FACT SHEET FOR PARTNERSHIP FIELD VALIDATION TEST

Partnership Name	Plains CO_2 Reduction (PCOR) Partnership – Phase II
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Principal Investigator	Edward Steadman
Field Test Information: Field Test Name	 Zama Field Validation Test
Test Location	Zama City, Alberta, Canada
Amount and Source of CO_2	Tons: 20–90 tons/day (approximately 20,000 tons to date) Source: Zama Gas-Processing Plant
Field Test Partners (Primary Sponsors)	Apache Canada Ltd. Alberta Energy and Utilities Board (EUB), Natural Resources Canada

Summary of Field Test Site and Operations:

The Zama Oil Field

A pinnacle reef structure is being used to demonstrate the efficiency of simultaneous CO_2/H_2S sequestration and enhanced oil recovery. The Zama oil field in northwestern Alberta (Figure 1) covers an area of about 300,000 acres (1200 km^2) in the Middle Devonian Zama subbasin (Figure 2). The sedimentary succession in the Zama subbasin consists, in ascending order from the Precambrian crystalline basement to the surface, of Middle and Upper Devonian carbonates, evaporites and shales, Mississippian carbonates, and Lower Cretaceous shales overlain by Quaternary glacial drift unconsolidated sediments (Figures 3 and 4).

Oil production is primarily from reservoirs in pinnacle reefs of the Middle Devonian Keg River Formation (Figure 3). These reef buildups were formed in a lagoon partially surrounded by carbonate banks and fronted by the Presqu'ile barrier to the west (Figure 2). To date, over 800 pinnacles have been discovered in the Zama subbasin. The pinnacles, on average, are about 40 acres (0.16 km^2) in size at the base and about 400 ft (120 m) high. They typically consist of dolomite of variable porosity and permeability and are overlain by anhydrite of the Muskeg Formation. While some Keg River pinnacle reefs have grown directly on the underlying low-permeability Lower Keg River carbonate platform (Figure 3), resulting in hydraulic isolation of the individual pinnacle reservoirs, others rest on higher-permeability Keg River bank facies which hydraulically connects several pinnacles, resulting in pressure support from an active water drive.

Reservoir Characterization

The F Pool was discovered in 1967 and brought on production in February of that year. A pressure/volume/temperature (PVT) sample was taken in October of 1967 by the Hudson's Bay Oil and Gas Company Limited and analyzed by Core Laboratories in November of 1967 (Apache Canada Ltd., 2003). The original reservoir pressure was recorded as 2095 psig (14,447 kPa) at datum depth of approximately 5000 ft (1500 m) mean sea level. By November of 1968, special core analysis was conducted on core samples taken during drilling of the 11–25 well (Apache Canada Ltd., 2003). Routine core analysis was performed on the 8-13-116-6W6 discovery well. Cumulative production has been approximately 1.1 million barrels (stb) oil (176,100 m^3), 533 million ft^3 gas (15 million m^3), and 500,000 stb water (70,000 m^3) since inception. As a secondary recovery effort, a brief water injection period was undertaken where approximately 2.3 million stb (366 thousand m^3) was injected into the pinnacle.

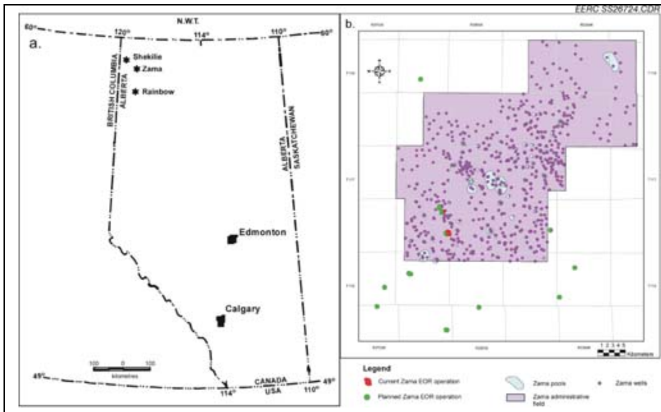


Figure 1. Location of the acid gas enhanced oil recovery (EOR) project at Zama: a) Keg River hydrocarbon fields in northern Alberta (Apache Canada Ltd., 2003) and b) the Apache Canada Ltd. Zama–Keg River acid gas EOR sites in the Zama oil field. Well locations shown are those where the Keg River Formation was penetrated.

