Plains CO_2 Reduction (PCOR) Partnership Phase II Field Validation Test: Zama Acid Gas EOR, CO_2 Sequestration, and Monitoring Project

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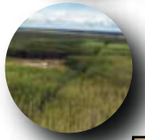
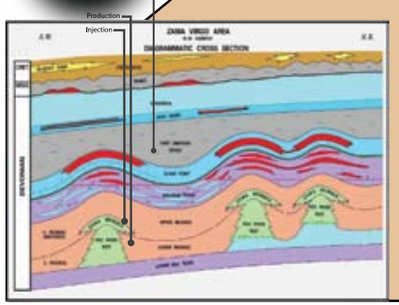
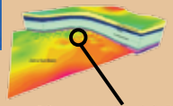




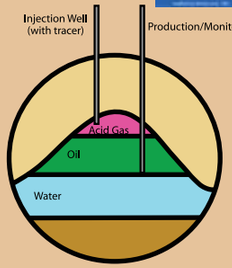
Monitoring

As part of monitoring, mitigation, and verification (MMV), new core that has been exposed to acid gas will be collected and a comparative analysis will be completed to identify the nature and magnitude of mineralogic changes that have occurred.

Geological characterization on the local, subbasinal, and regional scale are being conducted to predict the transport and fate of injected gas over short-, medium-, and long- term time frames.



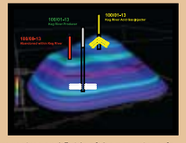
3-D cross section through the Zama subbasin showing multiple pinnacle reef structures.



Geomechanical Characterization to Confirm the Mechanical Integrity of the System

Laboratory Testing Program
- Compression tests
  - Strength
  - Static and dynamic elastic properties
  - Compressibility
  - Stress-dependent permeability
- Sonic tests
  - Compressional and shear wave velocities

Historical Correlation Program and Analytical Work
- Wireline logging
  - Dynamic elastic properties
  - Stress regime
- Analytical work
  - Correlation of static-to-dynamic elastic properties
  - Geomechanical simulation
- Assessment of rock integrity



Monitoring the pressure regime and fluids of the near pinnacle environment will ensure the safe and effective storage of all injected gas. A chemical perfluorocarbon tracer will be added to the injection stream to aid in the detection of leakage from the pinnacle into overlying formations. Fluids from monitoring wells will be periodically sampled and analyzed for the tracer.

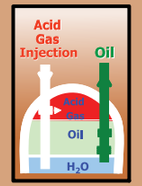
Photomicrograph of the anhydrite caprock showing virtually no porosity. Test results demonstrate the absence of permeability (below).

Permeability of Caprock		
Test Phase	Permeability, mD	Relative Permeability Fraction
Initial Absolute Brine Permeability	0.0001680000	1.0000
Supercritcal Acid Gas Permeability	0.0000000050	0.0000298
Post Acid Gas Brine Permeability	<0.0000000010	Too small to measure

Injected Miscible Gas	Biweekly
Produced Gas	Monthly basis
Slave Point Formation	Bimonthly basis
Reservoir Pressure Monitoring	Twice yearly
Perfluorocarbon Tracer	Biweekly to bimonthly

Sampling Schedule

Zama Acid Gas EOR

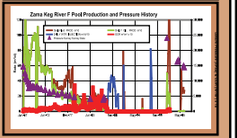


- Top-down injection
- Unique approach combining acid gas disposal and enhanced oil recovery (EOR)
- Potential to expand to over 800 additional pinnacles in northern Alberta and thousands of pinnacles throughout western Canada and the north-central United States.

Play type	Keg River Pinnacle Reef
Initial reservoir pressure	14,447 kPa (2095 psi)
Reservoir temperature	71° C (160° F)
Initial water saturation	15% (from logs)
Porosity	10% (from logs)
Initial formation volume factor	1.183 rvol/stdvol
Bubble point pressure	8791 kPa (1275 psi)
Gravity (oil)	35.2 API
Permeability	100–1000 mD
Original oil in place (material balance)	557,000 m^3 (3.5 million stb)

Cumulative "F" Pool Production (m^3)

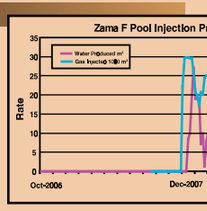
Oil	175,663
Gas	15,144,000
Water	59,898
Water Injected	366,424

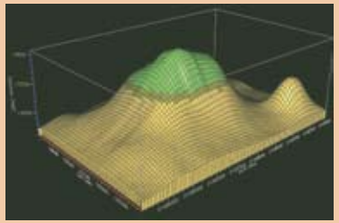


CO_2 Sequestration

Injection Zone Characteristics

- Devonian Carbonate Pinnacle Reef
- Approximately 16 ha (40 acres) wide at the oil–water contact
- Approximately 122 m (400) feet in height
- Injection depth = 1600 m (5300 ft)
- Reservoir pressure (current) = 15.3 MPa (2210 psig)
- Permeabilty = 100–1000 mD
- CO_2 capacity ≥1 MMT





- Currently injecting 25,000 m^3 of 70% CO_2, 30% H_2S acid as per day (approximately 50 tons CO_2 per day).
- At these rates, the sequestration of approximately 12 to 15 thousand tons of CO_2 will occur annually.

