EERC Technology… Putting Research into Practice

Zama Acid Gas EOR, CO_2 Storage and Monitoring Project

Plains CO_2 Reduction (PCOR) Partnership
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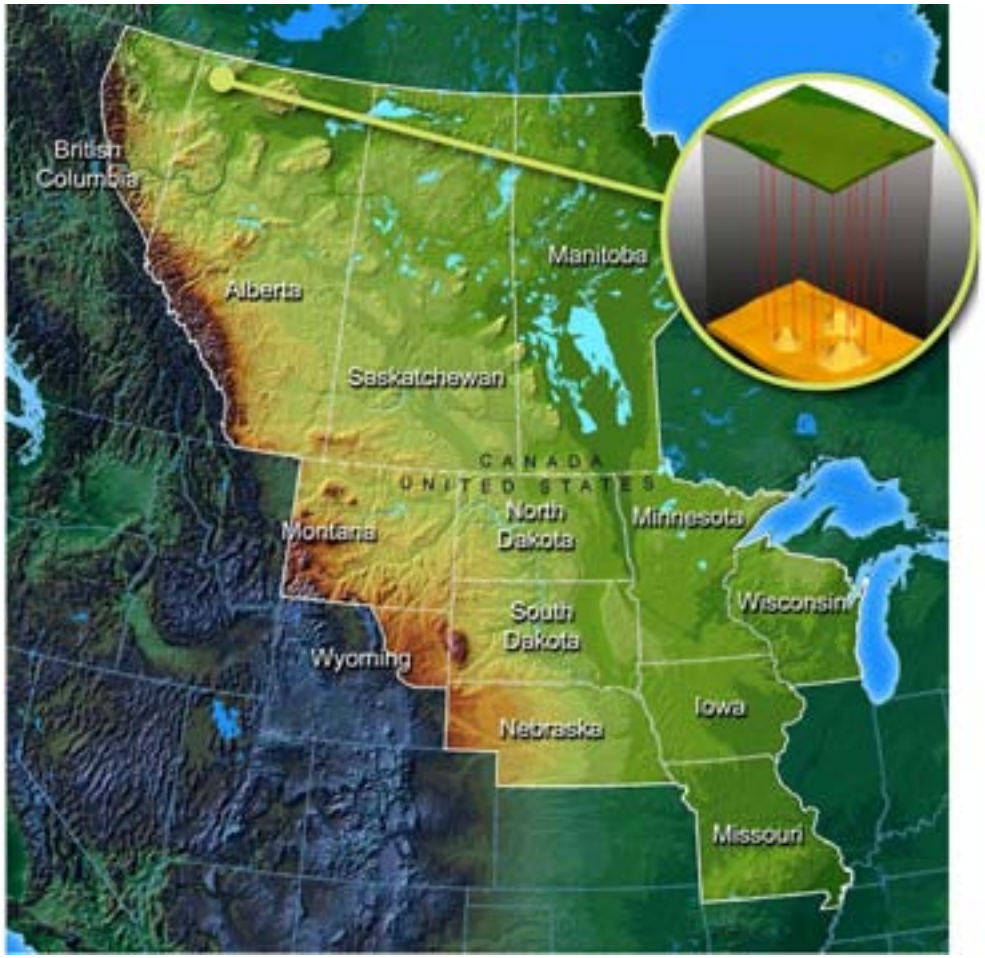
PCO2R Partnership

NETL

Acknowledgments

- Apache Canada, Ltd.
- Natural Resources Canada
- Alberta Energy Resources and Conservation Board
- RPS Energy
- Advanced Geotechnology, Inc.
- U.S. Department of Energy National Energy Technology Laboratory

