Discharge of CO$_2$ to the atmosphere is under regulatory review, and subsurface storage may be required for existing facilities and the financing and construction of new facilities.
CO$_2$ Sources, Capture, and Storage
House Bill 1, August 2007

- Kentucky House Bill 1, passed in a special legislature session and signed into law in August 2007, appropriated $5 million funding for KGS to research the storage and use of CO₂ throughout the Commonwealth.
- House Bill 1 mandates the drilling deep saline reservoir CO₂ storage demonstration wells in the East and West Kentucky Coal Fields, a CO₂ enhanced oil recovery (EOR) demonstration, and a CO₂ enhanced gas recovery (EGR) demonstration in the Devonian black shale.
- Additional funding was provided to the Center for Advanced Energy Research (CAER) at UK for research and development of carbon capture technology.
CO₂ Storage Principles

- CO₂ is produced by burning carbon-based fuels (coal, oil, natural gas)
- CO₂ is captured at its source, compressed, and injected into deep saline reservoirs in a supercritical state
  - Free CO₂ in reservoir rock pores, displacing storage reservoir brine
  - Dissolved in storage reservoir brine
  - Reacts with minerals in the storage reservoir rock
- Overlying impermeable strata contain the CO₂ in the storage reservoir
- Surrounding shallow aquifers and surface area is monitored for leaks
Minimum CO$_2$ storage depth in Kentucky

Large-scale CO$_2$ storage will require supercritical conditions: reservoir pressure $>1071$ psi and temperature $>88^\circ$ F. Supercritical CO$_2$ is a dense fluid with the viscosity properties of a gas. The volume reduction is 250 times (0.4%) that of gaseous CO$_2$. However, it is less than water, and thus buoyant.
Assuring Security: Monitoring Options

1. Surface and shallow groundwater
   - Very late leak detection
   - May be large annual variations in groundwater chemistry

2. Above-injection zone monitoring
   - First indicator
   - Monitors small signals
   - Annually more stable water chemistry, thus more sensitive

3. In injection zone - plume
   - Oil-field type technologies
   - Will not find small leaks

4. In injection zone - outside plume
   - Assure lateral migration of CO₂ and brine is acceptable
CO₂ Leakage Mechanisms

• Reservoir Seal Leakage
  – Requires stored gas in the reservoir to overcome capillary entry pressure of the reservoir sealing interval
  – Seal will not leak unless this occurs

• Seal integrity
  – Faults
  – Fractures

• Human intervention
  – Old oil and gas wells greatest problem
  – Failures in CO₂ injection wells
  – Wells drilled after injection begins

• CO₂ diffusion to the surface through rock strata is infinitesimally slow

Figure 5.26 Possible leakage pathways in an abandoned well: (a) and (b) between casing and cement wall and plug, respectively; (c) through cement plugs; (d) through casing; (e) through cement wall; and (f) between the cement wall and rock (after Gasda et al., 2004).
Monitoring CO$_2$ Plume Migration in the Sleipner Field, North Sea

Figure 2 | Diagram of carbon dioxide storage at the Sleipner Field based on seismic images. Rising CO$_2$ plumes impinge and spread out beneath thin mudstones within the reservoir before ponding beneath the top seal. This geometry causes a large increase in the CO$_2$-brine contact area, which will increase solubility trapping. Diagram redrawn from ref. 22, © 2007 Elsevier.
Figure 5.22 Comparison of the magnitude of CO$_2$ injection activities illustrating that the storage operations from a typical 500-MW coal plant will be the same order of magnitude as existing CO$_2$ injection operations (after Heinrich et al., 2003).
Project Goals

• Demonstrate CO$_2$ storage and EOR/EGR
• Demonstrate the integrity of reservoir sealing strata for long-term CO$_2$ storage
• Develop best practices for the evaluation of CO$_2$ storage in Kentucky deep saline reservoirs
• Publish the project results for use by government, industry, and the public
• Accomplish this project with consideration of the interests and concerns of industry and the citizens of the Commonwealth
Regional saline reservoirs:

- Mount Simon Sandstone
- St. Peter Sandstone
- Knox Group
Western Kentucky Stratigraphy

Just as important in an injection project are the sealing units:

- Eau Claire Formation
- Maquoketa Shale
- Ordovician carbonates
- Devonian Shales

- Potential CO₂ sinks/reservoirs
- Sealing interval
- Missing section
- Sink or seal (depends on location)
- Metamorphic and igneous rocks (mostly seal)
Minimum CO$_2$ storage depth in Kentucky

Research by the MRCSP and MGSC indicate that the critical point for CO$_2$ in the Midwest and Kentucky should occur at a depth of $\sim$2350 ft.

Key to being able to successfully store CO$_2$ is keeping it in a supercritical state.

