

# THE PLAINS CO<sub>2</sub> REDUCTION (PCOR) PARTNERSHIP – VALIDATING CO<sub>2</sub> STORAGE IN CENTRAL NORTH AMERICA PHASE II ACTIVITIES

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## Zama Acid Gas EOR, CO<sub>2</sub> Sequestration, and Monitoring Project

## CO<sub>2</sub> Sequestration and Enhanced Coalbed Methane in Lignite Coals Project

### Project Goal

- To validate the sequestration of CO<sub>2</sub>-rich acid gas in a depleted oil reservoir.

### Objectives

- Inject a stream of acid gas (70% CO<sub>2</sub>–30% H<sub>2</sub>S) for simultaneous acid gas disposal, CO<sub>2</sub> sequestration, and enhanced oil recovery (EOR).

- Determine the effects of acid gas injection on target reservoir and cap rock formations.

- Implement a cost-effective approach for measurement, mitigation, and verification (MMV) for sequestration of a CO<sub>2</sub>-rich acid gas stream.



### MMV Operations

#### Monitor the CO<sub>2</sub>/H<sub>2</sub>S plume through:

- Perfluorocarbon tracer injection.

- Reservoir pressure monitoring.

- Wellhead and formation fluid sampling (oil, water, gas).

#### Monitor for early warning of reservoir failure through:

- Pressure measurements of injection well, reservoir, and overlying formations.

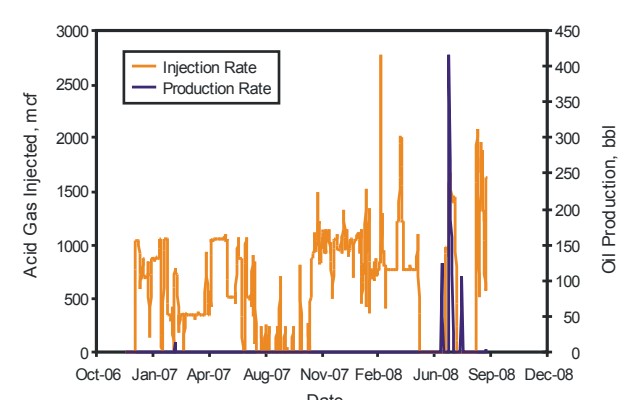
- Fluid sampling of overlying formations.

#### Determine injection well conditions through:

- Wellhead pressure gauges.

- Well integrity tests.

- Wellbore annulus pressure measurements.



- Injection has been ongoing since December 2006.
- Cumulative injection total is greater than 20,000 tons to date.
- Brief period of production was the result of a newly perforated interval in the pinnacle.

### Project Goal

- Determine the feasibility of simultaneous CO<sub>2</sub> sequestration and natural gas production from a lignite coal seam.

### Objectives

- Inject CO<sub>2</sub> into lignite coal seam and monitor CO<sub>2</sub> fate in the reservoir.

- Determine the potential for coalbed methane (CBM) production from the lignite seam.

- Determine the potential for production enhancement by CO<sub>2</sub> injection.

- Develop Regional Technology Implementation Plan for CO<sub>2</sub> sequestration in lignite coal.



