CO_2-Enhanced Oil Recovery, Applying a Mature Technology in Kentucky

CO_2-EOR Sub-Project Meeting,
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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."**

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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.

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**National information from Melzer (2007).*

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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.

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**Big Andy information courtesy of Bernie Miller.*

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Big Andy CO_2-EOR

Truck capacity=
20 tons CO2=
344,828 cu.ft. (STP)

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**Photos courtesy of B. Nuttall.*

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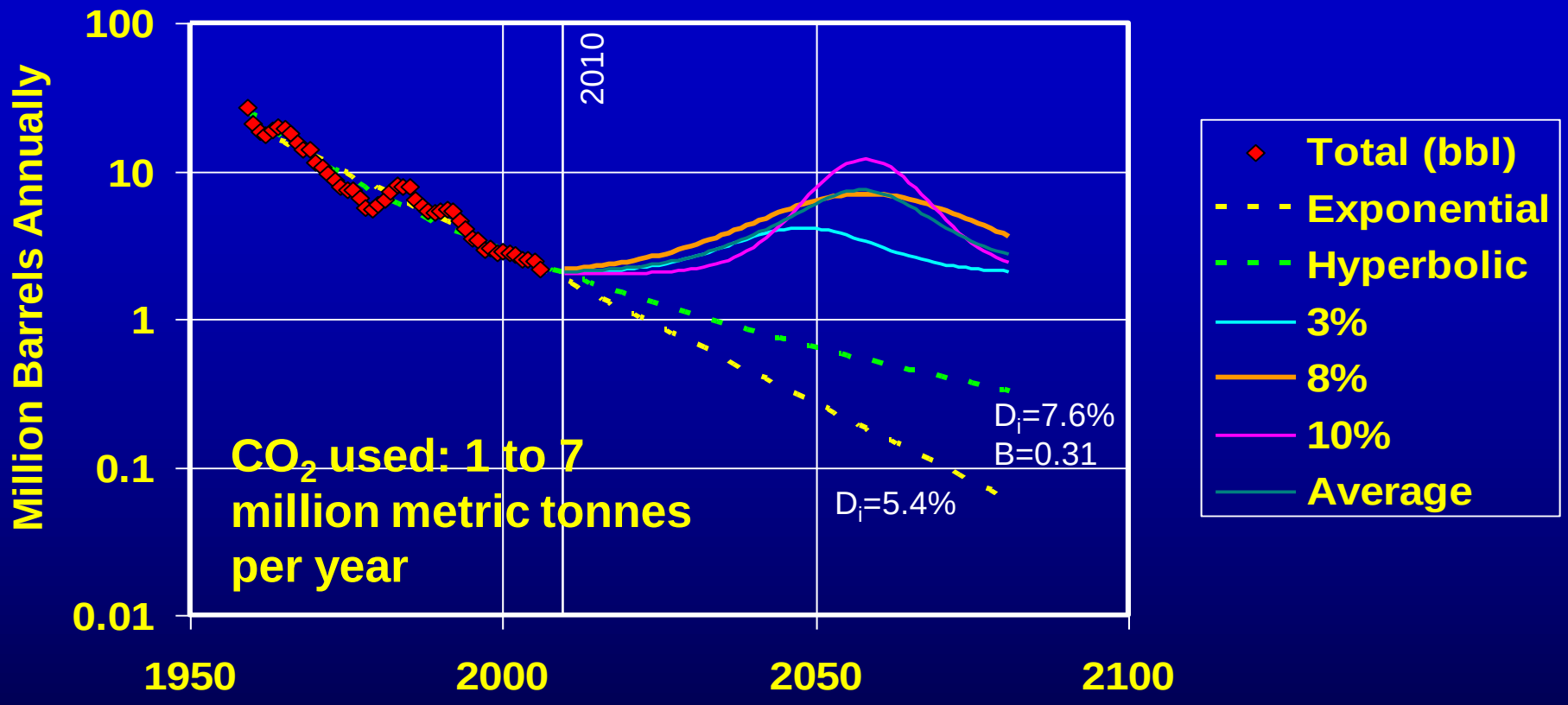
And, Kentucky's potential?