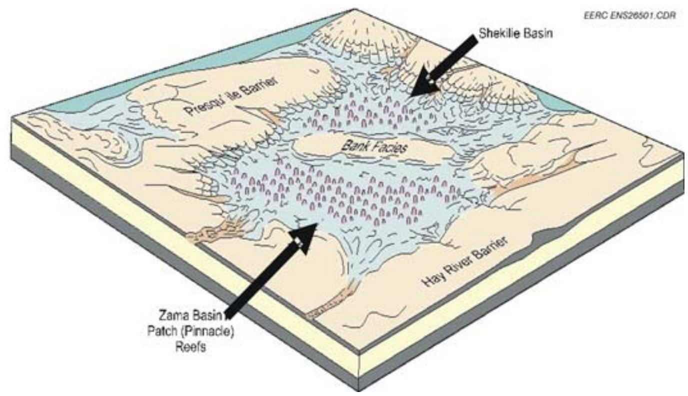
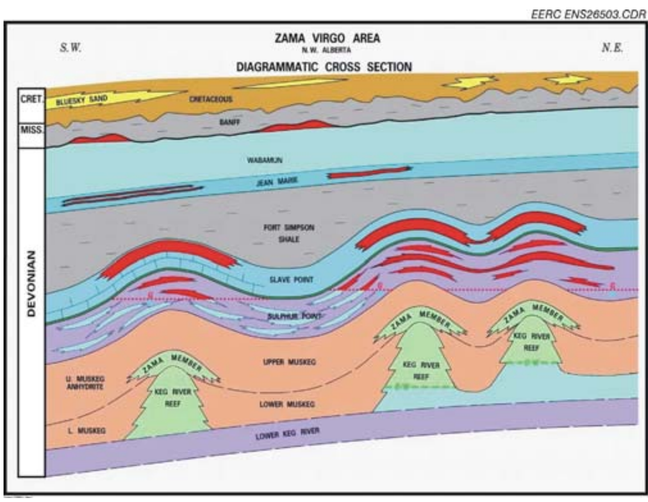


Figure 2. Schematic block diagram showing the Zama and Shekilie subbasins in northern Alberta.



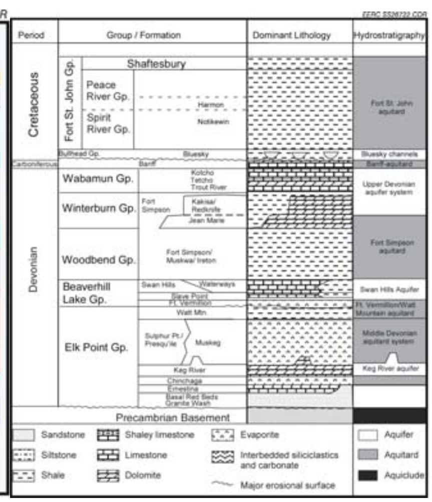


Figure 3. Schematic cross section illustrating the sedimentary succession in northwestern Alberta. Also shown are oil and gas occurrences.

Figure 4. Stratigraphic and hydrostratigraphic delineation and nomenclature as well as general lithology for the northern part of the Alberta Basin.

Current Estimated Conditions

During the 1990s, the F Pool was shut in. This resulted in reservoir pressure being recharged as a result of water injection activities in nearby Keg River pinnacles. Current reservoir pressure is below the initial reservoir pressure of 2095 psig (14,447 kPa) in accordance with the guidelines established by the Alberta EUB requirements before acid gas injection was initiated. A summary of initial reservoir conditions is given in Table 1.

