long-term CO<sub>2</sub> emissions in the MRCSP region would far exceed CO<sub>2</sub> requirements for EOR. It is possible, therefore, that because of their limited sequestration capacity and wellbore

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<sup>16</sup> According to the DOE Carbon Sequestration Atlas (pp. 38-39), there are one billion metric tons of total potential capacity for CO<sub>2</sub> in coal seams versus nearly 20 billion metric tons for the Rose Run sandstone.

<sup>17</sup> Cui, X., R. M. Bustin, and L. Chikatamarla, "Adsorption-induced Coal Swelling and Stress: Implications for Methane Production and Acid Gas Sequestration into Coal Seams," *Journal of Geophysical Research*, vol. 112, B10202 (2007).

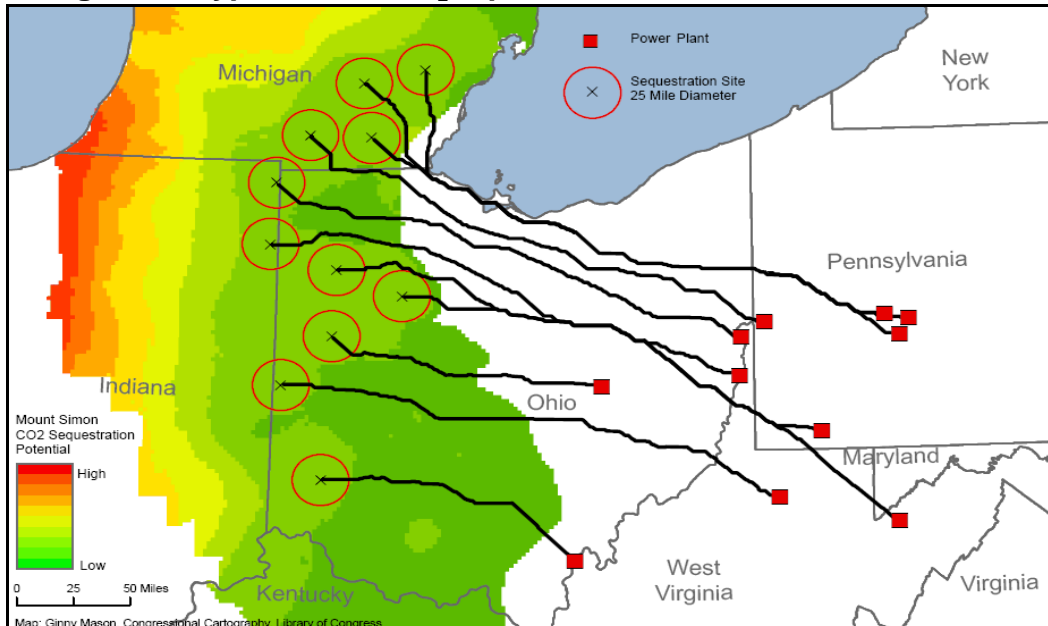
<sup>18</sup> U.S. Dept of Energy (2007):36.

<sup>19</sup> IPCC 2005:215; Charles W. Zuppann, "Too Much Fun? — Tales of 'Field Checking' at the Indiana Geological Survey," *The PGI Geology Standard*, No. 48 (April 2007): 6-9. [[http://www.indiana.edu/~pgi/docs/Standard%20Issues/PGL\\_Issue\\_48.pdf](http://www.indiana.edu/~pgi/docs/Standard%20Issues/PGL_Issue_48.pdf) ]

leakage concerns, oil and natural gas fields in the MRCSP region may not be viable sequestration sites for the largest CO<sub>2</sub> sources either.

**Mt. Simon Formation.** If neither the Rose Run formation nor regional coal, oil, or gas fields can provide adequate CO<sub>2</sub> sequestration for the major power plants in the MRCSP region, the next best potential CO<sub>2</sub> sequestration site is the Mt. Simon formation. This formation is a deep saline aquifer like the Rose Run formation, but it is over four times larger in terms of sequestration capacity and is less fractured.<sup>20</sup>

**Figure 3. Hypothetical CO<sub>2</sub> Pipelines to the Mt. Simon Formation**



**Source:** MRCSP, CRS. Geologic data for western Indiana are not provided by the MRCSP.

**Figure 3** shows hypothetical CO<sub>2</sub> pipelines which might be required if any of the major power plants in this analysis were required to transport CO<sub>2</sub> to the Mount Simon formation. As in the Rose Run case, **Figure 3** assumes pipelines use existing rights of way and that a 25-mile diameter, non-overlapping reserve area is needed for each plant's sequestration site. However, consistent with the Rose Run limitations, the Mt. Simon scenario assumes that the thinnest parts of the formation (the easternmost contours on the contour map) are unsuitable sequestration sites. As the figure shows, the pipelines required in such a scenario could be substantial, ranging in length from 130 to 294 miles, and averaging 234 miles. According to estimates from CMU, the approximate capital costs for these pipelines would range from \$70 million to \$180 million, and would average \$150 million. The average levelized cost would be approximately \$2.00 per ton of transported CO<sub>2</sub>.<sup>21</sup>

<sup>20</sup> U.S. Dept of Energy, (2007):38.