- 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 CO_2 EOR: 60 to 200 million barrels

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Modeling from Nuttall, unpublished.

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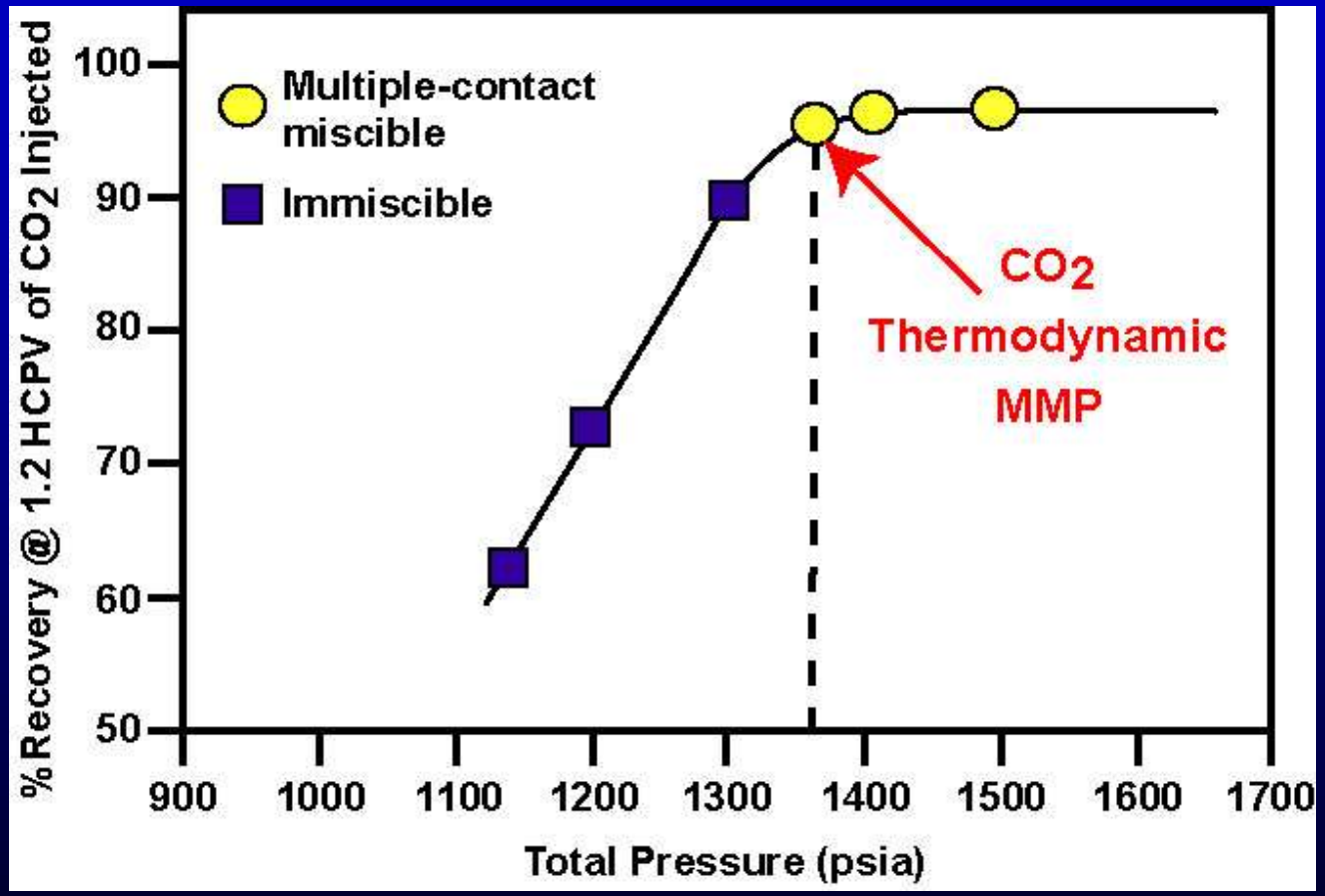
CO_2-EOR Mechanisms