Table 1. Initial Conditions

Play Type	Keg River Pinnacle Reef
Initial Reservoir Pressure	2095 psi (14,447 kPa)
Reservoir Temperature	160°F (71°C)
Initial Water Saturation	15% (from logs)
Porosity	10% (from logs)
Initial Gas:Oil Ratio	52 m^3/m^3
Initial Formation Volume Factor	1.183 r vol/std vol
Bubble Point Pressure	1275 psi (8791 kPa)
American Petroleum Institute Gravity	35.2 API
Calculated Original Oil in Place (OOIP)	2.2 million bbl 344,000 m^3 (volumetric using 3-D seismic data)
Calculated OOIP	3.5 million bbl 557,000 m^3 (material balance)

Research Objectives:

Work Plan

The overall purpose of these activities, from the perspective of the PCOR Partnership, is to create a best practices manual that outlines a set of guidelines for measurement, mitigation, and verification (MMV) operations at an oil production site that is using acid gas as a tertiary recovery mechanism for the purposes of EOR and CO_2 sequestration. One important factor is the effect of H_2S concentrations on EOR, CO_2 sequestration capacity, and MMV techniques. Research activities related to acid gas injection will be conducted at the Zama F Pool in the Zama oil field, Alberta. The goal of the PCOR Partnership's activities at the Zama site is to develop and implement an MMV strategy that establishes the integrity of the Zama pinnacle reefs for CO_2-rich acid gas storage. This will be accomplished by carrying out the following activities at the reservoir, local, and regional/subbasin scales:

- Assessment of baseline geology
- Assessment of rock mineralogy and composition of formation water
- Assessment of hydrogeological system
- Assessment of mechanical rock properties and stress regime
- Assessment of geochemical interactions between formation and injected fluids and reservoir rock and cap rock
- Assessment of wellbore integrity and leakage potential

Summary of Modeling and MMV Efforts:

Modeling

The Zama Keg River F Pool simulation study was conducted by the University of Regina in 2005 with the aim of investigating several injection/production strategies using an available nearby CO_2 gas source. An 8-component Peng–Robison Equation of State was tuned based on PVT lab data and used to simulate the reservoir fluid properties in an effort to better predict CO_2–oil-phase behavior in the pinnacle. Injecting from the top of the formation and producing from the bottom, using the existing vertical wells, gave higher oil recovery and needed less injection pressure. Prediction scenarios for drilling a new well on the other side of the pinnacle gave the highest recovery and improved the sweep efficiency as compared to the case of reentering the existing wells horizontally. In general, most of the predictive scenarios indicated that about 2 months of continuous CO_2 injection were necessary to reach the minimum miscibility pressure and initiate production.

In addition to the petrophysical modeling activities that were conducted to predict reservoir performance, geomechanical and geochemical models will be developed for the site. A geomechanical model will be created based on the unique geometry of the pinnacle and the contrasting anhydrite and dolomite lithologies. This model will be used to predict the ultimate mechanical integrity of this system and the expected response to acid gas injection. Geochemical modeling will be conducted to determine the ultimate fate of injected gas. Rates of mineralization will be evaluated with respect to a multiphase system and will be used to predict the long-term mobility of CO_2 in the subsurface.

As a means of predicting leakage from the reservoir, an evaluation of historical and current reservoir pressure is currently ongoing. Reservoir pressures are being modeled in the Keg River reservoir and overlying Slave Point reservoir to quantify the flux over time and correlate it to injection and production profiles. If wellbore leakage were to occur, an increase in pressure in a porous reservoir should be detectable. This study will result in a greater understanding of wellbore leakage scenarios and will make recommendations into the pressure difference needed to determine that leakage is occurring.

MMV Efforts

The techniques listed below are being employed over the course of the 4-year project to monitor the effects of acid gas injection at the Zama Field demonstration site. The preinjection state of each of these parameters will be determined either by currently available data or field activities to acquire new data.

