# $CO_2$ EOR Pilots in the Illinois Basin

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Midland, Texas

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- Gallagher Drilling, Inc and  Bi-Petro, Inc. field operation partners


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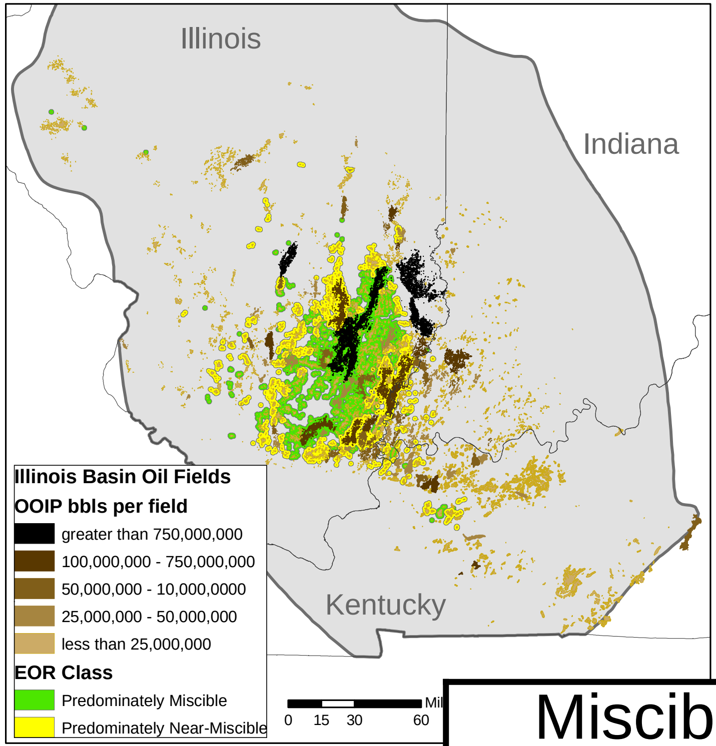
# Outline

- Conventional $CO_2$ EOR (Pilots):
  - EOR II:  Mumford Hills-Miscible (Liquid)
  - EOR III:  Sugar Creek-Immiscible (Gas)
- Nonconventional $CO_2$ EOR  (ROZ) and Associated Storage
  - ROZ assessments
  - Greenfield test: Carper Sandstone

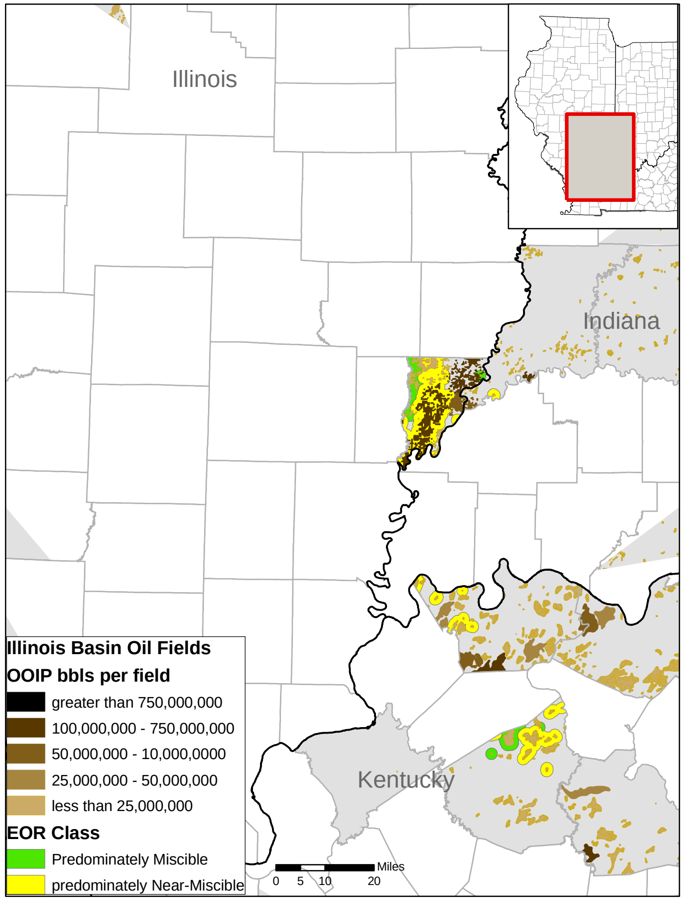
# $CO_2$ EOR and Storage Pilot Objectives

- Demonstrate miscible and immiscible $CO_2$ EOR in shallow low temperature oil reservoirs is possible
- Estimate $CO_2$ injectivity
- Validate Illinois Basin $CO_2$ EOR and storage estimates
- Identify Illinois Basin barriers to commercialization of $CO_2$ EOR and Associated Storage

# $CO_2$ EOR Illinois Basin Assessment




| Condition | $CO_2$ Tscf | EOR Bstb |
|---|---|---|
| Miscible | *1.1-3.4* | *0.24-0.38* |
| Near | *1.0-2.9* | *0.28-0.40* |
| Immiscible | *0.55-2.1* | *0.34-0.49* |
| Total | *2.6-8.3* | *0.86-1.3* |




*Immiscible-$CO_2$ gas*
*Near- transitional depth from miscible to immiscible*

| Miscibility Condition | OOIP Bstb |
|---|---|
| Miscible | *2.1-2.5* |
| Near | *3.5-4.1* |
| Immiscible | *6.4-7.5* |

| OOIP | #Oilfield |
|---|---|
| > 1 Bstb | *3* |
| > 100 MMstb | *11* |
| > 25 MMstb | *33* |

*Maps and tables for EOR and CSV based on geologic and reservoir modeling*

# Ideal EOR Pilot Site Screening and Selection

- Direct field data to calibrate a model for estimating full field $CO_2$ EOR
- Single zone completion (eliminate conformance issues)
- Prolific geologic formation (represent large part of OOIP)
- Good well coverage surrounding injector or geologic control
- Accessible by $CO_2$ tank truck year around
  - no winter road restrictions
- No problem wells in and near the pilot area.
- Relatively low oil cut (>2%), but not real low (<1%)

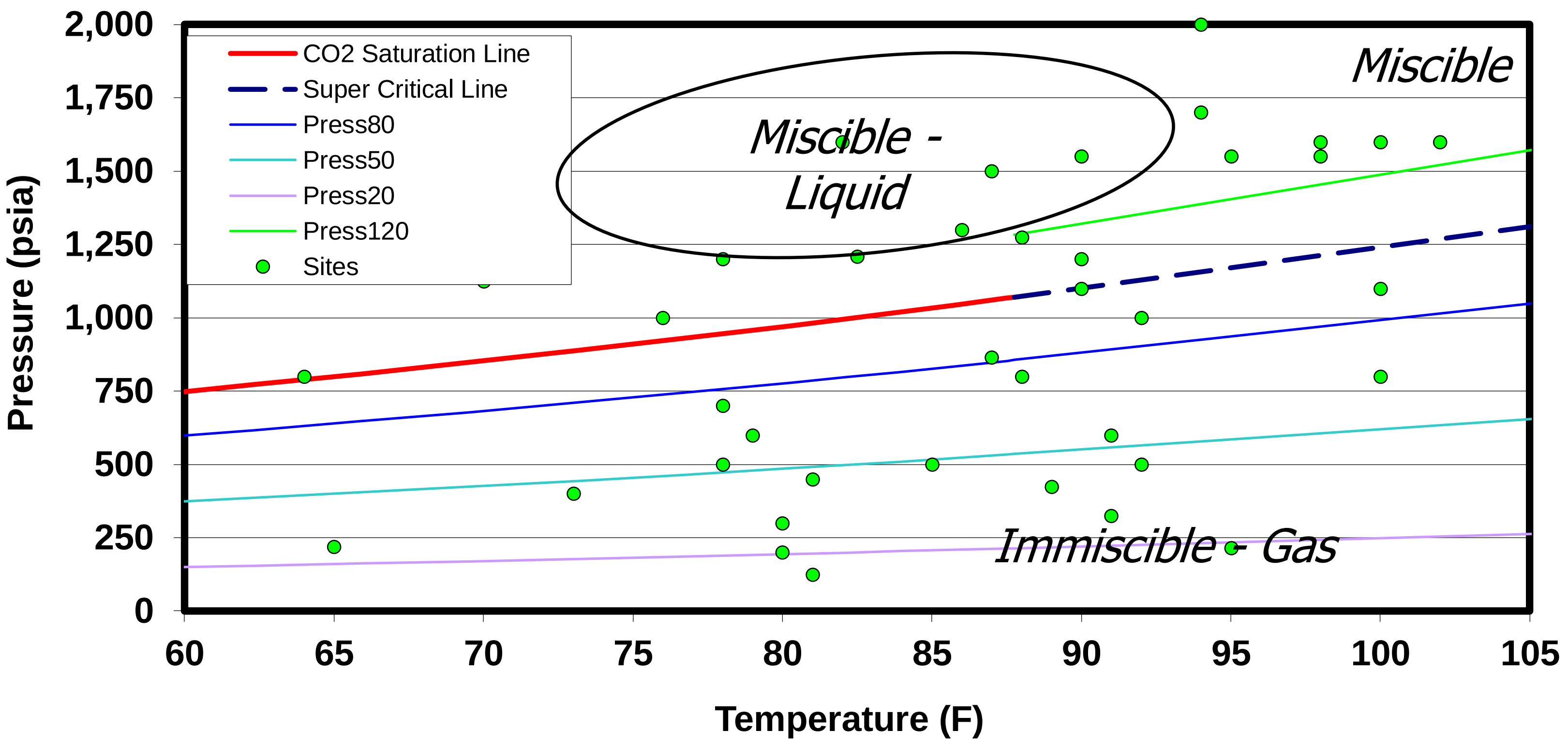
# EOR II: Miscible (Liquid) $CO_2$ Flood (Mumford Hills Field, Indiana)