<sup>21</sup> Sean T. McCoy and Edward S. Rubin (November 19, 2007). Cost estimates were provided by Sean McCoy at the request of CRS.

Although **Figure 3** shows a pipeline route for all the 11 power plants in question, how many of these pipelines might be needed depends upon which plants may be able to sequester their CO<sub>2</sub> emissions closer to home. Furthermore, there are potential scale economies for large, integrated CO<sub>2</sub> pipeline networks that link many sources together rather than single, dedicated pipelines between individual sources and sequestration reservoirs.<sup>22</sup> The individual pipelines required in **Figure 3** may be so large on their own that combining multiple CO<sub>2</sub> flows from multiple plants through shared trunk lines may be limited.<sup>23</sup>

While the Mt. Simon scenario in **Figure 3** is far less favorable in terms of cost and siting requirements than the Rose Run scenario in **Figure 2**, it is not necessarily the “worst” case in terms of overall pipeline requirements. Future work on sequestration capacity may conclude that the Mt. Simon sequestration sites should be located in thicker parts of the formation (in central Indiana and Michigan) to absorb the tremendous volumes of CO<sub>2</sub> generated by these power plants. Such a westward shift would require even longer pipelines than those illustrated here.

## Policy Implications

The MRCSP pipeline scenarios, while only illustrative, nonetheless highlight several important policy considerations which may warrant congressional attention. These include concerns about CO<sub>2</sub> pipeline costs, siting challenges, pipeline and sequestration site relationships, and differences in sequestration potential among regions.

### Variability of CO<sub>2</sub> Pipeline Costs

The cost of CO<sub>2</sub> transportation is a function of pipeline length (among other factors), which in turn is determined by the location of sequestration sites relative to CO<sub>2</sub> sources. The scenarios in this report illustrate how different assumptions about sequestration site viability in the MRCSP region can lead to a 20-fold difference in CO<sub>2</sub> pipeline lengths and, therefore, similarly large differences in capital costs. (In this regard, CO<sub>2</sub> pipeline costs may present the cost component in integrated CCS schemes with the greatest potential variability.) At the international and national policy levels, some studies have recognized this potential variability. For example, an MIT analysis states that the costs of CO<sub>2</sub> pipelines are highly variable due to “physical ... and political considerations.”<sup>24</sup> The IPCC report likewise estimates total costs of CO<sub>2</sub> mitigation of \$31- \$71 per ton of CO<sub>2</sub> avoided for a new pulverized coal power plant, assuming CO<sub>2</sub> pipeline transportation costs, including operations and

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<sup>22</sup> MIT 2007: 58.

<sup>23</sup> Gemma Heddle, Howard Herzog, and Michael Klett, “The Economics of CO<sub>2</sub> Storage,” MIT Laboratory for Energy and the Environment, Working Paper MIT LFEE 2003-003 RP (August 2003): 23.

<sup>24</sup> MIT 2007: 58.

maintenance costs, of \$0 to \$5 per ton.<sup>25</sup> Recent increases in the global price of steel used to make line pipe could push CO<sub>2</sub> pipeline costs above this range.<sup>26</sup> At \$5 per ton of transported CO<sub>2</sub>, pipeline costs account for a modest share of aggregate carbon control costs — between 7% and 16% based on the IPCC estimates. Nonetheless, if CCS technology were deployed on a national scale, overall CO<sub>2</sub> pipeline costs could be in the billions of dollars. Minimizing these costs while achieving environmental objectives may therefore be an important public policy objective.