Measurement Technique	Measurement Parameters	Application
Introduced and Natural Tracers	Travel time Partitioning of CO_2 into brine or oil Identification sources of CO_2	Tracing movement of CO_2 in the storage formation Quantifying solubility trapping Tracing leakage
Water Composition	CO_2, HCO_3, CO_3^{2-} Major ions Trace elements Salinity	Quantifying solubility and mineral trapping Quantifying CO_2–water–rock interactions Detecting leakage into shallow groundwater aquifers
Subsurface Pressure	Formation pressure Annulus pressure Groundwater aquifer pressure	Control of formation pressure below fracture gradient Wellbore and injection tubing condition Leakage out of the storage formation
Well Logs	Brine salinity Sonic velocity CO_2 saturation	Tracking CO_2 movement in and above storage formation Tracking migration of brine into shallow aquifers Calibrating seismic velocities for 3-D seismic surveys

Accomplishments to Date:

- Experimental design package
- National Environmental Policy Act compliance document
- Site Health and Safety Plan
- Regulatory Permitting Action Plan
- Outreach action plan
- Sampling protocols
- Tracer injection (February 2008)
- Baseline sampling
- Initiation of acid gas injection (December 2006)
- Geological evaluation
- Hydrogeological evaluation
- Wellbore integrity evaluation
- Carbon Sequestration Leadership Forum Recognition (March 2007)
- In situ stress test (July 2008)

Injection of acid gas commenced in December of 2006 at an average rate of 1 million cubic feet per day (60 tons). The average injected gas composition consists of 70% CO_2 and 30% H_2S, with minor traces of hydrocarbon gases. Oil production has been slow to develop in the reservoir, and the field operator is taking steps to understand the issues and expedite field activities to find a solution. During the summer of 2008, the production well in the reservoir was recompleted in an attempt to “find” the swept oil column. This technique was successful for a brief period after the well came back online; however, oil production quickly ceased and was replaced by production of injected gas. This aspect of the project is still being evaluated with respect to techniques to maximize production. Figure 5 illustrates the injection and production profile for the project.

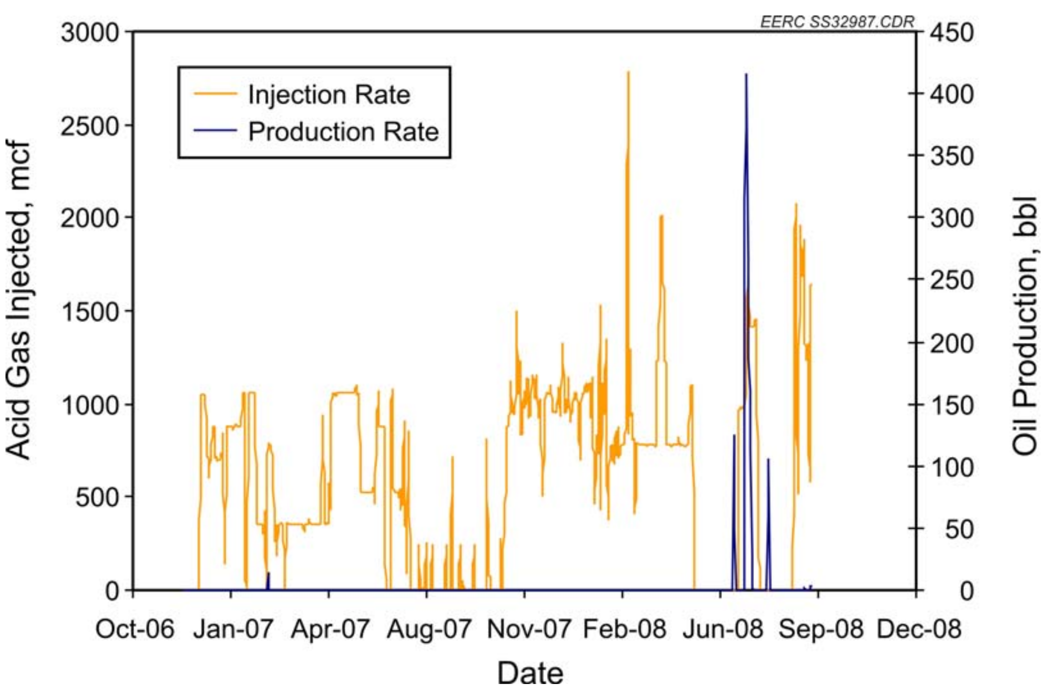


Figure 5. Injection profile from the Zama acid gas EOR, CO_2 sequestration, and monitoring project.

