Summary of Results from the EPRI Workshop on Costs of CO2 Transport and Storage

Prepared for:
Workshop on Future Large CO2 Compression Systems

Sponsored by:
U.S. DOE Office of Clean Energy Systems, EPRI, and NIST

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March 30, 2009

Outline of Presentation

- Background
- EPRI Workshop Session #2: Cost of Compression and Transport
- Lessons Learned from the Gas Storage Industry

Background

The Electric Power Research Institute (EPRI), with organizational assistance from Advanced Resources International, Inc. (ARI), sponsored the recent "Workshop on Costs of CO2 Transport and Storage". The Workshop was held in Palo Alto, California on March 17th and 18th, 2009.

The purpose of the Workshop was to gain up-to-date perspectives on: (1) recent experiences and cost information for transporting CO2 from a power plant gate to a geological storage site; (2) updates on the costs of installing and operating a CO2 storage facility; (3) updates on the costs of implementing a comprehensive CO2 storage monitoring system; and, (4) the need for and costs of a reliable remediation plan for addressing CO2 injection well or other problems associated with CO2 storage.

Background

The workshop was organized according to six topics, as follows:

- Session #1: Integrated Capture, Transport and Storage Modeling
- Session #2: Cost of Compression and Transportation
- Session #3: Cost of CO2 Storage Site Selection, Appraisal and Modeling
- Session #4: Cost of Designing, Constructing and Operating CO2 Storage
- Session #5: Cost of CO2 Storage Monitoring
- Session #6: Cost of CO2 Storage Remediation and Mitigation

The highlights from the various presentations and the subsequent extensive participant discussion during the Workshop have been documented in a Summary Report for EPRI.

Session #2: Cost of Compression and Transportation
Tuesday, March 17, 2009, 10:30AM – 12:00 Noon

The purpose of this second workshop session was to discuss and set forth methodology for calculating the capital and operating costs of CO_2 transportation systems, including taking a look at advances in CO_2 compression technology that may influence future costs.

Of particular interest was the discussion on: (1) the economies of scale for CO_2 transportation; (2) how incorporation of special features (e.g., river crossings) affects costs; and, (3) how to make optimum trade offs between size of pipe and booster compression.

Two presentations were provided on these important topics during Session #2, followed by Open Discussion:

- Costs of CO_2 Transportation Systems (Kinder Morgan), K. Havens (45 min)
- Advanced CO_2 Compression Systems (RAMGEN), P. Baldwin (15 min)
- Open Discussion w/K. Havens as Discussion Leader (25 min)