- 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



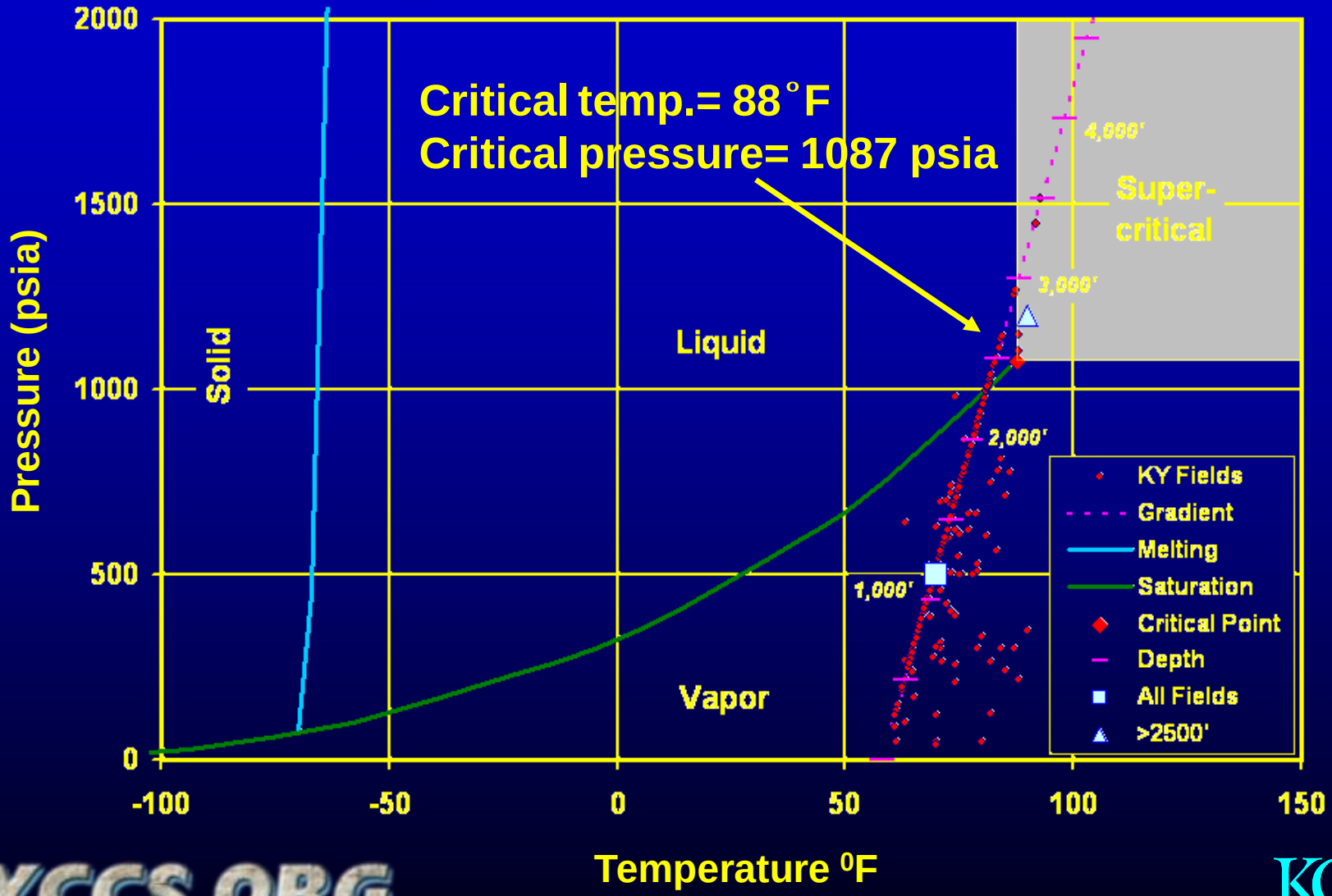
CO_2-EOR Mechanisms Cont'd

- 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 CO_2 Phase Behavior



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Courtesy of B. Nuttall

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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, 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

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*Information from: http://www.fossil.energy.gov/news/techlines/2004/tl_weyburn_phase2.html

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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

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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

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KGS Develops Best Practice Expertise To Apply CO_2-EOR Over Range Of Reservation Types and Conditions

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Screening and Scoping Process

- Assume CO_2 is available
- Scoping processes addresses:
  - Can CO_2 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