- Field History
  - Discovered 1974; OOIP 2,100,000 bbl
  - Edgewater injection 1976
  - Pre-$CO_2$, one water injector; two active oil producers on pump
- Production History
  - Primary oil production 41,000 bbl
  - Waterflood oil production 794,000 bbl
  - Total 835,000 bbl; 40% oil recovery
- Injection zone
  - Reservoir pressure 1,200-1,500 psi; wells can flow to surface
  - 1,000 bbl/day water injection; 3-5 bopd

# EOR II: Miscible (Liquid) $CO_2$ Classification

- Conditions to have miscible, liquid $CO_2$ flood
  - Low temperature 80°F ($< T_{cCO2}$)
  - High fracture pressure (1 psi/ft)

EOR II:
Temp: 80F
Press: 1200-1500 psi




Green points: operators' nominations of reservoirs w/these pressure and temperature

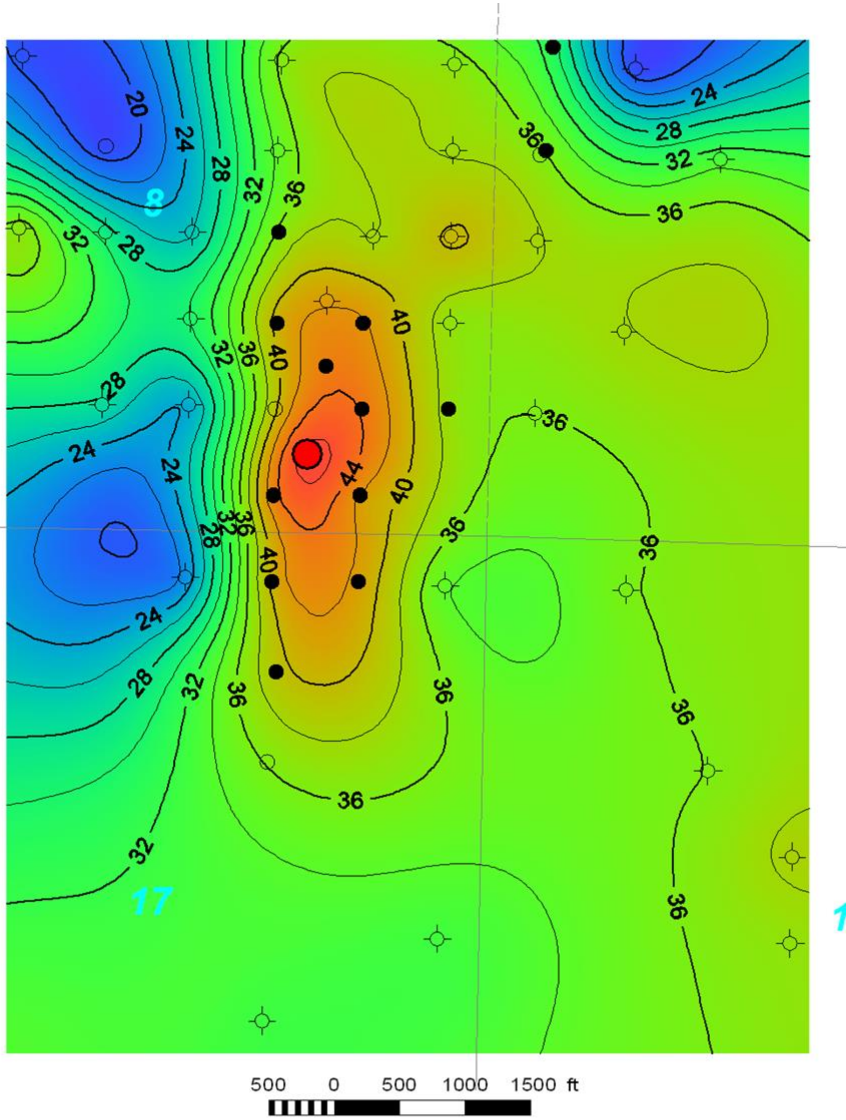
Dark blue dashed line: extension of p&T yielding the critical density of $CO_2$

Red line: vapor pressure of pure $CO_2$

General ILB
Temp - Depth
80 F - 1700 ft
90 F - 2700 ft

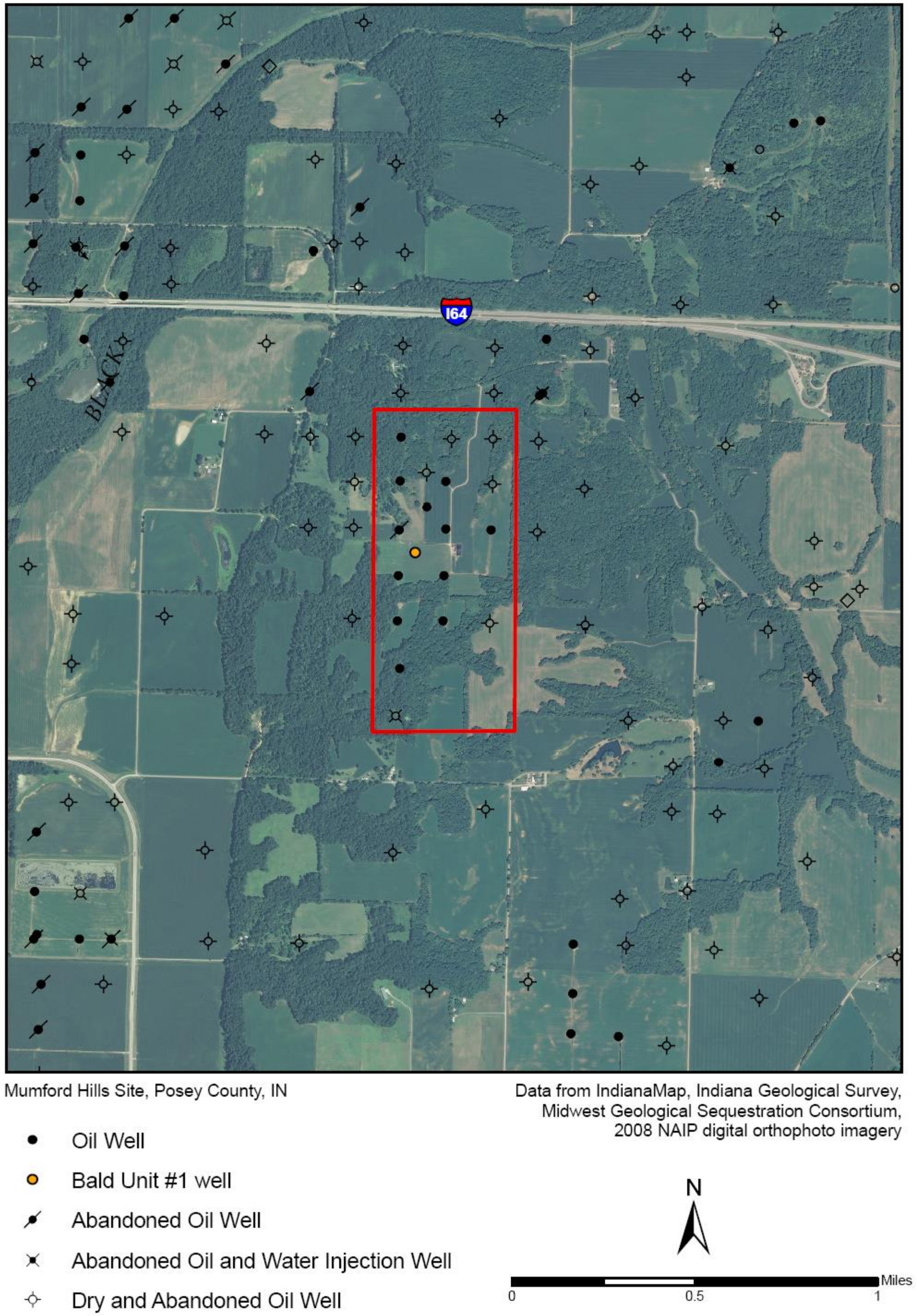
# EOR II: Miscible (Liquid) $CO_2$: Geology