EPRI Workshop

March 17, 2009

Costs of CO_2 Transmission Systems

Ken Havens

Director of Source and Transportation

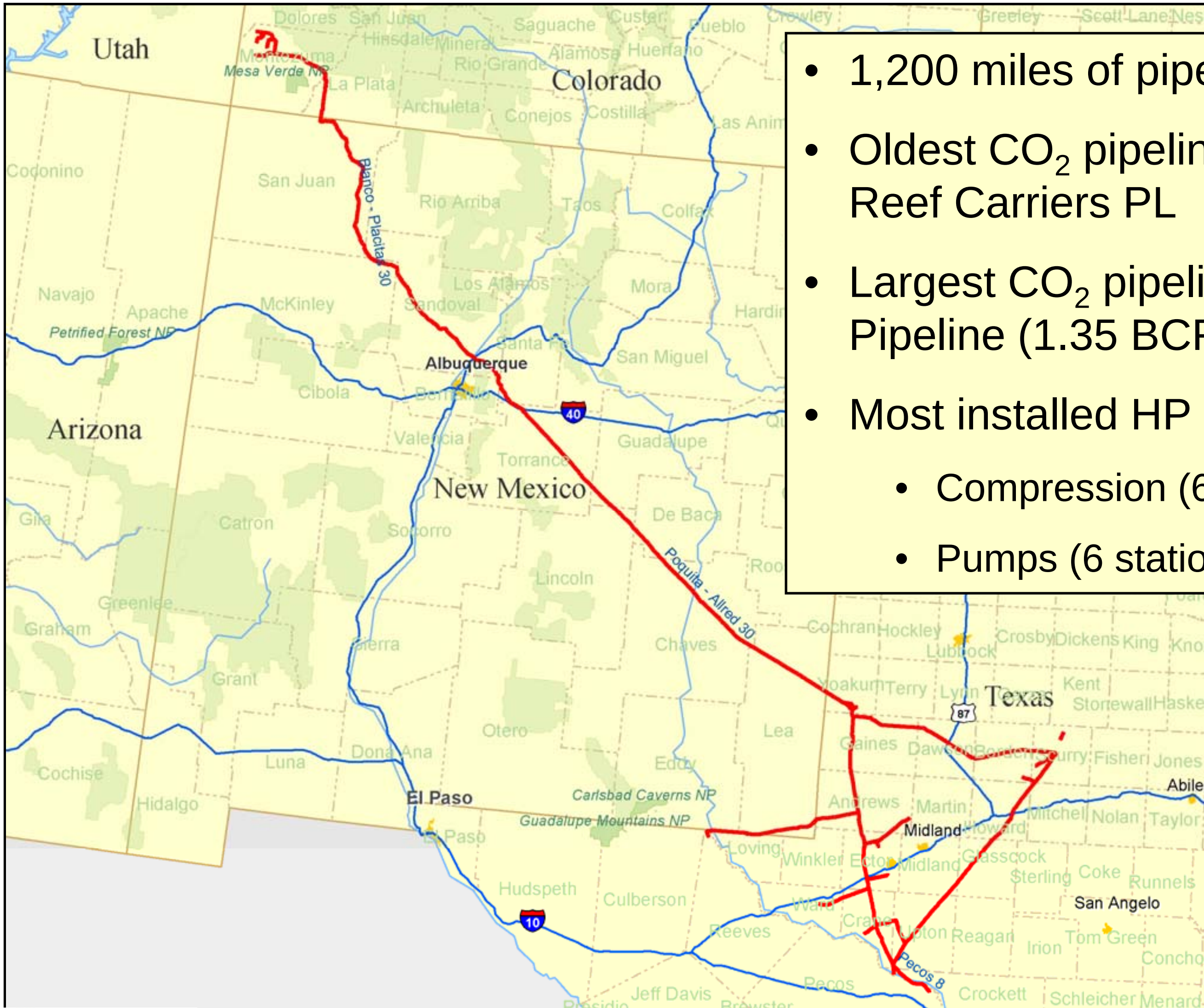
KINDER MORGAN
CO2 COMPANY, L.P.

Domestic CO_2 Industry Operational Achievements

Over the past 30+ years, the oil and gas industry has:

- Produced and safely transported more than 11 TCF of CO_2 from 7 sources.
  - 1.2 TCF of which came from sources that otherwise would have been vented.
- Constructed over 3100 miles of CO_2 mainline pipeline systems.
- Produced in excess of 1.2 billion barrels of incremental oil.
- Secured operating practices of:
  - Corrosion management, Metallurgies, Elastomers
  - Separation, Dehydration and Hydrocarbon extraction
  - Compression/pumping
  - Injection and production well completion and operation

KMCO$_2$ FACILITIES



- 1,200 miles of pipeline
- Oldest CO_2 pipeline (1974), Canyon Reef Carriers PL
- Largest CO_2 pipeline 30” OD Cortez Pipeline (1.35 BCFD)
- Most installed HP
  - Compression (6 stations) 70,000
  - Pumps (6 stations) 40,000

CO_2 vs Gas Pipelines

- Use same steel metallurgy as Natural Gas Pipelines
  - Keep CO_2 dry
- Higher operating pressures
  - Gas – 600 psig to 1200 psig
  - CO_2 – 2000 to 3000 psig
  - Why? Maintain CO_2 in dense phase (>1300 psig) to allow pumping rather than compression.
- Pumps rather than compression
  - Energy savings
- CO_2 - PHMSA regulated under CFR Part 195, “Transportation of Hazardous Liquids by Pipeline”

Environmental Health and Safety

- CO_2 pipelines are protected from damage by
  - 24 hour monitoring by Control Center
  - Membership in statewide one-call
  - Compliance with Common Ground Alliance Best Practices
  - Patrolled by air 26 times per year
- CO_2 pipelines are protected from corrosion by:
  - Annual pipe to soil survey of pipeline
  - Five year cycle of Close Interval Surveys
  - Assessments of High Consequence Areas under Pipeline Integrity Management program