Where's Zama?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Missouri

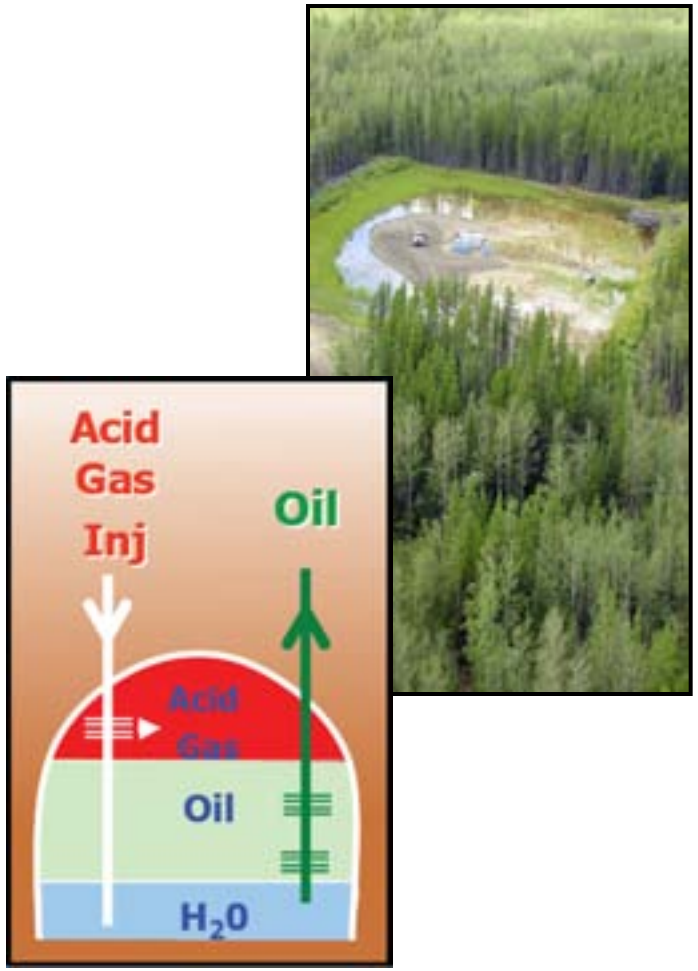
PCOR Partnership Involvement at Zama

Goal

- To validate the sequestration of CO_2-rich acid gas (CO_2 and H_2S) in a depleted oil reservoir.

Objectives

- Determine the effects of acid gas injection on target reservoir and cap rock formations.
- Implement a cost-effective approach for monitoring, verification, and accounting (MVA) for storage of a CO_2-rich acid gas stream.



Zama Acid Gas EOR Project

- Operated by Apache Canada, Ltd.
- Unique approach combining acid gas disposal and CO_2 enhanced oil recovery (EOR).
- Acid gas is obtained from EOR recycle and additional field production passed through the on-site gas plant.
- Shut down the sulfur plant and eliminated CO_2 venting.
- Five pinnacles currently accepting acid gas for EOR.
- Potential for expansion into hundreds of additional pinnacles.

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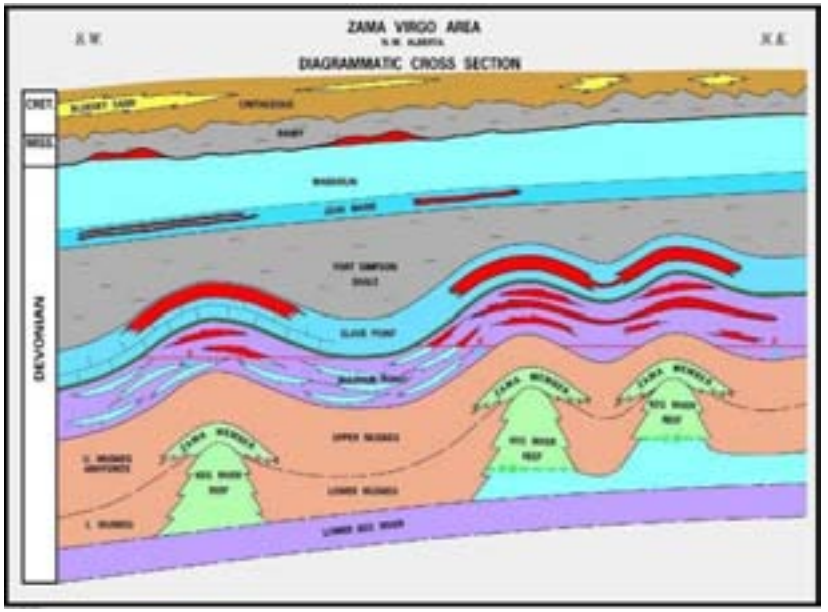
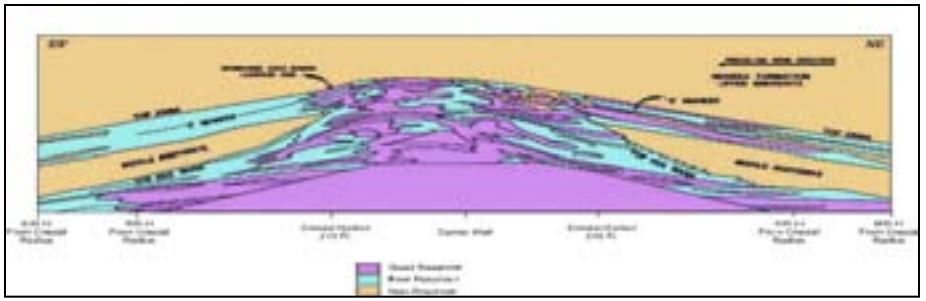
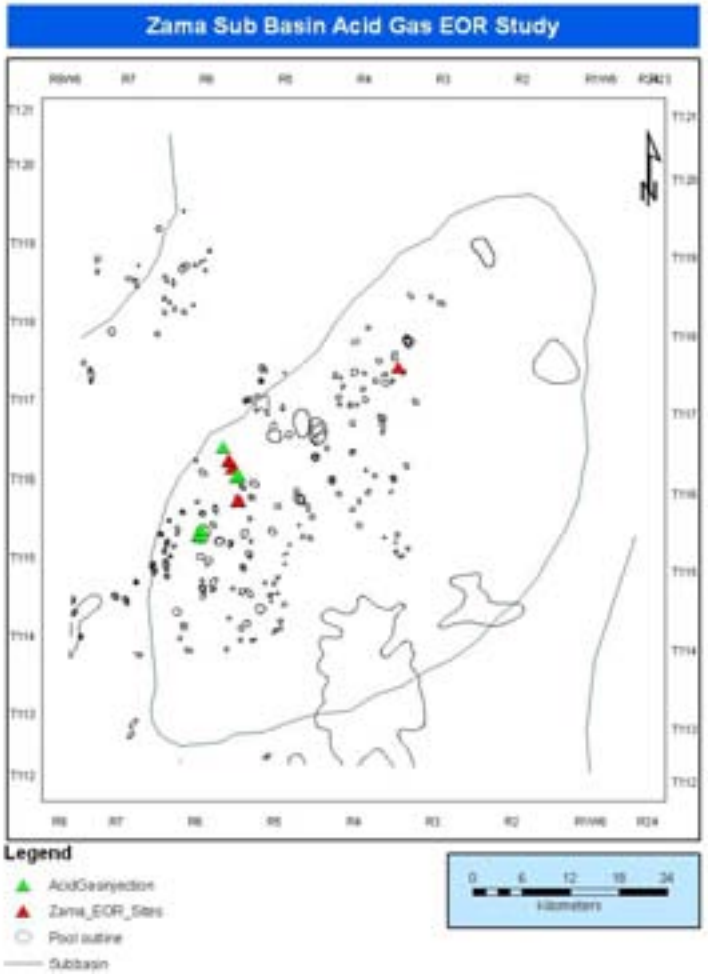
Zama Pinnacle