- Depth 1,900 ft; net thickness 10 -20 ft
- Reservoir: elongated channel sandstone body; good lateral communication.
- At this pilot site, sandstone about 40 ft thick
  - 20 ft oil column
  - Small structure with stratigraphic pinchout
  - Small underlying aquifer
- Porosity 19%; Permeability 155 md




Isopach

2 foot CI

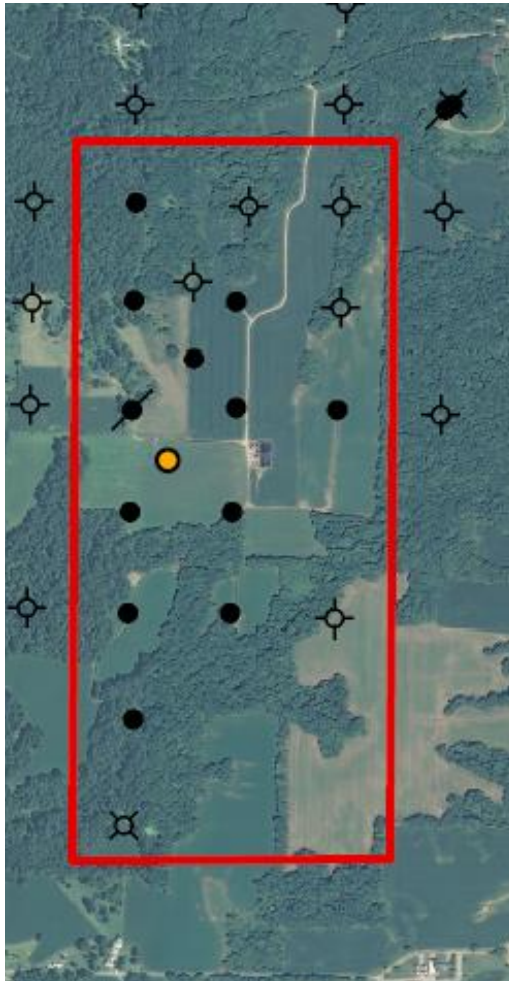



Mumford Hills Site, Posey County, IN

Data from IndianaMap, Indiana Geological Survey, Midwest Geological Sequestration Consortium, 2008 NAIP digital orthophoto imagery



# EOR II: Miscible (Liquid) $CO_2$: Pilot Area



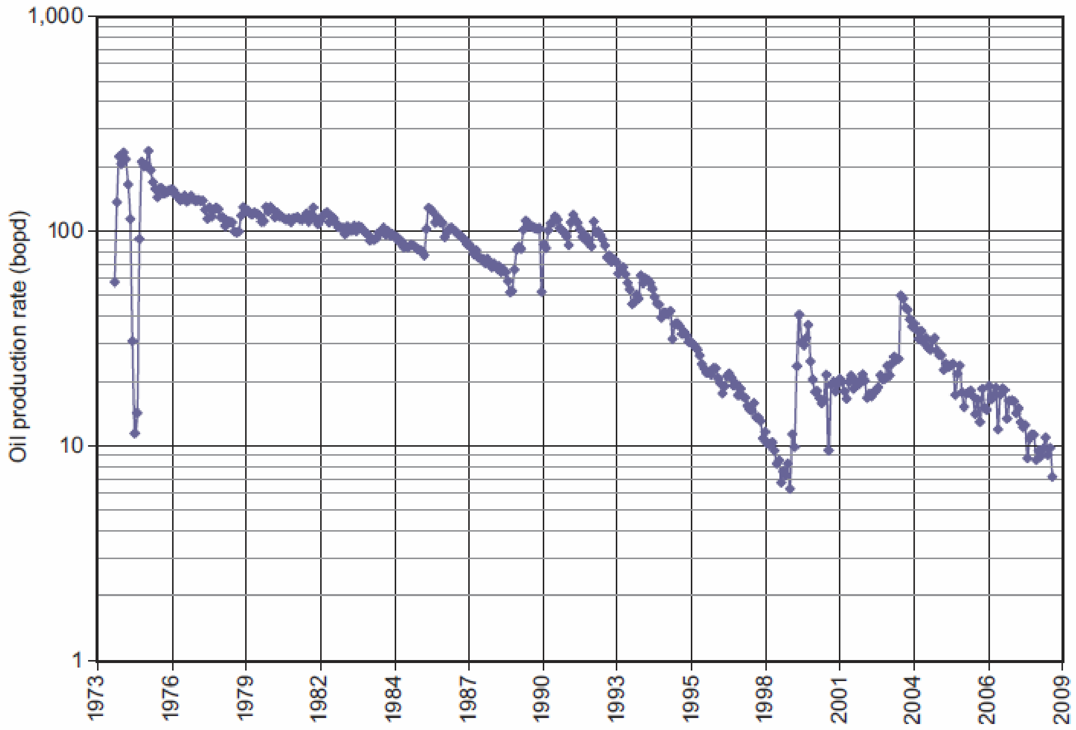
- Inverted 5-spot $CO_2$ injection pattern (10 acres)
  - Four flowing wells (through tubing) in pattern
  - Central $CO_2$ injection well converted from producer
  - Edge water injector: 1,000 bbl/day

# EOR II: Miscible (Liquid) $CO_2$ Model Results

**VIP Model Projections**

- VIP Models project 100-140 MMscf (6,000-8,000 tons) or 10-15% of HCPV of pilot area to have measurable oil response
- Requires 6-8 months of continuous injection, followed by 3-5 months of water injection
- Project oil increase of 2-4 times current rate

**Lease Production (35 yrs shown)**




*Entire units oil production*

# Data Acquisition Injection Equipment

- Bottomhole and surface pressure in flowing producing and injection wells. (5 wells)
- Pressure monitoring two wells:
  - out of pattern
  - nearest $CO_2$ injection well
  - downstream of general pressure gradient