From the perspective of individual power plants, or other CO<sub>2</sub> sources, highly variable costs for CO<sub>2</sub> pipelines may have more immediate ramifications. If CO<sub>2</sub> pipeline costs for specific regions reach hundreds, or even tens, of millions of dollars per plant, then power companies may have difficulty securing the capital financing or regulatory approval needed to construct or retrofit fossil fuel-powered plants in these regions. For example, in August 2007, the Minnesota Public Utilities Commission rejected a developer's proposal to construct a new coal-fired power plant in the state, in large part because the associated costs of a 450-mile CO<sub>2</sub> pipeline to an EOR site in Alberta, over \$635 million, were not viewed to be in the public interest.<sup>27</sup> To the extent that other, lower-cost power plant options are available, the failure of a costly project like the Minnesota plant may not be a problem. However, if other generation sources are constrained (e.g., nuclear, renewable), then the inability to construct a new fossil-fueled power plant may negatively impact the regional balance of electricity supply and demand. Higher electricity prices or reliability concerns might ensue.

Some analysts believe that CO<sub>2</sub> pipeline costs will be moderated in the future because generating companies will construct new power plants geographically near sequestration sites. Recent network cost models suggest otherwise. On a mile-for-mile basis, these models show that electricity transmission costs (including capital, operations, maintenance, and electric line losses) generally outweigh CO<sub>2</sub> pipeline costs in new construction. Accordingly, the least costly site for a new power plant tends to be nearer the electricity consumers (cities) rather than nearer the sequestration sites if the two are geographically separated.<sup>28</sup> Analysts have therefore

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<sup>25</sup> IPCC report: 347.

<sup>26</sup> For further information about steel prices, see CRS Report RL32333, *Steel: Price and Policy Issues*, by Stephen Cooney.

<sup>27</sup> Minnesota Public Utilities Commission, *Order Resolving Procedural Issues, Disapproving Power Purchase Agreement, Requiring Further Negotiations, and Resolving to Explore the Potential for a Statewide Market for Project Power under Minn. Stat. § 216b.1694, Subd. 5*, Docket No. E-6472/M-05-1993 (August 30, 2007):15; Minnesota Public Utilities Commission, *Staff Briefing Papers — Appendix I*, Docket No. E-6472/M-05-1993 (July 31, 2007):78. Cost estimate in 2011 U.S. dollars.

<sup>28</sup> Jeffrey M. Bielicki and Daniel P. Schrag, "On the Influence of Carbon Capture and Storage on the Location of Electric Power Generation," Harvard University, Belfer Center for Science and International Affairs, Working paper (2006).

concluded that “a power system with significant amounts of CCS requires a very large CO<sub>2</sub> pipeline infrastructure.”<sup>29</sup>

## CO<sub>2</sub> Pipeline Siting Challenges

Any company seeking to construct a CO<sub>2</sub> pipeline must secure siting approval from the relevant regulatory authorities and must subsequently secure rights of way from landowners. There is no federal authority over CO<sub>2</sub> pipeline siting, so it is regulated to varying degrees by the states (as is the case for oil pipelines). The state-by-state siting approval process for CO<sub>2</sub> pipelines may be complex and protracted, and may face public opposition, especially in populated or environmentally sensitive areas.<sup>30</sup> Securing rights of way along existing easements for other infrastructure (e.g., gas pipelines), as the scenarios in this report assume, may be one way to facilitate the siting of new CO<sub>2</sub> pipelines. However, questions arise as to the right of easement holders to install CO<sub>2</sub> pipelines, compensation for use of such easements, and whether existing easements can be sold or leased to CO<sub>2</sub> pipeline companies.<sup>31</sup> Although these siting issues may arise for any CO<sub>2</sub> pipeline, they become more challenging as pipeline systems become larger and more interconnected, and cross state lines. If a widespread, interstate CO<sub>2</sub> pipeline network is required to support CCS, the ability to site these pipelines may become an issue requiring new federal initiatives.<sup>32</sup>

## Pipeline and Sequestration Site Relationships

Due to potential CO<sub>2</sub> transportation costs, individual generating plants have a strong interest in the selection of specific sequestration sites under future CCS policies. Since transporting CO<sub>2</sub> to distant locations can impose significant additional costs to a facility’s carbon control infrastructure, facility owners may seek regulatory approval for as many sequestration sites as possible and near to as many facilities as possible. Furthermore, capacity limitations at favorably located sequestration sites (like the Rose Run formation) may lead to competition among large CO<sub>2</sub> source facilities seeking to secure the best local sequestration sites before others do. How the development of sequestration sites will be prioritized and how competition for such sites may evolve have yet to be explored, but they may create new and significant economic differences among facilities.

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<sup>29</sup> Adam Newcomer and Jay Apt, “Implications of Generator Siting for CO<sub>2</sub> Pipeline Infrastructure,” Carnegie Mellon Electricity Industry Center, Working Paper CEIC-07-11 (2007).