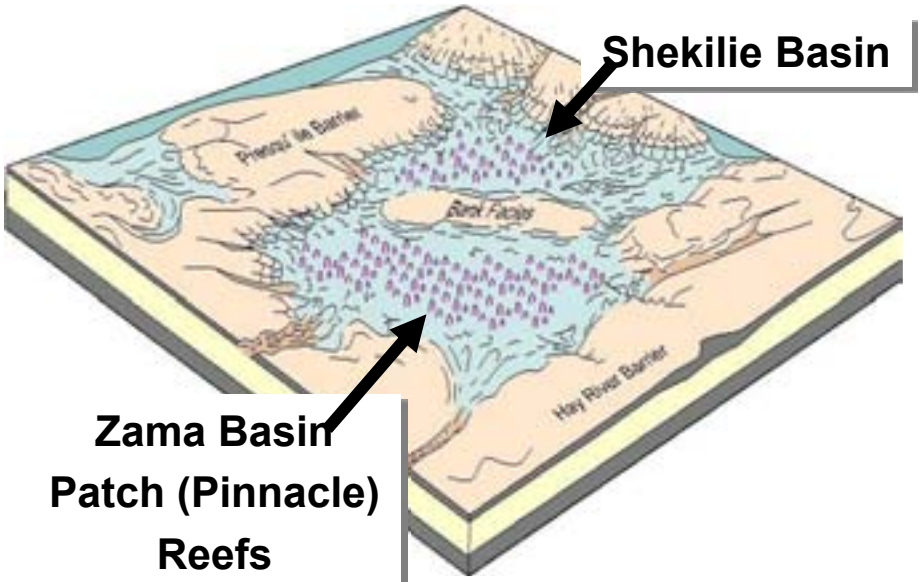
- Carbonate reservoir
- 5300 feet deep
- About 40 acres at the base (.16 Km^2)
- 400 feet tall (120 m)
- 10% average porosity
- 100–1000 md permeability
- 2100 psi initial reservoir pressure