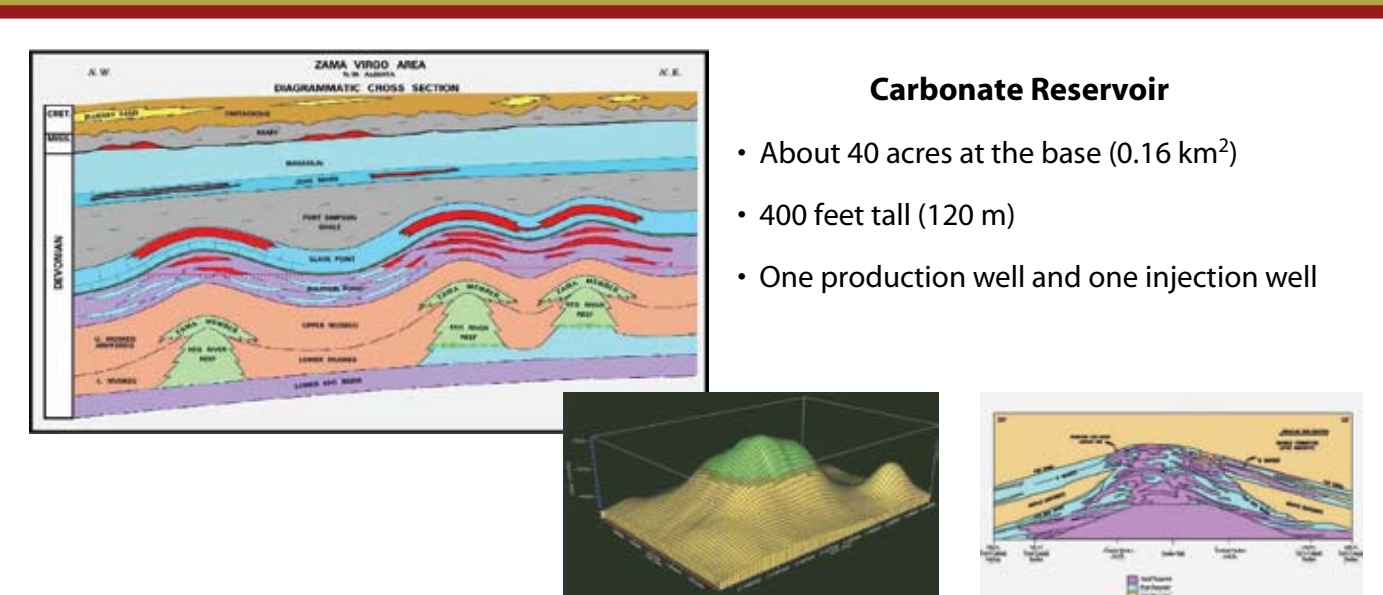
### Relative Permeability

- Completed to determine CO<sub>2</sub> and formation brine displacement characteristics of the pinnacle cap rock (anhydrite).

- Prior to testing:
  - Capillary pressure testing to determine pore throat opening size
  - Petrographic analysis

- Two samples were tested using formation brine, CO<sub>2</sub>, H<sub>2</sub>S, and an acid gas mixture of 70% CO<sub>2</sub> and 30% H<sub>2</sub>S.

Results show very low permeability in the cap rock, indicating low potential for natural fluid flow out of the pinnacle.



### Carbonate Reservoir

- About 40 acres at the base (0.16 km<sup>2</sup>)
- 400 feet tall (120 m)
- One production well and one injection well

### Core Evaluation Activities

- Lab studies on the recently collected core will examine:
  - Gas content.
  - Gas specific gravity.
  - CH<sub>4</sub> and CO<sub>2</sub> isotherms.
  - Diffusion coefficient.
  - Gas desorption time.
  - Coal ash and moisture contents.
  - Coal density and compressibility.
  - Rock porosity and permeability.

