Evaluation of
Geologic CO_2 Sequestration Potential and CO_2 Enhanced Oil Recovery
in Kentucky

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Executive Summary

Kentucky gets approximately 95 percent of its electricity from coal-fired power plants, which produce significant amounts of carbon dioxide (CO_2). In 2005, Kentucky coal-fired plants vented 102.8 million short tons of CO_2 into the atmosphere. The economic vitality of the state will be affected by its ability to develop and apply a portfolio of technologies that will mitigate input of CO_2 into the atmosphere. One technology that has the potential to assist in this challenge is geologic carbon storage, which captures CO_2 at point sources and injects it into deep rock strata that can store it for tens of thousands of years and longer.

Previous studies suggest that Kentucky has the capacity to store up to 11.6 billion tons of CO_2 in underground strata. By necessity, the capacity calculations are high-level estimates, and consequently, actual capacity remains unproved and even speculative. In addition, other factors such as infrastructure, engineering, and economic and regulatory policy will affect the viability of geologic carbon storage in the state.

This report is divided into five chapters, each addressing specific technical aspects pertinent to geologic carbon storage, which is the overarching theme. Chapter 1 is an introduction and overview of geologic carbon storage and the data needed to evaluate its potential. Chapter 2 is a geologic evaluation of the potential to use CO_2 for enhanced oil recovery. Chapter 3 is an evaluation of subsurface formation-water geochemistry and implications for CO_2 sequestration. Chapter 4 is an evaluation of CO_2 storage potential with an emphasis along some of the state's major river corridors. Chapter 5 is a geologic evaluation of CO_2 storage potential for nominated coal-to-liquids (gasification) sites.

Chapter 2, "Assessment of Kentucky Fields for CO_2-Enhanced Oil Recovery," analyzes 70 oil reservoirs in 51 oil fields in eastern and western Kentucky for their suitability for enhanced oil recovery (EOR) using CO_2. The relationship among calculated pressures, such as minimum miscibility pressure and fracture pressure, and measured original reservoir pressure, was analyzed and showed that most of Kentucky's oil fields were underpressured even before depletion from production. Nevertheless, if fields are repressurized to values equal to maximum reservoir injection pressures (0.8 psi/ft) as designated by the U.S. Environmental Protection Agency, then 53 percent of the fields could attain miscible or near-miscible conditions. Although the elevated pressures and miscibility would be a transient condition, it could serve to augment additional recovery of oil. In addition to pressure, other reservoir parameters were analyzed to estimate the EOR potential of the fields relative to each other. The fields were broadly ranked into quartiles, and 83 percent of the 18 fields-reservoirs in the uppermost quartile occurred in Mississippian Chesterian sandstones in western Kentucky. Sixty-seven percent of the upper-quartile fields occurred at depths of 1,500 ft or deeper. The chapter concludes with a brief discussion of other issues that affect the viability of a potential CO_2-EOR or storage project. Chief among these issues is the condition of plugged and abandoned and producing wellbores.

Chapter 3, "Geochemical Characterization of Formation Waters in Kentucky and Implications for Geologic Carbon Storage," details how formation-water chemistry measurements from previously archived data were analyzed in the context of geologic carbon storage. The measurements consisted of 356 discrete analyses, mostly from reservoirs in oil or gas wells located in 12 counties in the Illinois Basin of western Kentucky and 11 counties in the Appalachian Basin of eastern Kentucky. Concentrations of dissolved cations and anions provided in the analysis were used, along with temperature and pressure, as inputs to an equation of state that estimates the amount of CO_2 that can be dissolved in the formation waters. Formation-water chemistry was analyzed because dissolution of CO_2 into water—called solubility trapping—is one of the fastest reactions to occur in the reservoir, and it removes CO_2 as a separate phase (gas or supercritical fluid) that is driven upward by buoyancy forces. The magnitude of dissolution is a function of water chemistry and flow patterns. Our analysis of salinity in a depth and stratigraphic framework shows the likely presence of an aerially extensive seal interval in Upper Ordovician rocks that separate Pennsylvanian, Mississippian, Devonian, and Silurian strata from Ordovician and Cambrian strata into broad hydrogeologic compartments. The interval would represent a primary seal for possible CO_2 storage reservoirs in the Cambrian-Ordovician Knox Group. Though widely varying, measured salinity values (approximately 4,000 to 313,000 mg/L) in Cambrian and Ordovician reservoirs are often significantly less than what is predicted by salinity versus depth trends from shallower Pennsylvanian, Mississippian, Devonian, and Silurian samples. When analyzed with an equation of state for aqueous solutions containing

Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-}, the decreased salinity results in higher CO_2 solubilities (approximately 0.65 to 0.86 mol/kg H_2O) and hence more potential for solubility trapping in Cambrian and Ordovician reservoirs.

Chapter 4, "Geologic Carbon Storage (Sequestration) Potential in Kentucky," summarizes the geology of Kentucky and provides information on the area, depth, characteristics, and available data about the deep, subsurface rock units that might have storage capacity or be important parts of confining intervals for underlying storage reservoirs. Nine units were considered possible storage reservoirs, four units were investigated as confining intervals with local porosity and possibly storage capacity, and six units were investigated as seals. The Mount Simon Sandstone, which only occurs in the northern part of the state, has the largest calculated capacity. The Mount Simon occurs at depths of 3,000 to more than 10,000 ft, but below 6,000 ft may have little porosity. Our research suggests a reduced aerial distribution of the Mount Simon in western Kentucky and an attendant decrease in volume and storage capacity, though still significantly more than in other units. A well drilled in the summer of 2009 tested the Mount Simon at East Bend in Boone County, and provided data demonstrating the feasibility of using the Mount Simon for CO_2 storage in Kentucky.

Additional units have capacity that is more difficult to quantify. The Devonian black shale is Kentucky's primary natural gas producer. Experimental studies suggest that the Devonian shale could preferentially adsorb CO_2 and desorb CH_4. Moreover, studies by KGS researchers estimate that the shale has the capacity to store more than 27.6 billion tons of CO_2. The concept of storage in a tight shale is still theoretical, however, and it is probably better to consider the use of CO_2 for enhanced gas recovery (significantly lower volumes) rather than for permanent large-scale storage at this time.

Another unit for which storage capacity has not been quantified is the Knox Dolomite. The lower part of the Knox has been used for industrial-scale waste disposal in Kentucky. Two wells at the DuPont plant in Jefferson County (currently plugged) and the IMCO recycling well in Butler County (active) used porosity zones in the lower Knox as storage reservoirs. For this report, known reservoirs in the Knox were investigated to illustrate the types of reservoirs that might be possible. The Kentucky Consortium for Carbon Storage drilled a well in 2009 in Hancock County and tested the Knox to demonstrate its feasibility as a carbon storage reservoir.

Chapter 5, "Site Bank Assessment Geologic Data Report, Round 2, 2008," evaluates results from 23 specific sites for geologic carbon storage potential. Recognizing the importance of the coal industry, the Commonwealth of Kentucky identified locations appropriate for deployment of next-generation coal-based industries that would include possibilities for sequestering carbon emissions. Nominations were requested for potential locations suitable for development of coal-to-liquids or integrated gasification combined-cycle electricity-generation utilities. Nineteen original sites were proposed and assessed in October 2007. In December 2007, an additional 26 sites were nominated for evaluation and included in a "site bank." A total of 23 sites were evaluated by the Kentucky Geological Survey to provide geologic criteria related to carbon storage potential (three were not evaluated because of lack of location data). This assessment was incorporated along with infrastructure, environmental, and demographic data into an overall site assessment report published in June 2008.

In summary, this report was written to serve as a resource for evaluating carbon dioxide management options in Kentucky. From potential economic benefit in enhanced oil and gas recovery, to permanent deep saline storage, the commonwealth has a variety of possible options for geologic disposal of CO_2. Further demonstrations and pilot projects are necessary to fully characterize this potential, and to reduce the risks of implementing a commercial CO_2 storage field.