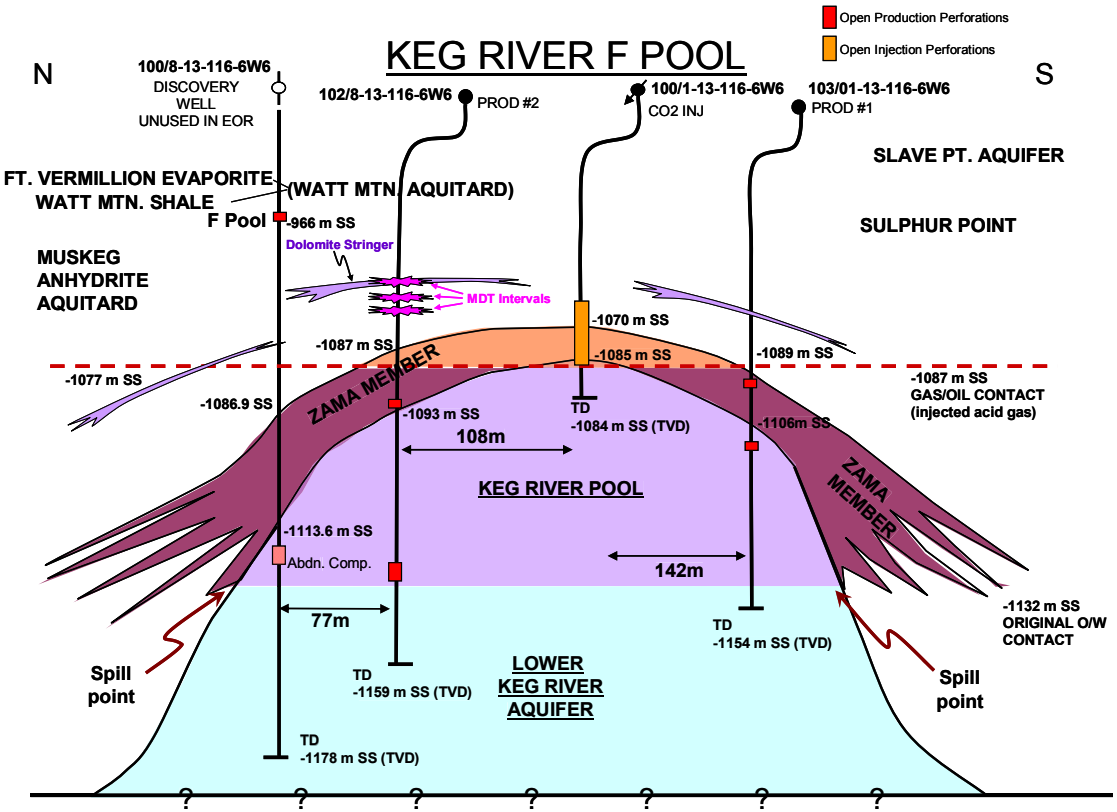
Zama Geological Setting





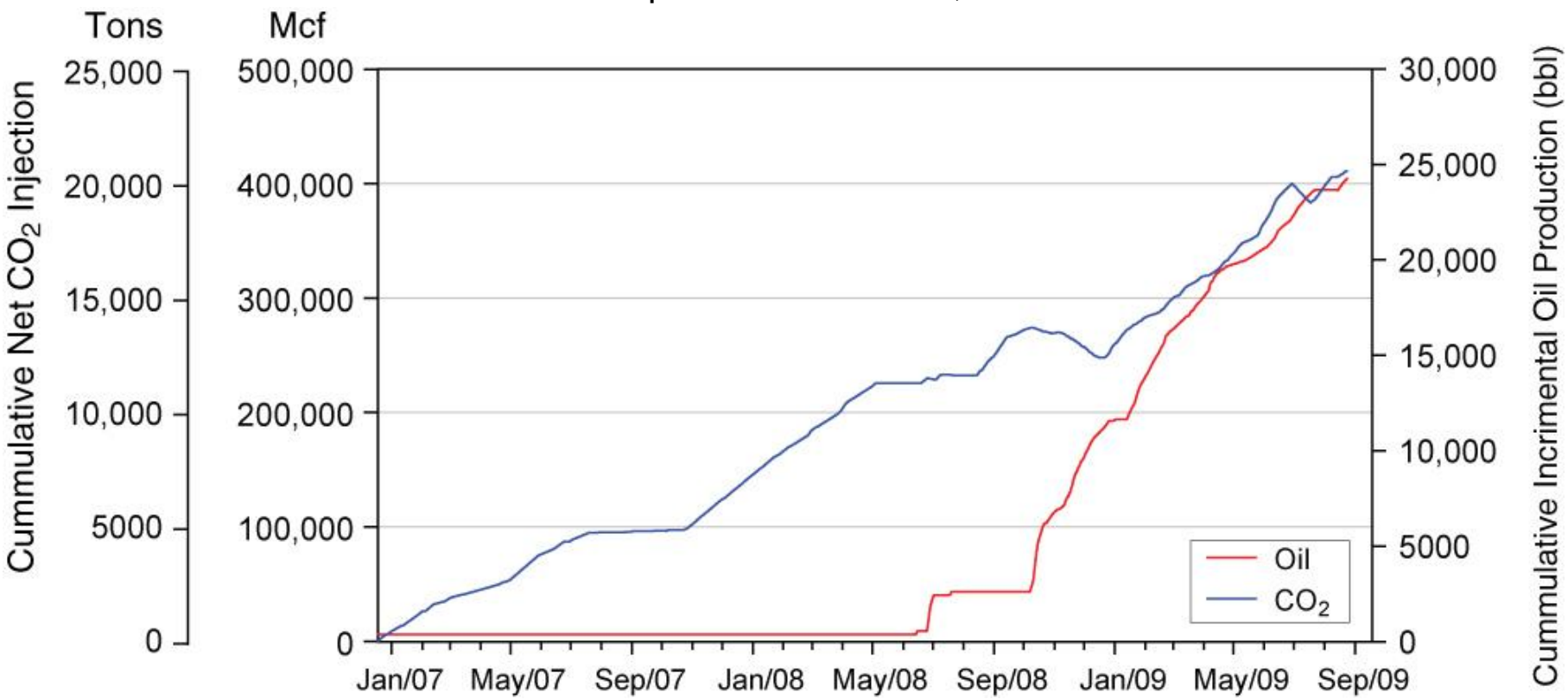
Current Pinnacle Configuration

- Top-down injection scheme through one wellbore
- Injected gas stream is approximately 70% CO_2 and 30% H_2S
- Two production wells
- Observation well completed in the Sulphur Point reservoir. Former producing unit into top of pinnacle, currently plugged to104 m above top of pinnacle.