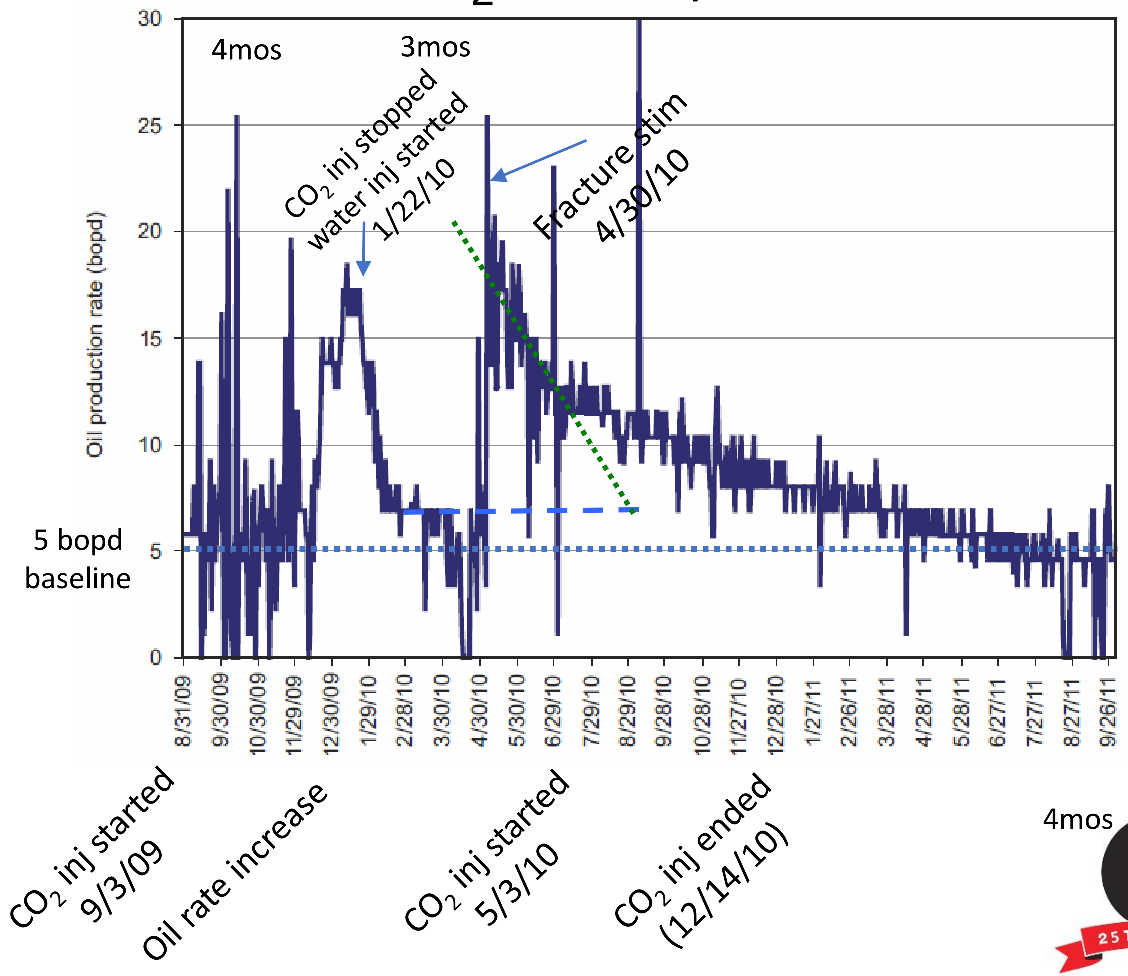
- Injection pump and booster pump
- Two, 60 ton storage tanks
- Inline propane-fired heater

# EOR II: Miscible (Liquid) $CO_2$ Pilot: Oil Production

- "Accidental" WAG
- 4 mos $CO_2$
  - 51 MMscf; 340-600 Mscf/day
  - 2945 tons; 20-35 tons/day
- 3 mos water
  - 13,000 bbl @150 bwpd
- 3 mos $CO_2$
  - 43 MMscf; 340-600 Mscf/day
  - 2500 tons; 20-35 tons/day

*Minimal $CO_2$ produced*

Project IOR 1,811 bo
$CO_2$ EOR 1,301 bo




No decrease in oil production when $CO_2$ injection ended, 2nd time.

# EOR II: Miscible (Liquid) $CO_2$ Full field Model Predictions
## (calibrated to the pilot field data)

| | Field Case 1 | Field Case 2 |
|---|---|---|
| EOR, stb | 106,309 | 169,263 |
| EOR, % OOIP | 9.8% | 11.8% |
| Net utilization, scf/stb | 34,352 | 30,907 |
| Gross utilization, scf/stb | 203,324 | 162,250 |
| $CO_2$ storage, tons | 213,065 | 305,213 |
| $CO_2$ storage factor, Mscf/stb OOIP | 3.3605 | 3.6345 |
| Storage efficiency, % HCPV[1] | 131.6% | 150.3% |

[1]Hydrocarbon pore volume; the storage efficiency is relatively high due to additional storage in the pore space of the aquifer underlying the oil reservoir.

- Field Case 1:
  - Four regular 5-spot patterns
  - Three new wells added
- Field Case 2:
  - Case 1 PLUS three additional 5-spot patterns
  - Nine new wells added (includes 3 from Case 1)

*Simulations by Roland Okwen, ISGS*

# EOR II: Miscible (Liquid) $CO_2$: Observations

- Production results indicative of miscible $CO_2$ flood at 1900 ft
- Incremental $CO_2$ EOR and Project IOR
- Flowing production wells eliminates electrical costs of pumping wells, but no easy mans to administer corrosion inhibitor
- Well work (fracture stimulation) changed baseline and made EOR estimate challenging
- No significant $CO_2$ production
- No out-of-zone indication of $CO_2$

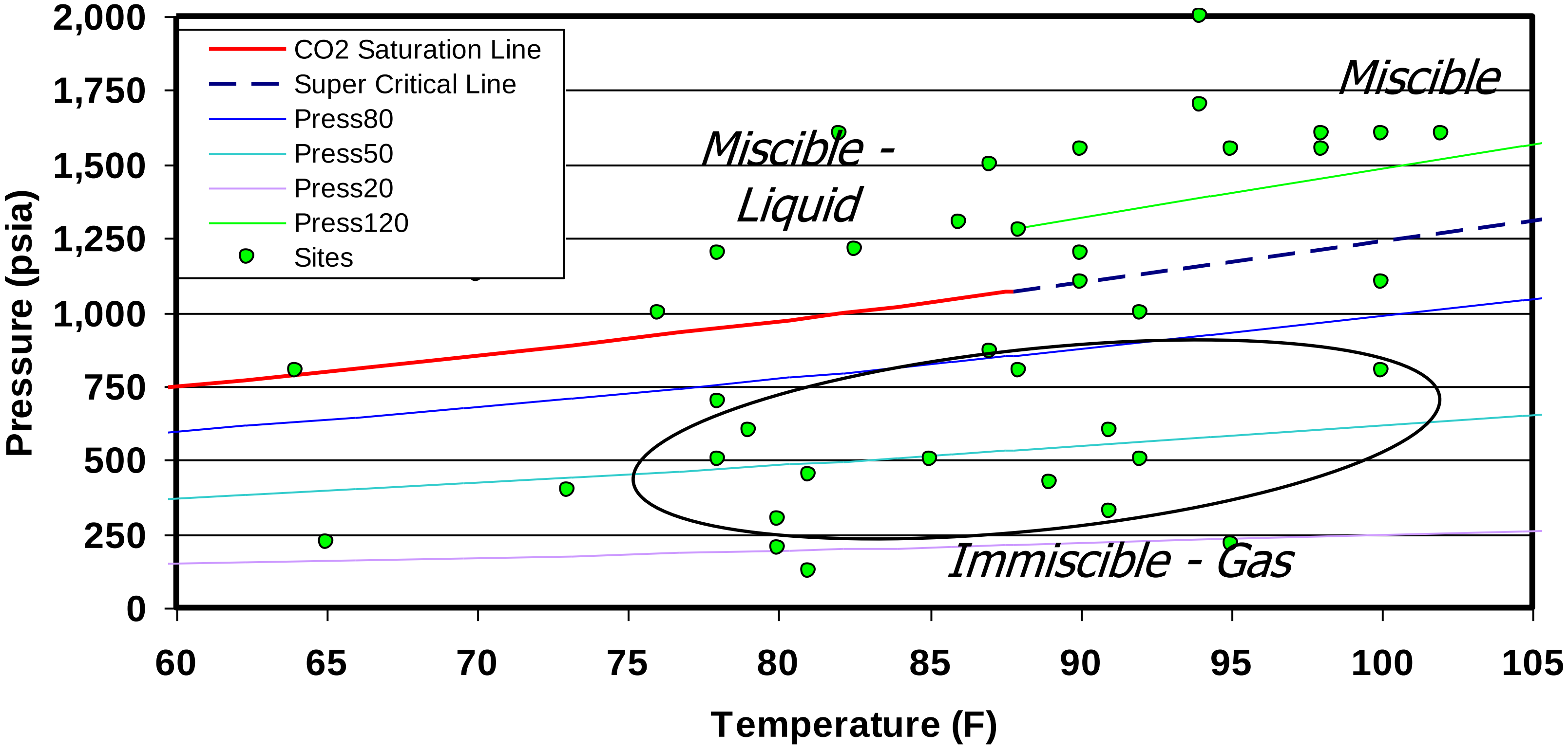
# EOR III: Immiscible (Gas) $CO_2$ Flood (Sugar Creek Field, Kentucky)