Recent activities have also focused on further characterization of the overall strength of the cap rock and the likelihood of failure. In July 2008, an in situ stress test was conducted on the Muskeg anhydrite formation that acts as the sealing formation for the Keg River reservoir. The test utilized a Schlumberger’s Modular Formation Dynamics Tester wire line tool to inject approximately 5 liters of water into the formation to determine the maximum horizontal stress of the formation. Three intervals were tested in anhydrite and dolomite lithologies of the cap rock at pressures exceeding 5000 psi. This represents a pressure of approximately 3000 psi above the permitted injected pressure at the site. Preliminary results confirm that the cap rock is extremely competent as evidenced by the inability to fracture the anhydrite intervals tested. The third interval tested was a dolomite stringer (encased in anhydrite) within the cap rock that was fractured at the previously mentioned pressure. Final results will be used in the geomechanical modeling activities to better understand the maximum injection thresholds of the pinnacle.

Summarize Target Sink Storage Opportunities and Benefits to the Region:

The PCOR Partnership is working with Apache Canada Ltd. to determine the effect of acid gas injection for the purpose of simultaneous acid gas disposal, sequestration of CO_2, and EOR. Apache Canada Ltd. is carrying out the injection process and subsequent hydrocarbon recovery, while the Energy & Environmental Research Center is conducting CO_2 MMV activities at the site. This is a unique opportunity to develop a set of MMV protocols for CO_2 sequestration for a commercial-scale hydrocarbon recovery project.

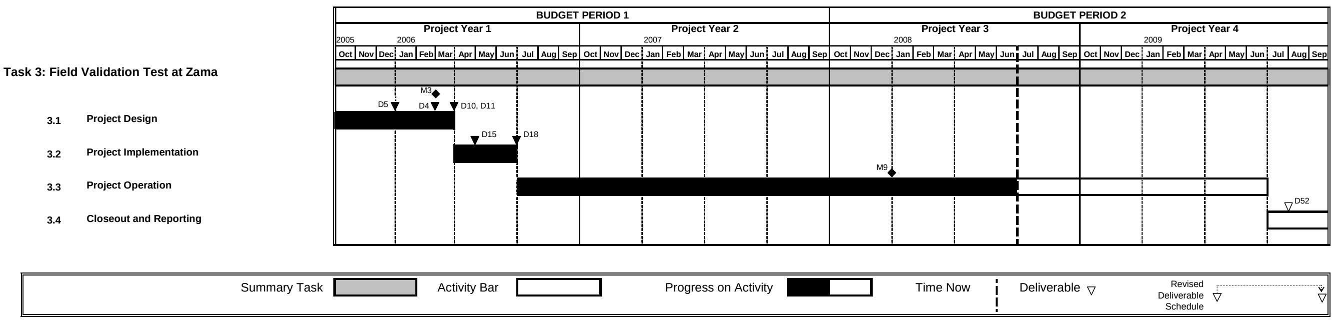
The validation test conducted in the Zama Field of Alberta is evaluating the potential for geological sequestration of CO_2 as part of a gas stream that also includes high concentrations of H_2S. The results of the Zama activities will provide key insights regarding the impact of high concentrations of H_2S (20% to 40%) on sink integrity (i.e., seal degradation), MMV, and EOR success within a carbonate reservoir. The acid gas is sourced at the Zama gas-processing plant and is being injected into a pinnacle reef, the F Pool, at a depth of approximately 4900 feet (1500 meters).

The activities at Zama will address two critical environmental issues. First is the reduction of anthropogenic CO_2. This project will sequester up to 36,500 metric tons of CO_2 annually. Second, the Zama Acid Gas Miscible Flood Project is injecting the entire acid gas stream into nearby Keg River Formation pinnacles. This will effectively use all of the acid gas handled at Zama as a miscible fluid and has enabled the shutdown of the Claus unit, eliminating the accumulation of elemental sulfur. With respect to EOR, it is anticipated that the acid gas miscible flood will ultimately yield between 180,000 and 276,000 barrels of incremental oil recovery each year.