Acid Gas Injection

- Began Injection December 15, 2006
- Average injection rate around 1 MMCF/D
- Second production well completed June 2008
- Cumulative injection over 20,000 tons
- Cumulative production over 25,000 barrels



Philosophy of Monitoring

- Maximize the use of existing data sets in an effort to characterize the baseline conditions of the site.
- Minimize the use of invasive or disruptive technologies to acquire new data.
- MVA data acquisitions will be coordinated with routinely scheduled operation activities.
- Ensure that the monitoring operations are as transparent as possible to the day-to-day field operations.

The Zama MVA program was developed using current Alberta regulatory framework for Acid Gas injection. Characterization activities were added to fully describe the system and provide confidence in the safe and secure storage of injected fluids.

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MVA Operations

Monitor the CO_2/H_2S plume through:

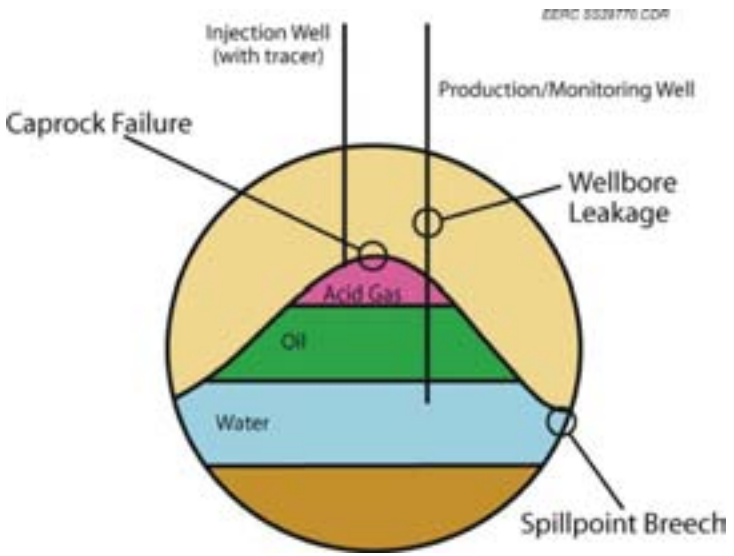
- Perfluorocarbon tracer injection.
- Reservoir pressure monitoring.
- Wellhead and formation fluid sampling (oil, water, gas).

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.
- Well bore annulus pressure measurements.



Zama Characterization Activities

Hydrogeology

Where's the gas going?

Geomechanics

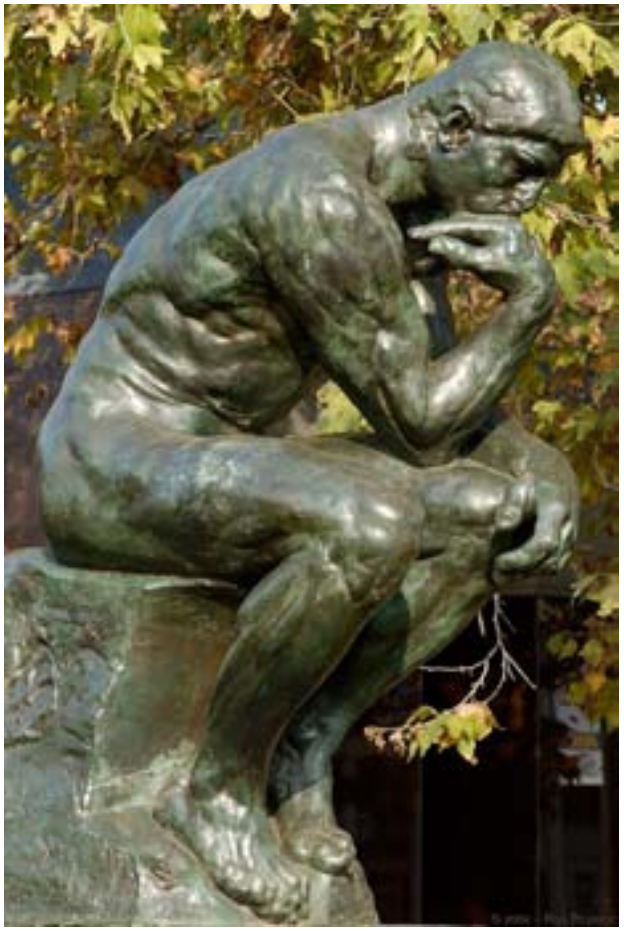
Is the container going to break?

Geochemistry

What's happening down there?

Engineering

How did you do that?