### Test Design Activities

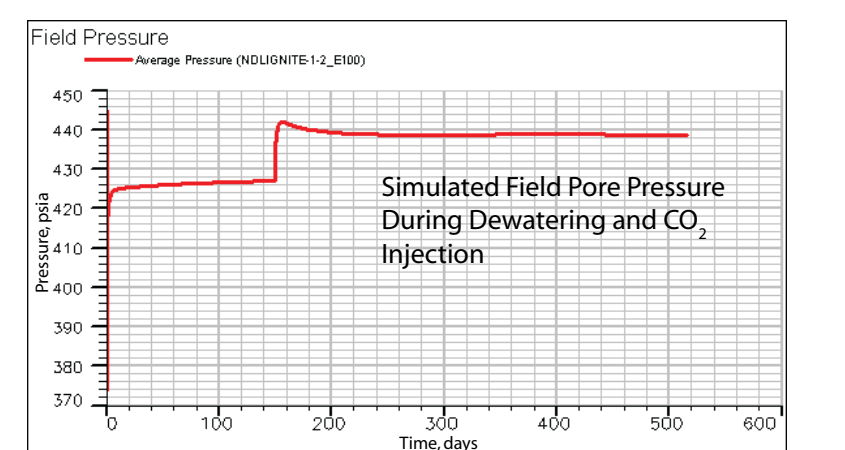
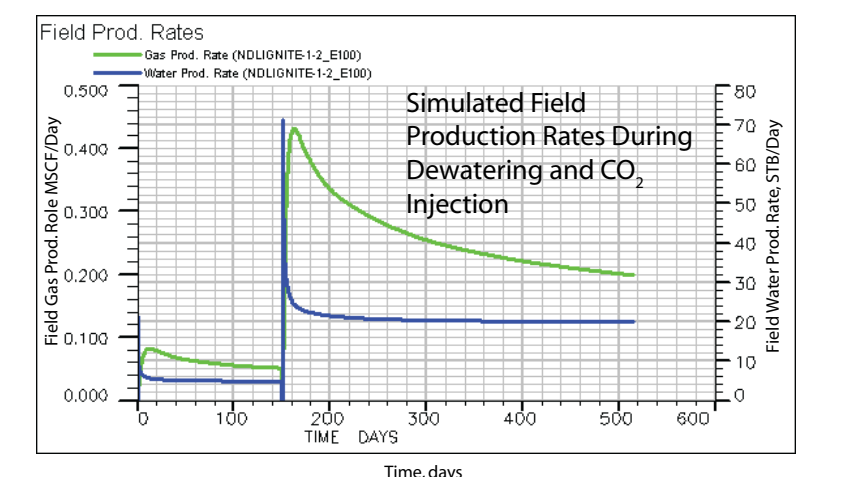
- Analysis of the existing well data served for choosing the location of the test site and supported the creation of a preliminary numeric model of the coal seam using ECLIPSE.

- Five-spot well configuration allows for effective and efficient operation and monitoring of the water production and CO<sub>2</sub> injection program.



### Input Parameters and Preliminary Results of Simulations Using Schlumberger's ECLIPSE Software

Characteristics	Reported Value
Depth $H$ , ft.....	1040–1175
Reservoir Temperature $T$ , °F.....	70.8–73.5
Reservoir Pressure, psi.....	478.4–540.4
Coal Thickness $h$ , ft.....	7–9
CO <sub>2</sub> Langmuir Pressure $PLCO_2$ , .....psi	528–1150.2
CO <sub>2</sub> Langmuir Volume $VLCO_2$ , scf/ton.....	1125–1779
CH <sub>4</sub> Langmuir Pressure $PLCH_4$ , .....psi	18.26
CH <sub>4</sub> Langmuir Volume $VLCCH_4$ , scf/ton.....	71.42
Ash Content, %.....	6.0–8.8
Moisture Content, %.....	24.1–39.2
Coal Gas Concentration $C$ , scf/ton.....	0.02–22.68
Coal Density .....lb/ft <sup>3</sup>	1.29–1.75
Diffusion Coefficient $D$ , ft <sup>2</sup> /day.....	$0.358–49.2 \times 10^{-7}$
Desorption Time $t$ , h.....	3.76–516.9



### Acid Gas–Brine Partitioning Results

- Completed to assess the potential for early detection of acid gas in case of leakage into overlying aquifers.

- Performed at 140°F and 1960 psi, the conditions of the Zama F-pool pinnacle reservoir.

- Brine composition 119,000 ppm total dissolved solids (TDS).

Results indicate CO<sub>2</sub> will lead H<sub>2</sub>S in the sweep displacement front. May provide warning of a potential future breakthrough of acid gas.

### Rock Mechanics Results



- Lab testing of eight core samples has occurred, primarily dolomite from the Keg River reservoir and dolomite and anhydrite from the Muskeg cap rock.

- Tests include:
  - Bulk density.
  - Acoustic velocity.
  - Uniaxial strength.
  - Triaxial strength.
  - Residual friction measurements.