Pipeline Integrity Management

- Assess, evaluate, repair and validate the integrity of the pipeline systems to meet or exceed the requirements of CFR Part 195.452, Pipeline Integrity Management
- Worked with PHMSA to utilize External Corrosion Direct Assessment to assess High Consequence areas
- Worked with high-resolution Magnetic Flux Tool manufacturers to develop pig to run in CO_2
- Completed high-resolution Magnetic Flux Tool run in November 2007 on the oldest CO_2 PL

CRC Pipeline Hydrotest

- 36 days out of service
- Tested 131 miles of 16” pipeline
- Raised MOP 1792 to 2025

CO_2 Pipeline Specifications

Following are specifications for CO_2 pipeline quality CO_2.

9.1 Specifications. The Product delivered by Seller or Seller's representative to Buyer at the Delivery Point shall meet the following specifications, which herein are collectively called "Quality Specifications":

(a) **Product.** Substance containing at least ninety-five mole percent (95%) of Carbon Dioxide.

(b) **Water.** Product shall contain no free water, and shall not contain more than thirty (30) pounds of water per mmcf in the vapor phase.

(c) **Hydrogen Sulfide.** Product shall not contain more than twenty (20) parts per million, by weight, of hydrogen sulfide.

(d) **Total Sulfur**. Product shall not contain more than thirty-five (35) parts per million, by weight, of total sulfur.

(e) **Temperature.** Product shall not exceed a temperature of one hundred twenty degrees Fahrenheit. (120°F).

(f) **Nitrogen.** Product shall not contain more than four mole percent (4%) of nitrogen.

(g) **Hydrocarbon**s. Product shall not contain more than five mole percent (5%) of hydrocarbons and the dew point of Product (with respect to such hydrocarbons) shall not exceed minus twenty degrees Fahrenheit (-20oF).

(h) **Oxygen.** Product shall not contain more than ten (10) parts per million, by weight, of oxygen.

(i) **Other.** Product shall not contain more than 0.3 (three tenths) gallons of glycol per MMcf and at no time shall such glycol be present in a liquid state at the pressure and temperature conditions of the pipeline.

KINDER MORGAN CO2 COMPANY, L.P.

Pipeline Costs

100 miles of 24" pipe line (500 MMCFD)	
• Flat Dry Land	$120,000,000
• Mountains	$204,000,000
• High Populated Urban	$250.000.000
• Offshore 150 – 200 ft.	$1,680,000,000
Compression - 5,000 HP Electric Drive	$10,000,000
Pumps - 4,000 HP Electric Drive	$8,000,000
Measurement Station (500 MMCFD)	$500,000

KINDER MORGAN CO2 COMPANY, L.P.

Lessons Learned from the Gas Storage Industry

Prepared for:

EPRI Workshop on Costs of CO2 Transport and Storage

Prepared by:

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Palo Alto, CA
Stanford Park Hotel
March 17-18, 2009

What Lessons Have We Learned From the Gas Storage Industry?

The oldest U.S. gas storage site is the Zoar field, a depleted gas reservoir located south of Buffalo, NY. It has been in operation since 1916 and is still in use today.

The U.S. has 400 active underground gas storage facilities, with 43 of these aquifers, holding 8.4 trillion cubic feet (140 million metric tons of CH_4, equal to 380 million metric tons of CO_2). Annually, 3 to 4 Tcf of natural gas are injected and withdrawn, equal to 160 million metric tons of CO_2.

Worldwide there are 634 underground gas storage facilities:

- 83.5% in depleted oil/gas fields
- 12.6% aquifers
- 3.9% salt caves/abandoned mines

What Lessons Have We Learned From the Gas Storage Industry?

- Lesson #1. The Operation of Underground Natural Gas Storage Has Been Extremely Safe.
- Lesson #2. Improperly Selected Storage Sites With Caprock Problems Have Led to Gas Leakage.
- Lesson #3. Extensive Use of Monitoring Wells Is Used to Detect Loss of Gas from the Storage Structure.
- Lesson #4. Improper Well Plugging, Defective Casing and Poor Cement Placement Can Lead to Gas Leakage.
- Lesson #5. It May Be Possible to Improve the Injectivity of Lower Permeability Storage Sites With “New and Novel” Well Stimulation Technologies.