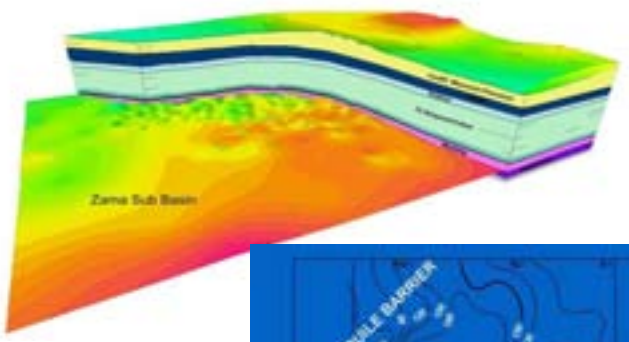


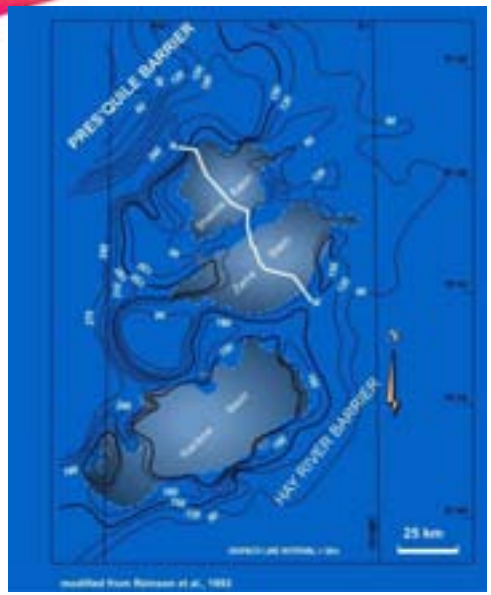
Geology and Hydrogeology Results

- Conducted to better understand the storage characteristics of regional aquifer systems and the fate of acid gas.
- Results indicate there is minimal potential for acid gas migration to shallower strata and potable groundwater.

Conclusion:

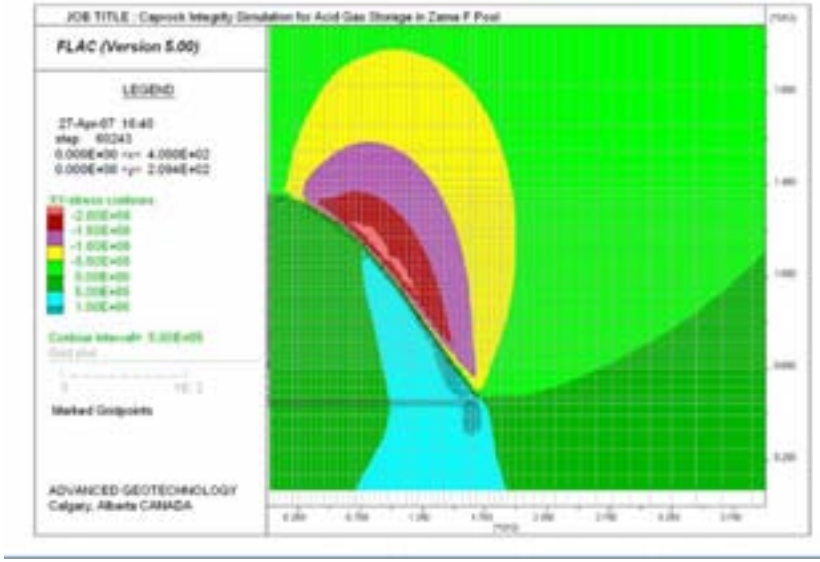
Leakage migration, should it occur, would be a very slow process (thousands of years) and would likely be limited to much less than a kilometer from the site because of dissolution, dispersion, and residual gas trapping along the migration pathway.





Mechanical Integrity

- Program elements include:
  - Evaluation of possible cap rock leakage mechanisms.
  - Triaxial and unconfined compressive strength.
  - Uniaxial pore volume compressibility.
  - Schmidt rebound hammer.
  - Minimum horizontal in situ stress orientations.
  - Vertical stress magnitude
  - Geomechanical simulation of acid gas injection.



Conclusion:

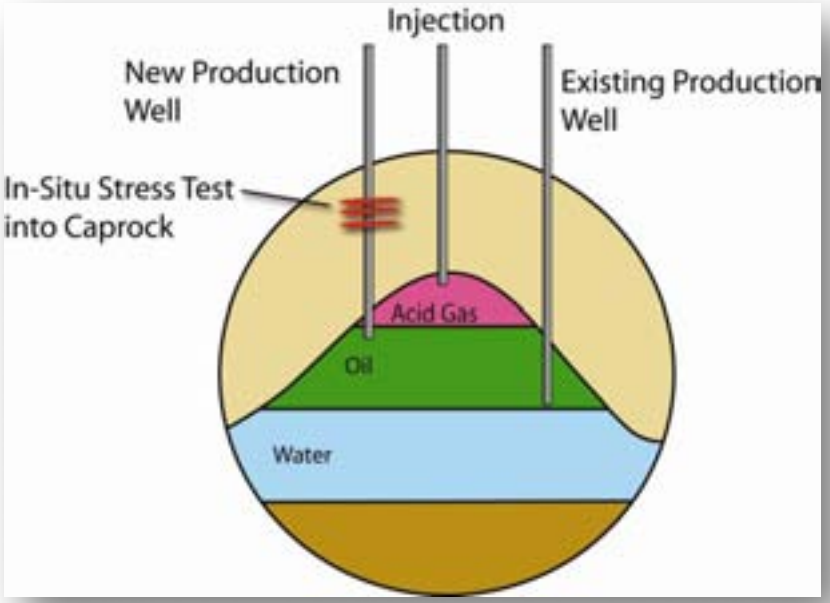
Mechanical integrity at Zama is ideal for CO_2 storage.