- Field History
  - Discovered 1963; OOIP 2,410,000 bbl
  - Waterflood 1993
- Production History
  - Primary oil production 475,000 bbl
  - Waterflood oil production 314,000 bbl
  - Total 793,000 bbl; 33% oil recovery
- Water injection
  - Low water injectivity and low injector/producer ratio; low reservoir pressure, not depleted (500-600 psi)
  - 100 bbl/day water injection; 36-42 bopd

# EOR III: Immiscible (Gas) $CO_2$ Classification

- 80°F (< $T_{cCO2}$); pressure 500-600 psi

EOR III:
Temp: 80F
Press: 500-600 psi




Green points: operators' nominations of reservoirs w/these pressure and temperature

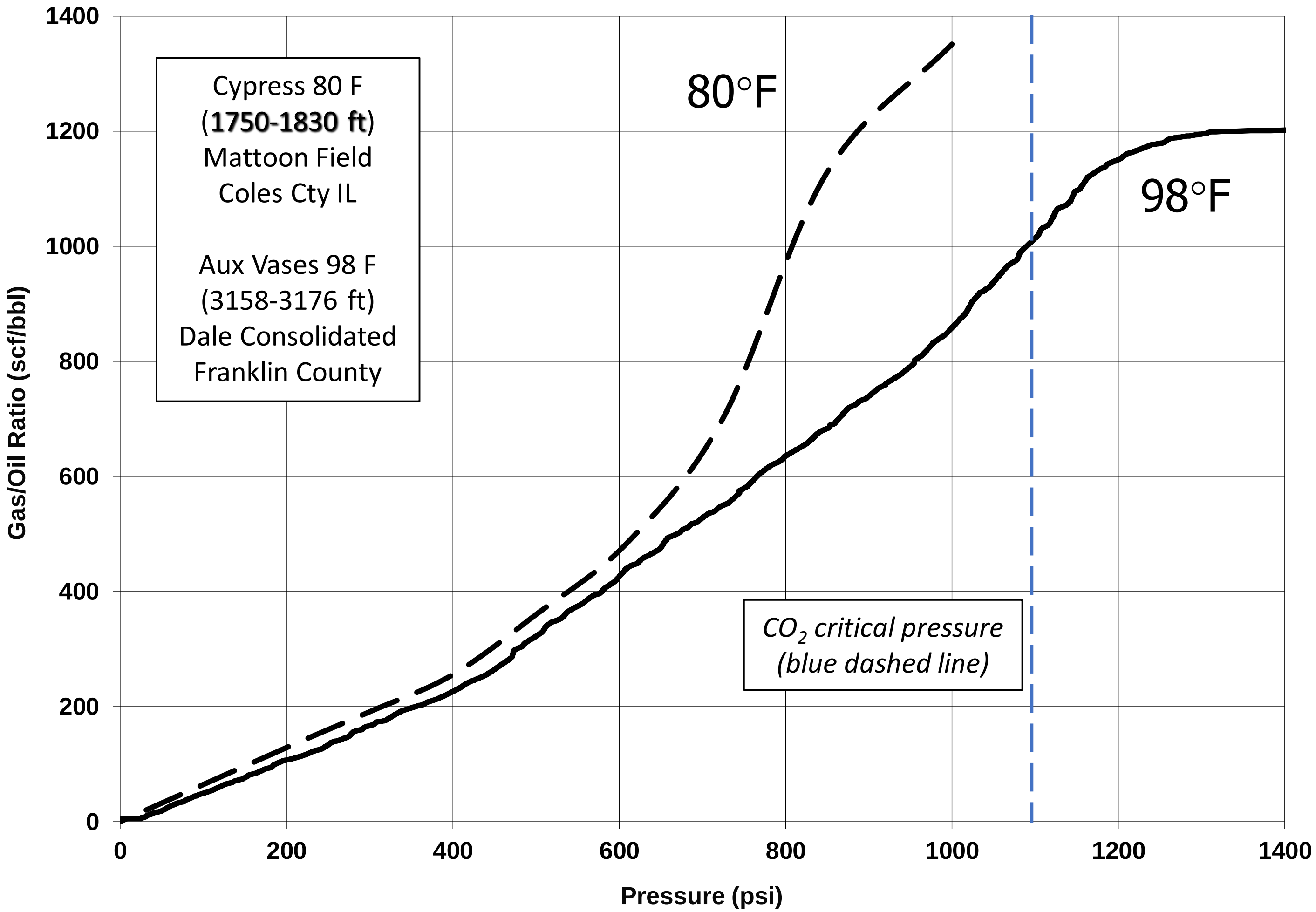
Dark blue dashed line: extension of p&T yielding the critical density of $CO_2$

Red line: vapor pressure of pure $CO_2$

General ILB
Temp - Depth
80 F - 1700 ft
90 F - 2700 ft

# $CO_2$ Solubility (vs. Miscibility) in Illinois Oil

In situ $CO_2$ solubility in oil, higher for low temperature Illinois Basin Oil fields



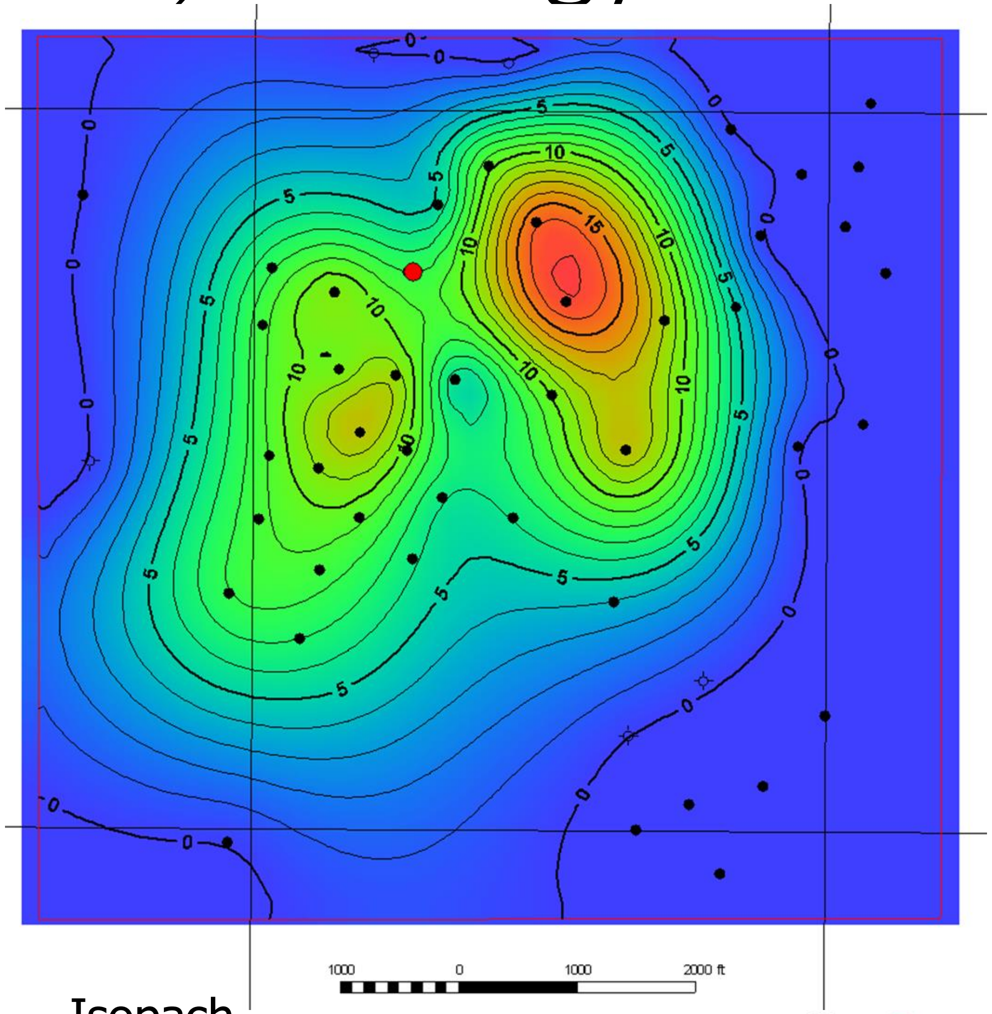

- $CO_2$ solubility increases with
  - increasing pressure
  - decreasing temperature.
- IL has relatively high fracture gradients (1 psi/ft)
  - high injection pressure is possible
- Combining low temperature with high pressure gives miscible conditions and high solubility at lower pressure and at **shallow depths**