Cost:	Field Project Key Dates: See Gantt Chart below.
Total Field Project Cost: $7,053,826 **U.S. Department of Energy (DOE) Share: $2,689,485 38%** **Non-DOE Share: $4,364,341 62%**	**Baseline Completed: December 1, 2006** **Drilling Operations Begin: Existing wells that have been completed are being utilized for injection while a new production well was completed in 2005.** **Injection Operations Begin: December 15, 2006** **MMV Events: The monitoring well above the injection zone has been sampled and shows no evidence of increase in pressure and acid gas concentrations. This is a positive indication of no leakage.**

Field Test Schedule and Milestones (Gantt Chart):

- Experimental Design Package due February 28, 2006 – completed on schedule
- National Environmental Policy Act compliance document due February 28, 2006 – completed on schedule
- Site Health and Safety Plan due March 31, 2006 – completed on schedule
- Regulatory Permitting Action Plan due March 31, 2006 – completed on schedule
- Outreach Action Plan due April 30, 2006 – completed on schedule
- Sampling Protocols due June 30, 2006 – completed on schedule
- Regional Technology Implementation Plan due July 31, 2009



Key for Phase II Deliverables ▼		Key for Phase II Milestones ◆
D4 Zama Field Validation Test Site – Experimental Design Package	D15 Zama Field Validation Test Site – Outreach Action Plan	M3 Zama Field Validation Test Site – Experimental Design Package Completed
D5 Zama Field Validation Test Site – NEPA Compliance Document	D18 Zama Field Validation Test Site – Sampling Protocols	M9 Progress of Geomechanical Evaluation Reported
D10 Zama Field Validation Test Site – Site Health & Safety Plan	D52 Zama Field Validation Test Site – Regional Technology Implementation Plan	
D11 Zama Field Validation Test Site – Regulatory Permitting Action Plan		

Additional Information

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 in the project.

2. EOR – Lessons to be applied to other storage reservoirs. Acid gas used for EOR, if successful, which is increasingly being produced as deeper sour gas pools are produced, could be used for additional acid gas EOR projects, thereby increasing energy supplies from remote, dispersed, and smaller oil pools that will not justify major CO_2 infrastructure.

3. Depleted oil and gas field viability – The utilization of depleted oil fields for sequestration purposes will be validated throughout the life of this project. In addition, as recovery is from carbonate pinnacle reefs, using a different strategy than in the case of reservoirs of large lateral extent, if successful, could be applied to other similar reservoirs elsewhere.

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 new 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 in situ conditions.

The following reports have been completed through the project since inception:

- Acid Gas–Brine Static Partitioning Study
- A Study of the Reservoir Condition Drainage and Imbibition Permeability
- Displacement Characteristics of Supercritical Carbon Dioxide in the Zama Area, Sulfur Point Formation
- Experimental Study of CO_2 and H_2S Partitioning in a Brine-Saturated Porous Medium
- Evaluation of Zama Field Wellbore Integrity, Part I
- Evaluation of Zama Field Wellbore Integrity, Part II (Evaluation of Leakage Potential by Well)
- Regional-Scale Geology and Hydrogeology of Acid-Gas
- Enhanced Oil Recovery in the Zama Oil Field in Northwestern Alberta, Canada
- Reservoir Condition CO_2-Brine Drainage and Imbibition Relative Permeability Displacement Characteristics in the Zama Area, Muskeg Anhydrite Formation (Cap Rock)
- Uniaxial, Triaxial, and Elastic Properties Determinations on Samples from the Zama Field, Northwest Alberta
- Evaluation of Deep Wellbore Integrity In the Zama Field
- Petrographic and Reservoir Quality Assessments Vol. I
- Petrographic and Reservoir Quality Assessments Vol. II
- Petrographic and Reservoir Quality Assessment, Dolostone and Limestone, Muskeg and Zama
- Formations 05-10-117-04W6

References

Apache Canada Ltd., 2003, Resource application for approval to implement an enhanced oil recovery scheme in the Zama Keg River F Pool using acid gas as a miscible flooding solvent: EUB Guide 65, Schedule 1.