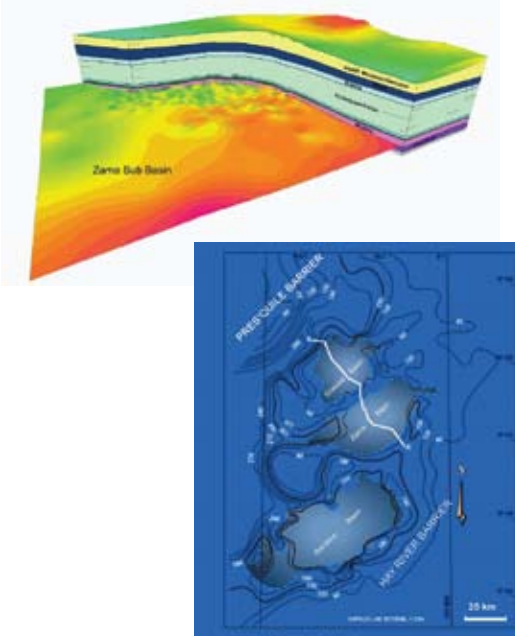
Results indicate that the cap rock is significantly stiffer than the reservoir rock and is, therefore, a competent seal.

### Geology and Hydrogeology Results

- Conducted to better understand the storage characteristics of regional aquifer systems and the fate of acid gas in case of leakage outside the pinnacle.

- Leakage migration, should it occur, would be a very slow process (thousands of years) and would likely be limited to much less than a kilometer from the site because of dissolution, dispersion, and residual gas trapping along the migration pathway.

Results indicate there is minimal potential for acid gas migration to shallower strata and potable groundwater.



### Zama Path Forward

- Injection of acid gas will continue through Year 4 of Phase II.

- Core samples will be collected from an acid gas disposal zone to examine the mineralogical and geomechanical changes that can occur in a carbonate rock exposed to high-pressure acid gas.

- Geomechanical data will be used to populate a database that will support the creation of a geomechanical model of the pinnacle reef.

- Geochemical modeling activities will be conducted to predict the long-term effects of acid gas injection on the reservoir and cap rock formations.

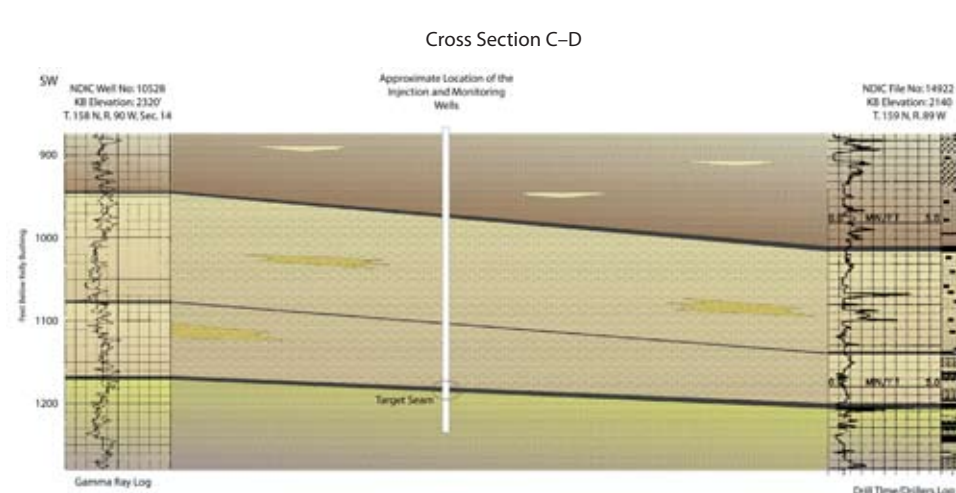
- A Regional Technology Implementation Plan will be developed.

PCOR Partnership



### Key Results to Date

- Well drilling is completed.
- Logging is completed, and logs are being processed in collaboration with Schlumberger.
- Core has been collected and is being analyzed by TerraTek.
- Initial numerical model has been created.
- Preliminary simulations have been run which provide guidance for the possible outcome of CO<sub>2</sub> injection activities in the coal seam.



### Lignite Path Forward

- Pressure and water quality measurements from monitoring wells.
- May include tiltmeter and microseismic.
- MMV plans will be finalized after analysis of collected field data.
- CO<sub>2</sub> injection to occur in fall 2008.