CO$_2$-Enhanced Oil Recovery, Applying a Mature Technology in Kentucky


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HB-1, Section 57 Highlights

- $5,000,000 appropriated to KGS to conduct research addressing varied energy resource and sequestration issues.
- HB-1 thus has multiple goals addressed in sub-projects.
- CO$_2$-EOR sub-project: “quantify the potential for enhanced oil and gas recovery…using carbon dioxide.”
Talk Outline

• Project goals
• National context of CO$_2$-EOR
• CO$_2$-EOR and its potential in Ky.
• CO$_2$-EOR mechanisms
• Going forward:
  – Short-term mileposts
  – Advisory committee role
  – Long-term mileposts
CO$_2$-Enhanced Oil Recovery Sub-Project Goals

- Facilitate and participate in pilot projects that test CO$_2$-EOR suitability of representative reservoirs and field conditions.

- Identify and trouble-shoot geologic, engineering, and economic challenges.

- Develop “best practices” criteria to be used in future CO$_2$-EOR projects.

- Evaluate carbon storage potential.
National Context of CO$_2$-EOR*

- First large-scale projects developed early 1970’s in Permian basin, TX and NM.
- Permian basin dominantly miscible pattern flooding - recovered 7-25% additional of original-oil-in-place (OOIP).
- 2005 - west Texas used ~1.4 BCFD of “new” CO$_2$ ($10-20$/ton) to produce 180,000 BOPD.
- Elsewhere, ~72 active projects in OK, WY, CO, MI, MS, NM, and Saskatchewan.

*National information from Melzer (2007).
CO$_2$-EOR in Kentucky

• One active project: N$_2$/CO$_2$ huff-n-puff in Big Andy field (Lee and Wolfe Counties).*

• CO$_2$ trucked from ethanol plant in Loudon, TN.

• CO$_2$ costs ~$87/ton to wellsite (no guaranteed availability).

• N$_2$ gathered using field deployed molecular membrane.

• Reservoir response and economics being evaluated.

*Big Andy information courtesy of Bernie Miller.
Truck capacity = 20 tons
CO2 = 344,828 cu.ft. (STP)

*Photos courtesy of B. Nuttall.*
And, Kentucky’s potential?

- Ky. original-oil-in-place ~2.4 billion barrels (Nuttall, 2005, unpublished data)
- Remaining oil ~ 1.7 billion barrels; implies ~29% recovery efficiency
- Additional recovery @ 7% = 119 million barrels
- Bank et al. (2007) estimate 25 million barrels (SPE Paper 111282)
Kentucky’s Potential Cont’d

INCREMENTAL PRODUCTION FROM CO₂ EOR: 60 TO 200 MILLION BARRELS

CO₂ USED: 1 TO 7 MILLION METRIC TONNES PER YEAR

MODELING FROM NUTTALL, UNPUBLISHED.
CO$_2$-EOR Mechanisms

- Miscibility, or lack thereof, between injected CO$_2$ and oil is main factor influencing how oil is recovered.
- Miscibility is controlled by temperature, pressure, and oil composition.
- Miscible CO$_2$-EOR is most effective.
- Condensing/vaporizing mechanism between CO$_2$ and oil produces low viscosity single hydrocarbon phase in reservoir.
CO2-EOR Mechanisms Cont’d

Thermodynamic Minimum Miscibility Pressure (MMP)—minimum pressure at which miscibility occurs.
• In contrast, where reservoir pressure is low or the oil is heavy, injected CO$_2$ will be immiscible with oil.

• CO$_2$ unable to vaporize components heavier than C$_6$ and solubility is too low to lighten the oil.

• Recovery occurs primarily by:
  – Oil swelling
  – Reduce viscosity
  – Extraction of lighter hydrocarbons
  – Reservoir pressurization
Analyzing Ky. Reservoirs

• Tertiary Oil Recovery Information System (TORIS)- database developed by DOE to characterize national oil and gas resources

• In Ky. analyzed 46 largest reservoirs among 33 fields

• TORIS provides fundamental reservoir parameters (e.g. temperature, pressure, porosity, permeability) needed for characterization and modeling
Ky. Reservoirs and CO₂ Phase Behavior

Critical temp. = 88°F
Critical pressure = 1087 psia

Temperature 0°F
Pressure (psia)

Courtesy of B. Nuttall

Super-critical

KY Fields
Critical Point
Depth
All Fields
>2500’
Implications for Ky. Reservoirs

• Analysis of temperature and pressure gradients shows that for most Ky. reservoirs, conditions necessary for supercritical behavior will occur at depths >2500 ft.

• And, analysis of 1660 fields shows that ~14% have sufficiently high temperature and pressure to expect supercritical CO$_2$.

• So, most Ky. CO$_2$-EOR projects will be immiscible.
CO$_2$-EOR Life Cycle and Carbon Storage

- **Early Stage:**
  - Capital expenditures of injection and production equipment
  - Purchase “new” CO$_2$

- **Mature Stage:**
  - Recycling of CO$_2$
  - Economic oil:CO$_2$ ratio
  - Maximum return on investment

- **Twilight Stage:**
  - Decreasing oil:CO$_2$ ratio, eventually sub-economic
  - Cont’d injection of CO$_2$ for storage driven by credits or tradable offsets
Weyburn Field- Example of EOR and Carbon Storage*

- Williston basin oil field (Saskatchewan) discovered in 1954
- CO$_2$ flood begun in 1996 w/ CO$_2$ from synfuels plant in North Dakota
- To date, >110 BCF CO$_2$ injected and 6 MMBO produced
- Looking forward, 22 million tons CO$_2$ to be stored and 130 MMBO produced over 20 year life of project

Going Forward - KGS Expertise and Capabilities

• TORIS database
• CO2-PROPHET: software developed by Texaco, as part of DOE cost share program, to calculate incremental oil produced from CO2-EOR.
  – Generates streamlines for fluid flow between injection and production wells
  – Calculates oil displacement and recovery along streamlines
• Schlumberger modeling software: Petrel and Eclipse
Going Forward- KGS Expertise and Capabilities

- Petra and ARC-GIS mapping software
- **In-House Analytical Capabilities:**
  - Petrographic and CL microscopy
  - Core housing and analysis facility
  - X-ray diffraction and fluorescence
  - Analyze oil field water chemistry
- Reservoir characterization expertise
- Need to contract engineering expertise
Near-Term Project Mileposts

- Lock-in industry participation
- Formulate business participation plan
- Address liability issues
- Form advisory committee:
  - KGS head
  - Subject matter experts
  - Industry representatives
Near-Term Cont’d

• Advisory committee duties:
  – Develop objective set of criteria for screening projects
  – Screen and select projects
• Solicit pilot projects for review
• Develop time-line for project implementation
Long-Term Project Mileposts

• Implement projects w/ some likely to be concurrent
• Evaluate reservoir and economic performance
• Publish results
Project Success

Partner Companies Safely & Successfully Produce Incremental Oil

KGS Develops Best Practice Expertise To Apply CO$_2$-EOR Over Range Of Reservation Types and Conditions
Screening and Scoping Process

• Assume CO2 is available
• Scoping processes addresses:
  – Can CO2 recover incremental oil?
  – If so, what rates and volumes?
  – What are investment and operating costs?
Reservoir Scoping

- Average reservoir pressure
- Thermodynamic MMP
- Viscosity
- Well patterns and stage of depletion
- Residual oil saturation to waterflooding
- Wettability
- Heterogeneity
- Injection well conformance
- Inject and produce fluids at economic rates