ISGS IP 140

*DOE Rept, 1995 DE-FC22-93BC 14955*

# EOR III:  Immiscible (Gas) $CO_2$- Geology

- Depth:  1,900 ft; thickness 5 – 20 ft
- Modest geologic structure present
- Reservoir:
  - Lenticular reservoir sandstone bodies,
  - Likely a shallow marine environment,
  - Poor to fair communication
  - Aquifer to the north
- Pilot site:
  - Site 12 ft thick, oil column
- Porosity 15%; permeability 15 md



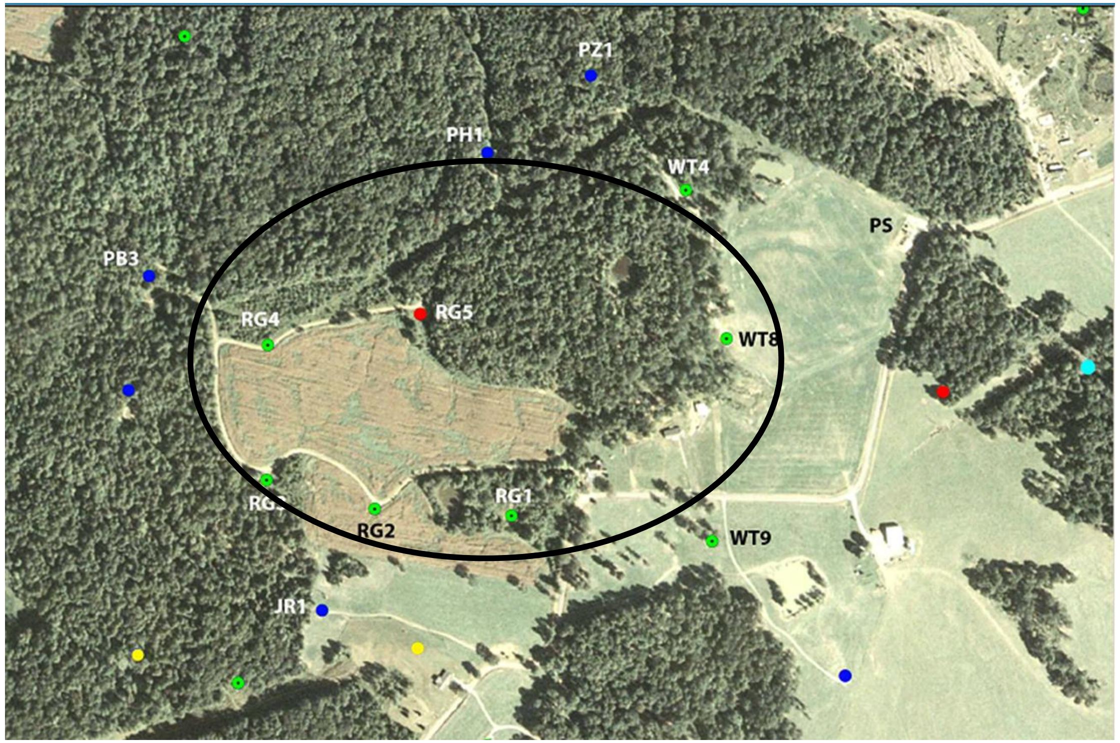

Isopach

1 foot CI

# EOR III: Immiscible (Gas) $CO_2$ - Pilot Design

- Central $CO_2$ injection pattern
  - Eight oil producing wells on pumping units
  - 400-600 MMscf
  - (20-30 tons/day)
- Low injection rate may lead to 1-3 injection wells

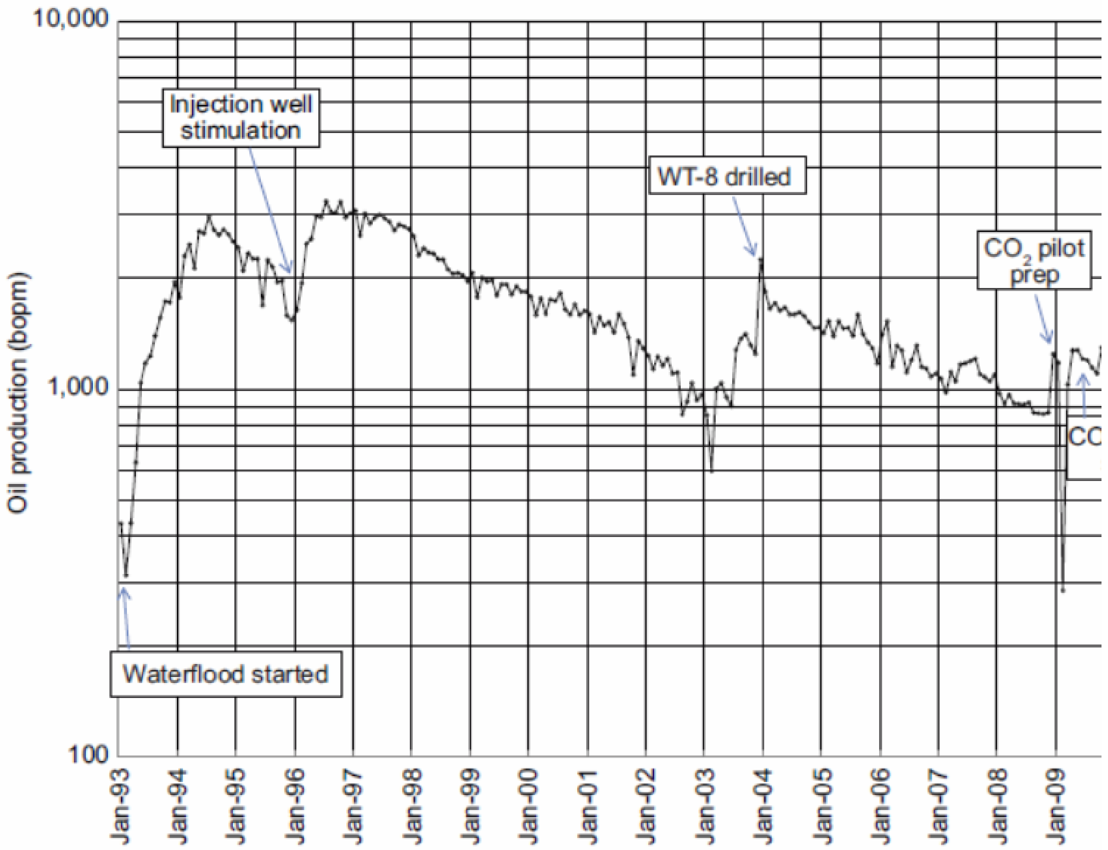
Equipment (PS)