Mechanical Integrity (cont.)

- **Modular Dynamics Test – July 2008**
  - Performed to obtain horizontal stresses in reservoir cap rock.
  - Tested three intervals:
  - Two anhydrite
  - One dolomite stringer (encased in anhydrite)
- Unable to fracture anhydrite!
- Fracture attained in dolomite at over 5000 psi.
  - Allowable injection pressure is approximately 2100 psi.

Conclusion:

All results to date indicate that cap rock leakage potential due to a geomechanical mechanism appears to be very low.



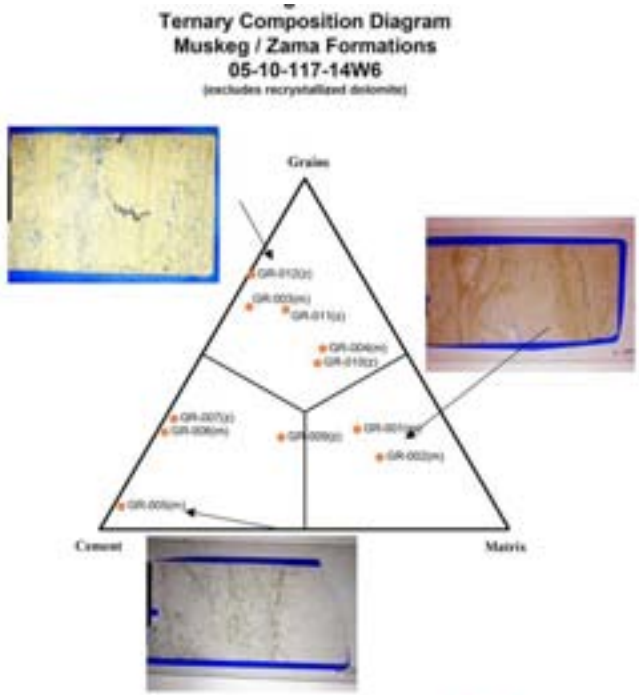
Geochemistry

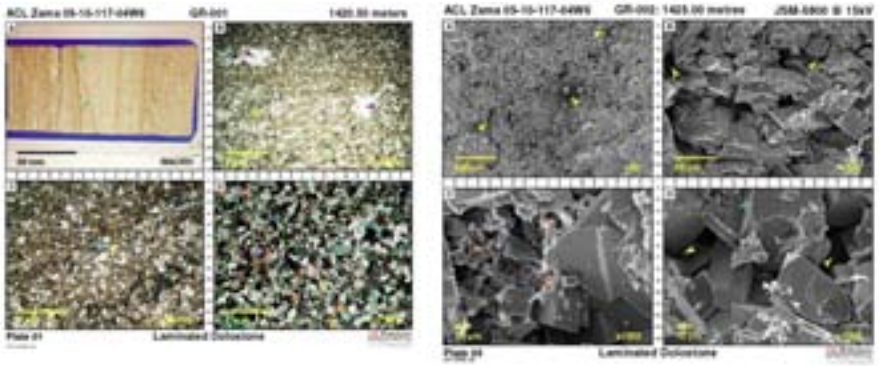
Petrophysical Evaluation
- Injection zone, cap rock, and overlying porous intervals.

Laboratory Work
- EERC acid gas soak test to determine rates of mineral reactions in carbonates and evaporites

Modeling
- To evaluate reactions in carbonates with respect to:
  - Acid gas.
  - Formation fluids.
  - Formation minerals.

Conclusion:
- ***Cap rock is very tight.***
- ***The reactivity of the reservoir is low.***
- ***The primary form of acid gas trapping is solution trapping.***





Wrap-Up Activities

- Catalog the “process” of acid gas injection from cradle to grave.
- Pressure monitoring evaluation:
  - Model historical and current pressure regimes in the injection and monitoring zones.
  - Quantify pressure difference across zones.
  - Determine flux necessary to identify leakage concern.
  - May be used to indicate leakage from the reservoir through cap rock and or along well bores.
- Evaluate and coordinate:
  - Tracer injection.
  - Sampling procedures.
  - Coring activities.
- Acid gas-phase behavior:
  - Determine what’s happening in the well bore and reservoir in a multiphase system.