The Zama Field Validation Test was recognized in March 2007 as an official Carbon Sequestration Leadership Forum (CSFL) Geological Storage project. This has given additional exposure to the project and to the validation of geological stiorage of anthropogenic CO_2.

Project Goal:
To validate the sequestration of CO_2-rich acid gas in a depleted oil reservoir.

Project Description:
The Energy & Environmental Research Center (EERC), through the Plains CO_2 Reduction (PCOR) Partnership, one of the U.S. Department of Energy's (DOE) National Energy Technology Laboratories (NETL) Regional Carbon Sequestration Partnerships, is working with Apache Canada, Ltd., to determine the effect of acid gas (70% CO_2, 30% H_2S) injection for the purpose of simultaneous acid gas disposal, sequestration of CO_2, and EOR. The injection process and subsequent hydrocarbon recovery will be carried out by Apache Canada, Ltd., while the EERC will conduct MMV activities at the site with as little disruption to the ongoing oil production as possible. The MMV activities have been designed in such a way as to be cost-effective while still providing critical data on the behavior and fate of the acid gas mixture.

In this project, acid gas is redirected through injection wells into the top of pinnacle reef structures which have been depleted of oil from primary and secondary (water flood) oil production techniques. The reef is repressurized using the acid gas, and incremental oil is produced from a second well in the reef completed near the oil–water contact. Additional inactive wells are used to monitor acid gas migration uphole and, in some cases, the effect of the acid gas on the completed wellbore.

Prior to this process, the acid gas was sent to a Claus-based sulfur removal plant for the processing of acid gas into elemental sulfur, which was stored above ground in blocks, and CO_2, which was vented to the atmosphere. With over 800 pinnacles in the Zama Field, the potential for expansion with regard to EOR and CO_2 sequestration is significant.

Relevance to Carbon Sequestration Leadership Forum (CSLF) Gaps Analysis:

Four CSLF storage gaps will be addressed during the project including:

1. Reservoir engineering aspects – Challenges in dealing with acid gas as a miscible fluid for EOR and the ultimate sequestration of associated CO_2 will be identified and examined in the project.
2. EOR – Lessons regarding the use of acid gas for EOR can be applied to other potential storage reservoirs. Acid gas, which is increasingly being produced as deeper sour gas pools are produced and exploited for natural gas, could be used as a miscible fluid for EOR projects in areas around the world. Where such fields are remote, dispersed, or small, this technique could offset the cost of a sequestration infrastructure that could not otherwise be justified.
3. Depleted oil and gas fields viability—The utilization of depleted oil fields for sequestration purposes and the potential to produce previously uneconomic oil will be validated throughout the life of this project. While it is anticipated that oil will be produced over the course of the injection period, prior to the initiation of this project, the target pinnacle was considered to be depleted of economically recoverable oil.
4. CO_2 properties – This storage gap will be addressed with the collection and comparative analysis of new sections of core. The Zama project will include the collection of fresh core that has been exposed to supercritical acid gas. Analyses of mineralogy and geochemistry will be conducted and compared to that of core from unexposed rock from the same formation in the vicinity of Zama. This will provide previously unavailable insight regarding the effects of supercritical acid gas on carbonates and anhydrites under real-world

Monitoring, Mitigation, and Verification:

Philosophy
MMV activities for oil field sequestration through EOR should:
- Maximize the use of existing data sets to develop background and baseline conditions.
- Minimize the use of invasive or disruptive technologies to acquire new data.
- Coordinate MMV data acquisition with routinely scheduled operational data acquisition activities.
- Use resources to target the best sites for EOR and secure sequestration.

Research Activities
- Baseline data collection
- Geological characterization
- Geomechanical characterization
- Sampling program

Operations
- Monitor the CO_2/H_2S plume through:
  - Perfluorocarbon tracer injection.
  - Reservoir pressure monitoring.
  - Wellhead and formation fluid sampling (oil, water, gas).
  - Geochemical changes in wells.
- Early warning of reservoir failure:
  - Pressure measurements of injection well, reservoir, and overlying formations.
  - Fluid sampling of overlying formations.
- Injection well conditions:
  - Wellhead pressure gauges.
  - Well integrity tests.
  - Wellbore annulus pressure measurements.
- Monitor for leakage through faults or fractures:
  - Reservoir and aquifer pressure monitoring