Flowline across pasture along, woods

# EOR III: Immiscible (Gas) $CO_2$ - Model Results

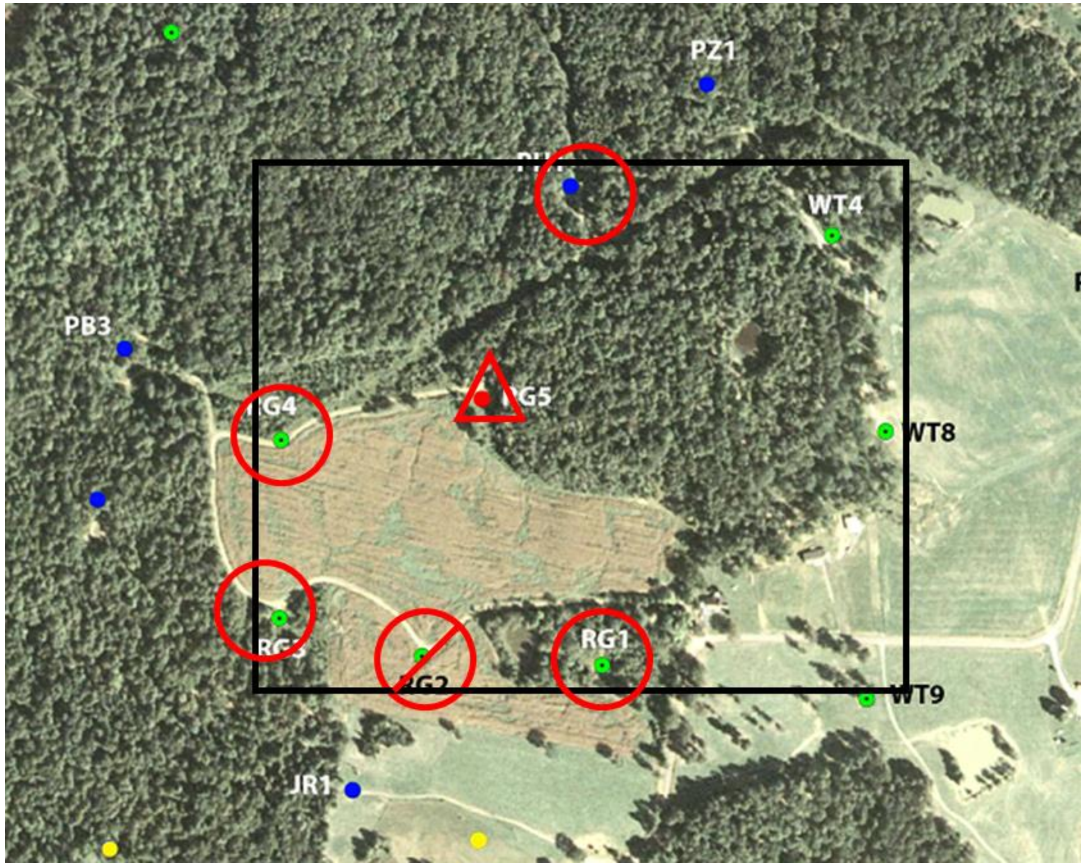
- VIP Models project 100-140 MMscf (6,000-8,000 tons) or 10-15% of HCPV of pilot area to have measurable oil response
- Requires 6-8 months of continuous injection, followed by 3-5 months of water injection
- Project oil increase of 2-3 times current rate



# Data Acquisition and Injection Equipment

- Surface casing pressure in producing wells (8 wells)
- Surface and bottomhole pressure in injection well
- Injection zone monitoring wells (3 outside of area)

# Break through of $CO_2$ and Pressure
## (Detected via pressure and gas sampling)




Very Early $CO_2$ Breakthrough@ RG-2
(two weeks after injection startup)

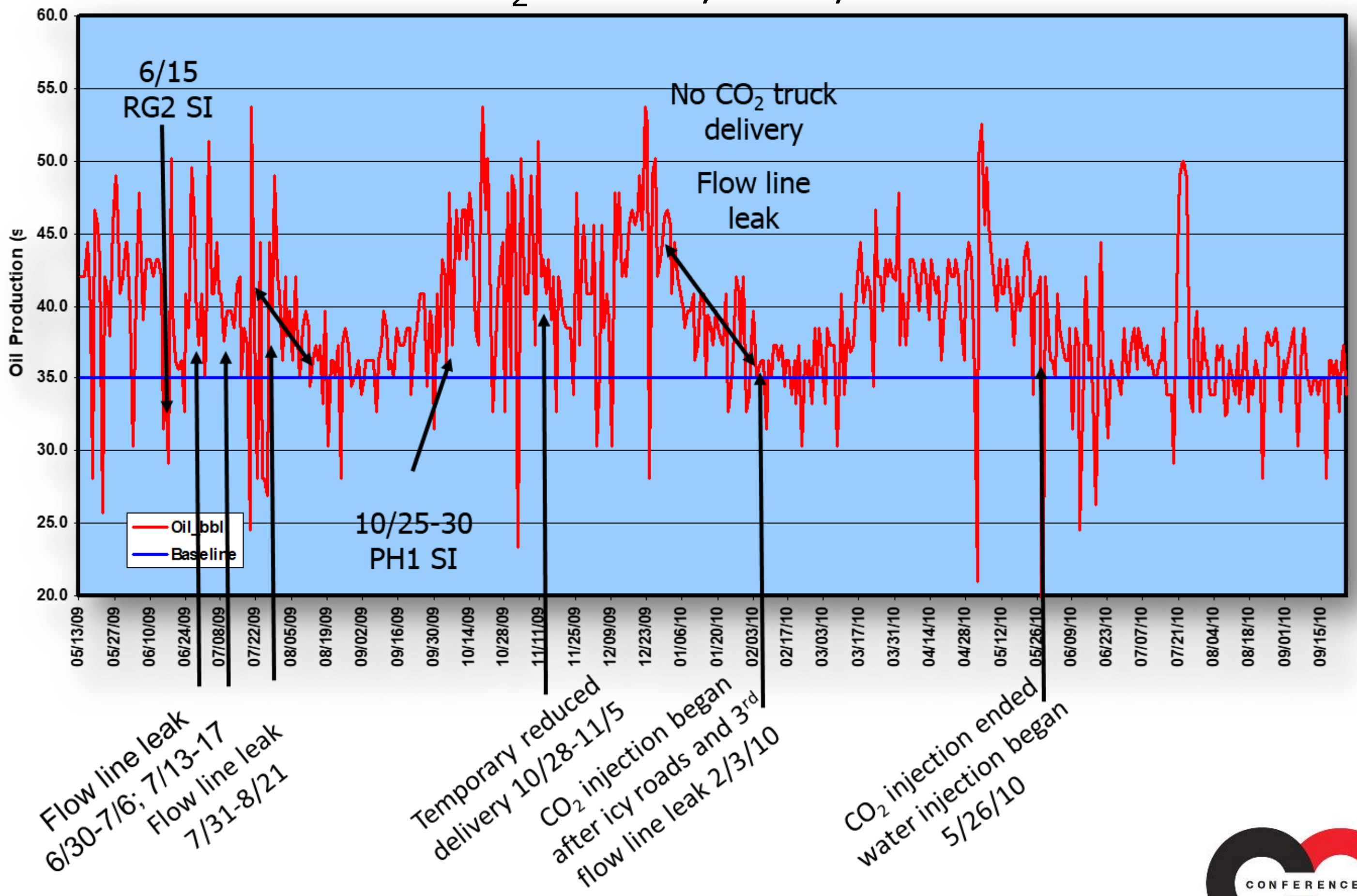
| Well | $CO_2$ | Press |
|---|---|---|
| RG2 | 5/20 | 5/19 |
| RG3 | 6/29 | 9/8 |
| RG1 | 9/15 | 9/12 |
| RG4 | 9/15 | 9/25 |
| PH1 | 10/7 | 10/6 |

RG-2
eventually SI due to
high CO2

# EOR III: Immiscible (Gas) $CO_2$ Oil Production

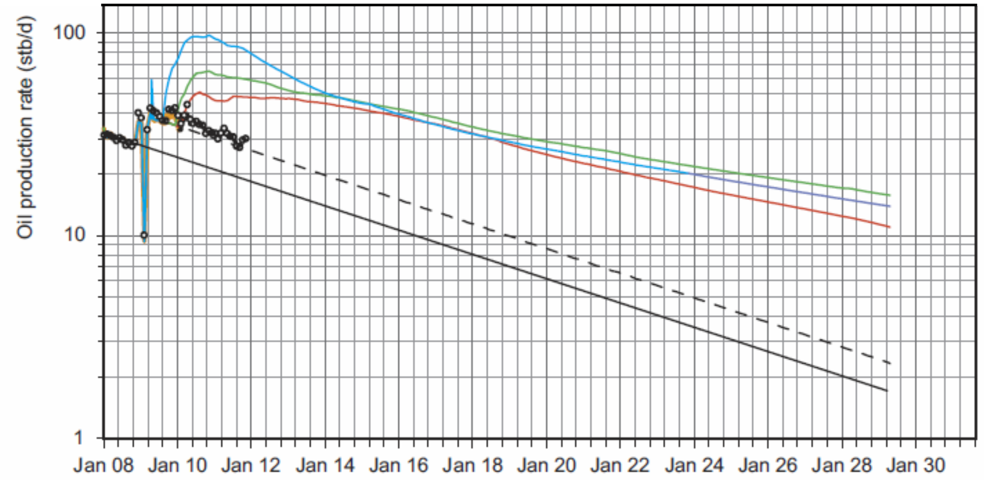
- Injected: 137MMscf (7,267 tons)
- Produced approximately 2% of injected $CO_2$; 55% from RG2 (at that time).
- 15,000 bbl water injected 6/7/10-9/30/10
  - 100-150 bwpd