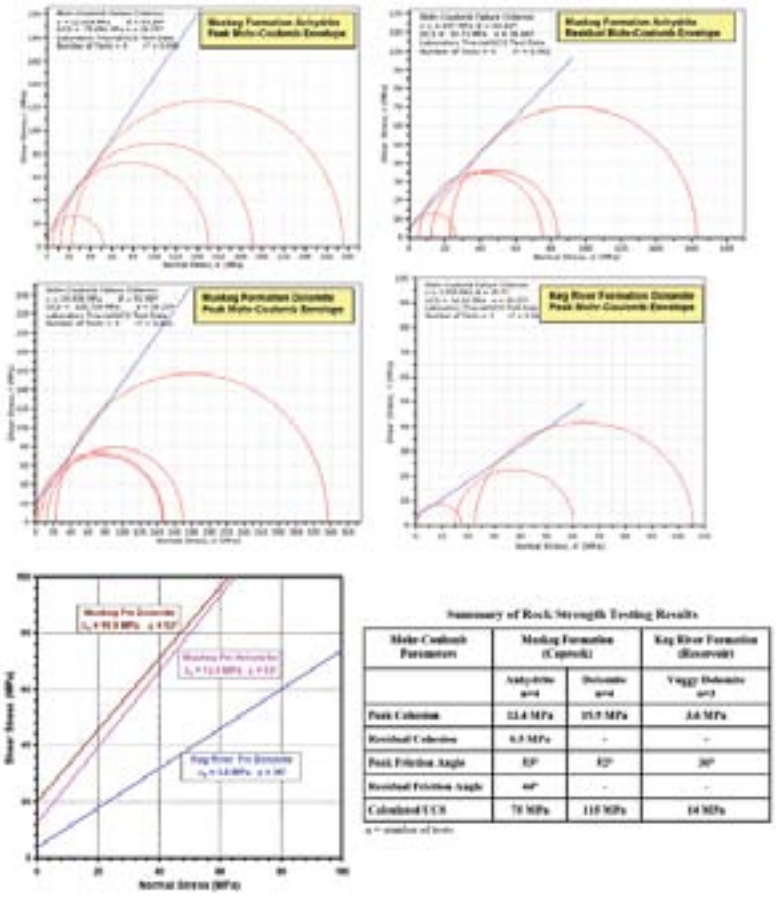
Current Activities

New laboratory work to determine:

- Capillary threshold pressure of caprock
- Threshold intrusion pressures for acid gas rich brine
- Mechanical changes before and after acid gas exposure

This work will allow field operator to determine maximum operating pressures in this regime. Work has been funded by Natural Resources Canada and Apache Canada, Ltd.

Additional funding is being sought through US DOE to conduct additional laboratory and field based activities at Zama



Summary of Rock Strength Testing Results

Mohr-Coulomb Parameters	Muskeg Formation (Caprock)		Keg River Formation (Reservoir)
	Anhydritic unit	Dolomitic unit	Vuggy Dolomitic unit
Peak Cohesion	11.4 MPa	15.5 MPa	14 MPa
Residual Cohesion	6.5 MPa	-	-
Peak Friction Angle	32°	32°	26°
Residual Friction Angle	44°	-	-
Calculated UCS	70 MPa	110 MPa	64 MPa

a = number of tests

Project Recognition

Officially recognized by the Carbon Sequestration Leadership Forum in March 2007

Zama Key Findings

Hydrogeology: ***Where's the gas going?***

Nowhere! Pinnacle geometry, excellent cap rock, and extremely slow groundwater flow preclude migration**.**

Geomechanics: ***Is the container going to break?***

No! Safe operating practices and a thorough understanding of the mechanical rock properties at Zama will help prevent this.

Geochemistry: ***What's happening down there?***

Current results indicate:

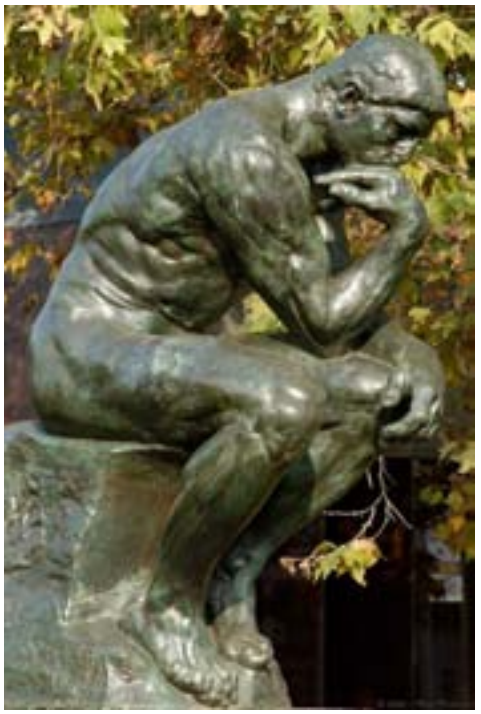
1. The reactivity of the reservoir is low.
2. The primary form of acid gas trapping was solution trapping.

Engineering: ***How did you do that?***

Comprehensive planning using proven oil field practices.

MVA: ***Could the site be considered for carbon credits?***

All characterization activities and current monitoring results indicate that the Zama Field would be an ideal candidate for consideration as a large-scale CO_2 storage location.



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