Figure 23.—Diagram showing CO$_2$ density with depth for a typical pressure gradient, surface temperature, and geothermal gradient in the MRCSP area. CO$_2$ density data is from Lemmon and others (2003).
While CO₂ EOR potential is significant, Devonian shales or deep saline reservoir storage will be needed to handle expected CO₂ volumes, currently 98.3 MT/yr.
The challenge for Kentucky is to demonstrate CO$_2$ EOR/EGR and storage in diverse reservoirs with a limited number of tests.
Marvin Blan #1, Hancock County

• Drilling commenced on April 24, 2009
• Seven cores cut to test reservoir and seal properties
  – Reservoir seals
    • New Albany Shale (30 ft)
    • Maquoketa Shale (31 ft)
    • Black River Limestone (61 ft)
  – CO₂ storage reservoirs
    • Knox Group (three cores, 243 ft total)
    • Precambrian Middle Run Sandstone (30 ft)
• Reached TD at 8126 ft on June 14 after 63 days of drilling
Maquoketa Shale Reservoir Sealing Formation

- Maquoketa Shale was cored 2800-2831 ft to test reservoir seal properties
- Analyses of seal properties
  - Core analysis: impermeable
    - Porosity 0.4%
    - Permeability $1.63 \times 10^{-5}$ md
  - Compressive strength 17,264 psi
  - XRD mineralogy
    - 39% clays, 15% carbonates, 36% silicates, balance other minerals
Knox Dolomite Cores

- Knox Dolomite was cored in three intervals (total 243 ft) to test reservoir properties
  - “St Peter”-Beekmantown (123 ft)
  - Beekmantown-Gunter (101 ft)
  - Copper Ridge (19 ft)
- Found porosity system to be a complex of preserved fabric, primary dolomite porosity, vugs, and fractures
  - Average porosity 6.7%
  - Fracture system trends NNW and dips to the SW
- Knox sealing intervals variable
  - Porosity 0.4 to 10.4%
  - Permeability <0.0001 to 15 md
Marvin Blan #1
Potential Reservoir Volume in the Knox

- **Base**
  - All data
  - Volume 240 Ac-ft
  - Storage 3200 T/Ac
  - Requires 208 Ac/MT

- **Case 3**
  - Porosity >5%
  - Volume 180 Ac-ft
  - Storage 2743 T/Ac
  - Requires 365 Ac/MT

- **Case 8**
  - Porosity >10%
  - Volume 41 Ac-ft
  - Storage 1022 T/Ac
  - Requires 978 Ac/MT
CO$_2$ EOR in Kentucky

- CO$_2$ has been used for EOR for over 30 years
- Limited use of CO$_2$ in Kentucky to date despite very good results

- Advantages
  - Proposed coal gasification plants could provide a CO$_2$ source closer to our producing areas
  - Waste CO$_2$ may have value and could improve production in Kentucky oil and gas fields

- Problems
  - CO$_2$ sources, cost, and pipeline infrastructure
  - Nature of our oil reservoirs
    - Small size and shallow depths
    - Low reservoir temperatures
    - Extensive reservoir fracturing
Kentucky Oil and Gas Fields CO\textsubscript{2} EOR/EGR Pilot Tests

- Western Kentucky Coal Field
- Eastern Kentucky Coal Field
- Sugar Creek Oil Field

- OOIP: 2.4 MMMBO
- Gas resource: 125 Tcfg
- Cumulative Production 780 MMBO and 5.6 Tcfg

Devonian Shale EGR test
CO₂ Enhanced Oil Recovery

- Pilot site is Sugar Creek oilfield near Madisonville. It is an immiscible CO₂ flood (CO₂ gas in the reservoir).
- Eight oil producing wells and three monitoring wells surrounding the centrally located injection well.
- 8800 tons of CO₂ are budgeted for this pilot.
- CO₂ injection is planned for about 6-10 months into one injector, followed by water injection.
- KGS is providing funding and field and lab support to the MVA shallow groundwater program of this pilot.
CO$_2$ Cyclic Stimulation EOR in Big Andy Field

Photo by Brandon Nuttall, KGS
Devonian Shale EGR Test
Success Measures

- Increased gas production
- Mass balance indicates CO$_2$ adsorption vs methane
- Minimal CO$_2$ content of produced gas after flowback and cleanup
- Marvin Blan #1 Results
  - est. 10% storage efficiency
  - est. 181 tons CO$_2$/Ac possible storage
Additional Work

- Testing planned for 2010, funded by DOE research award of $1.6 million
  - Additional brine, possibly additional CO$_2$ injection
  - 3D VSP to image injection plume
  - Knox reservoir evaluation
- Plug and abandon the Marvin Blan #1 in compliance with State and EPA regulations
- Remediate drillsite
- Groundwater and soil gas monitoring through 2012
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