<sup>30</sup> National Commission on Energy Policy, *Siting Critical Energy Infrastructure: An Overview of Needs and Challenges*. (Washington, DC: June 2006): 9. (Hereafter referred to as NCEP 2006.)

<sup>31</sup> Partha S. Chaudhuri, Michael Murphy, and Robert E. Burns, “Commissioner Primer: Carbon Dioxide Capture and Storage” (National Regulatory Research Institute, Ohio State Univ., Columbus, OH: March 2006): 17.

<sup>32</sup> For further discussion, see CRS Report RL34307, *Regulation of Carbon Dioxide (CO<sub>2</sub>) Sequestration Pipelines: Jurisdictional Issues*, by Adam Vann and Paul W. Parfomak.

Because CO<sub>2</sub> pipeline requirements in a CCS scheme are driven by the relative locations of CO<sub>2</sub> sources and sequestration sites, identification and validation of such sites must explicitly account for CO<sub>2</sub> pipeline costs if the economics of those sites are to be fully understood. Proposals such as S. 2323, which would require an integrated evaluation of CO<sub>2</sub> capture, sequestration, and transportation (Sec. 3(b)(5)), appear to promote such an approach, although the details of future sequestration site selection have yet to be established. If CCS moves from pilot projects to widespread implementation, government agencies and private companies may face challenges in identifying, permitting, developing, and monitoring the large number of localized sequestration reservoirs that may be proposed.

## **Advantaged and Disadvantaged Regions**

Geologists have long recognized that some regions in the United States have high potential for carbon sequestration and others do not. For example, a 2007 study at Duke University concluded that “geologic sequestration is not economically or technically feasible within North Carolina,” but “may be viable if the captured CO<sub>2</sub> is piped out of North Carolina and stored elsewhere.”<sup>33</sup> Likewise, states in the Northeast, Minnesota, Wisconsin, and possibly parts of other states appear to lack geological formations with potential for large-scale sequestration of the volumes of CO<sub>2</sub> they produce. If national CCS policies are implemented, power plants and other CO<sub>2</sub>-producing facilities in these states may face more extensive, and more costly, pipeline requirements than other states if they are to sequester their CO<sub>2</sub>. States such as North Carolina, with limited sequestration potential and a relatively high proportion of coal or natural gas in their electric generation fuel mix, may face particular challenges in this regard. The Duke study, for example, estimated it would cost \$5 billion to construct an interstate pipeline network for transporting CO<sub>2</sub> from North Carolina’s electric utilities to sequestration sites in other states.<sup>34</sup>

One particular concern among some stakeholders is that high CO<sub>2</sub> transportation costs could increase electricity prices in “sequestration-poor” regions relative to regions able to sequester CO<sub>2</sub> more locally. For states like Massachusetts, for example, which has some of the highest electricity prices in the country and may have little sequestration potential, CO<sub>2</sub> transportation costs could raise electricity prices even higher above the national average. Moving beyond this illustrative example to evaluate comprehensively the distribution of CO<sub>2</sub> transportation costs across the United States is beyond the scope of this report. Nonetheless, these kinds of regional price impacts, and their implications for regional economies, may become an issue for Congress.

## **Conclusion**

The socially and economically efficient development of the nation’s public infrastructure is an important consideration for policymakers. In the context of a

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<sup>33</sup> Williams, et al., (2007): 4.

<sup>34</sup> Williams, et al., (2007): 20.

national program for CCS, CO<sub>2</sub> pipelines may be a major addition to this infrastructure. Yet there are many uncertainties about the cost and configuration of CO<sub>2</sub> pipelines that would be needed to meet environmental goals within an emerging regulatory framework. Exactly who will pay for CO<sub>2</sub> pipelines, and how, is beyond the scope of this report, but understanding ways to minimize the cost and environmental impact of this infrastructure may be of benefit to all.

In addition to specific questions about CO<sub>2</sub> pipeline requirements, the scenarios in this report raise larger questions about the ultimate development and allocation of sequestration capacity under a national CCS policy. How much individual companies may have to spend to transport their CO<sub>2</sub> depends upon where it has to go. However, even as viable sequestration reservoirs are being identified, it is unclear which CO<sub>2</sub> source facilities will have access to them, under what time frame, and under what conditions. While Congress is beginning to turn its attention to these questions, it will likely require sustained attention and the input of many stakeholders to refine and address them. Given the potential size of a national CO<sub>2</sub> pipeline network, many billions of dollars of capital investment may be affected by policy decisions made today