$CO_2$ EOR: 2,800-3,300 stb




Numerous Definitive oil response to changes in injection rates CO2-gas (immiscible)

# EOR III: Immiscible (Gas) $CO_2$ - Full field Predictions (calibrated to the pilot field data)




| | Field Case 1 | Field Case 2 | Field Case 3 |
|---|---|---|---|
| EOR (stb) | 112,671 | 147,886 | 173,976 |
| EOR, % OOIP | 2.8 | 4.1 | 5.5 |
| Net Utilization (scf/stb) | 880 | 1,214 | 876 |
| Gross Utilization (scf/stb) | 23,993 | 19,452 | 24,892 |
| $CO_2$ Storage (tons) | 5,785 | 10,479 | 8,893 |
| $CO_2$ Storage Factor, (Mscf/stb-OOIP) | 0.0247 | 0.0502 | 0.0485 |
| Storage Efficiency, % HCPV* | 12.6 | 22.3 | 20.6 |
| EOR as % of primary and waterflood production | 12.9 | 16.9 | 19.9 |

* Hydrocarbon pore volume

- Field case 1: Full field
  - All existing water injection wells converted to $CO_2$ injection wells
- Field case 2: Full field-Modified
  - Field case 1 PLUS 7 production wells converted to injectors
- Field case 3: Full field-Infill Drlg
  - Field case 1 PLUS most producers converted to $CO_2$ injection PLUS 7 new infill production wells

*Simulations by Roland Okwen, ISGS*

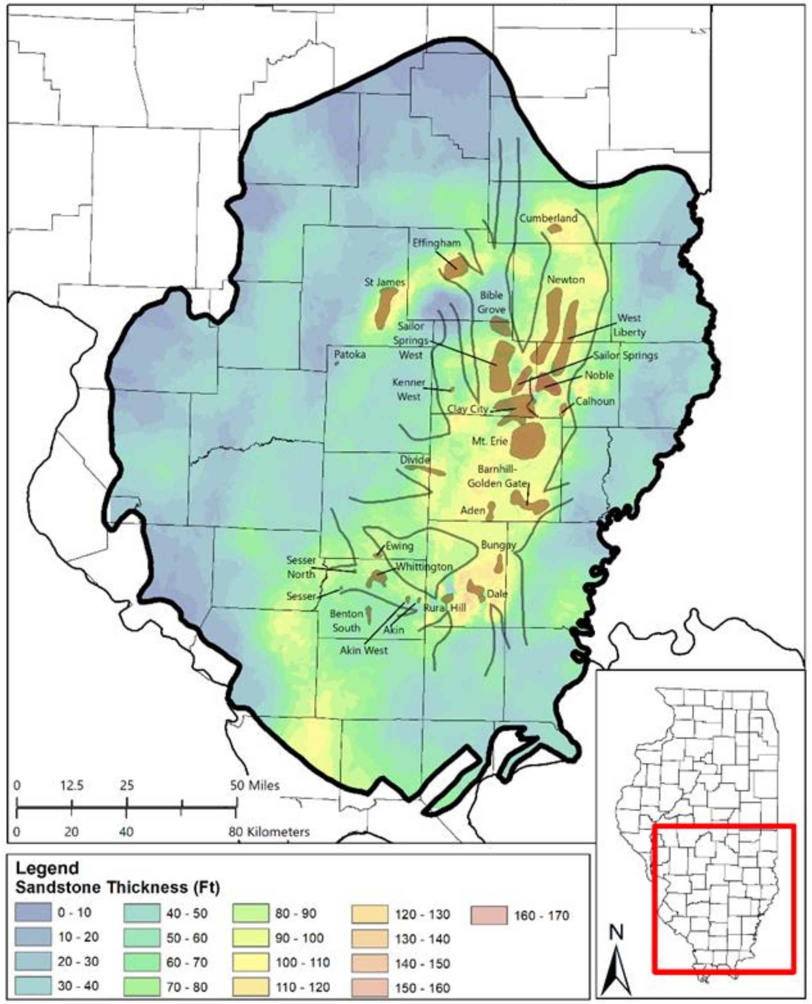
# EOR III: Immiscible (Gas) $CO_2$ - Observations

- Production results indicative of immiscible $CO_2$ flood at 1900 ft
- Incremental $CO_2$ EOR and Project IOR
- Single well performance (RG-2) adversely affect direct field measurements of pilot performance
- Pre-$CO_2$ well work changes baseline and makes EOR estimate challenging
- No significant $CO_2$ production
- No out-of-zone indication of $CO_2$

# Nonconventional $CO_2$ EOR: Residual Oil Zones in the Illinois Basin

- Cypress $CO_2$-EOR and storage resource
  - ROZ fairway covers ~1.9 million acres
    - Contains ~1 million acre-ft of pore volume
  - Estimated resource in ROZ prospects:
    - 1.8 billion barrels of oil in place
    - 196 million barrels recoverable
    - 10.4 billion tonnes associated $CO_2$ storage
- Current study: ROZ characterizations
  - Tar Springs Sandstone
  - Carper Sand
  - Geneva Dolomite/Dutch Creek Sandstone

Cypress Sandstone ROZ Prospects




*ROZ Assessments led by Nathan Webb, Greenfield Test Site led by Nate Grigsby, ISGS*

# Greenfield “Carper” ROZ Site Test Preparation

- Perform pressure transient tests to design injection test
- Conduct $CO_2$ injection test
  - huff n’ puff (1 month, 1000 ton) or
  - single well chemical tracer test
- Demonstrate efficacy of $CO_2$-EOR in ROZ in
  - low perm clastic (<1 md)
  - low oil saturation (20-30%)
  - low solution gas (<100 scf/stb)

*Use field laboratory test data to calibrate reservoir models*

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# Greenfield "Carper" ROZ Site – Current Work

- Working with site operator (Bi-Petro Inc.) to analyze existing well data
  - Reconciling six months of production data with reservoir properties derived from core and logs to identify what additional analyses are needed
- Correlating reservoir with nearby wildcat wells and oil fields to determine ROZ extent and continuity
- Very high water rate, 150-200 bwpd, from 0.2 md, 15 ft formation
- Natural fractured reservoir current working model
- Identifying challenges to the injection test presented by fractured reservoir.

# Publications


- “$CO_2$ Storage and Enhanced Oil Recovery: Bald Unit Test Site, Mumford Hills Oil Field, Posey County, Indiana”, S.M. Frailey, I.G. Krapac, J.R. Damico, R.T. Okwen, R.W. McKaskle. J.H. Goodwin and C.C. Monson (eds.): Illinois State Geological Survey, Open File Series 2012-5, 172 pp., 2012
- “$CO_2$ Storage and Enhanced Oil Recovery: Sugar Creek Oil Field Test Site, Hopkins County, Kentucky”, S.M. Frailey, T.M. Parris, J.R. Damico, R.T. Okwen, R.W. McKaskle. C.C. Monson and J. H. Goodwin (eds.): Illinois State Geological Survey, Open File Series 2012-4, 234 pp., 2012
- “Overview of the Illinois Basin's Sequestration Pilots”, Scott M. Frailey and Robert J. Finley, paper SPE 113418, SPE/DOE Improved Oil Recovery, April 19–23, 2008 Tulsa, Oklahoma
- “Overview of the Midwest Geologic Sequestration Consortium Pilot Projects”, Scott M. Frailey and Robert J. Finley, SPE 139746, SPE International Conference on CO2 Capture, Storage, and Utilization held in New Orleans, Louisiana, USA, 10–12 November 2010
- “Investigation of Liquid $CO_2$ Sequestration and EOR in Low Temperature Oil Reservoirs in the Illinois Basin”, Scott M. Frailey, John P. Grube, Beverly Seyler, and Robert J. Finley, paper SPE 89342, SPE/DOE Fourteenth Symposium on Improved Oil Recovery, April 17–21, 2004 Tulsa, Oklahoma
- http://isgs.illinois.edu/research/ERD/NCO2EOR

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