CO₂ EOR – Quite a Story
...and a couple of tall tales
US EOR Production - CO₂ is playing a greater role

Reference: O&GJ
CO$_2$ Source and Transportation
Business has doubled in size since 2003

Sources: KM estimates, Oil and Gas Journal, EIA, XOM, Dakota Gasification, DRI
Domestic crude production peaked October 1970

- Production replacement ratio >1.0 became essential
- Production from large oil fields were declining
- Large Fields became the focus of Technology Development
College Days – The Missouri School of Mines

Who would have thought...

SACROC, 62' under CO2 miscible, h = 230'
160-46900', Deep. Has been successfully H2O flood (backward).
$S_{OR} = 24\% = 106 \times 10^4 \text{ BBLs}$
Lean Gas - have to inject at 5000 psi
Enriched - would work, but was expensive
CO2 miscible pressure in reservoir was 1850
Pressure in res (2100)
CO2 injection wells inverted 9 spot
20% PV slug
Press = 2400 psi in 1976
230 mile 16" Pipeline of gas CO2
A pivotal moment in time

The model was they built with heterogeneities; this indicated that CO₂ was forced out and contacted more oil. 4% more recovery.

Advantages:
- Low pressure
- Miscible displacement
- Ed = 95-98% (Es is bad)

Cost of CO₂ if available is reasonable $0.85/1.25 mcf now $1.25/mcf

Disadvantages:
- Usually not available
- Cannot combine with H₂O to form Carbonate Acid
- High pressure & Temp. and some H₂S, this can be corrosive.
- Must have two injection systems (CO₂ & H₂O)
- 15-20% of PV for cycling
- Alternate injection slug size max is 18%
- Same with simultaneous & pushed with water

The time: 2:30 PM

The date: Wednesday April 20, 1977

The Class: Petr Eng 417
Recovery Methods

The Instructor: Dr. Len Koederitz

The Conclusion:
1. CO₂ EOR was what I wanted to do!
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The Conclusion:
1. CO₂ EOR was what I wanted to do!
2. CO₂ price of $1.00-2.00/mcf was reasonable
Supply/Demand Studies

- EOR screening tools developed
- By-product supplies were insufficient
- Exploration efforts commenced

Source Fields were identified and tested

- McElmo Dome, Doe Canyon
- Sheep Mountain
- Bravo Dome
- Jackson Dome
Perspectives from the 70’s – Source and Pipeline

Pipeline concepts were evaluated

- Sizing, Quality Specs, Operating Specs
- Commercial Structures, Tariffs
- Regulatory impacts

By the end of the decade

- Sources had been found
- Development plans were underway
- CRC Pipeline began deliveries 4/71
EOR Technologies were brought forward

- CO$_2$, Thermal, Gas, Chemical

R&D spending focused on technologies applicable to large oil fields

- Pilot Testing
- Sorw
- Phase Behavior
- Reservoir Modeling, Core Floods, 3-phase Kr
- Metalurgy and Elastomer Selection

Sacroc and North Cross commence 4/71
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The ’80s

With high oil prices expectations; the major infrastructure and project work began.
Source Field Developments

- McElmo Dome ‘83 1 BCF/d
- Sheep Mountain ‘83 300 MMCFD
- Bravo Dome ‘84 400 MMCFD
- Jackson Dome ‘85 240 MMCFD
Perspectives from the 80’s – Source and Pipeline

Source Wells and Field:

- Flow vs ESP
- Fiberglass Tubing
- Stainless Steel Flowlines
- Operating Pressures, Temperatures
- Dehydration with glycol and glycerol

Pipelines:

- Crack arrestors
- Water content spec
- Metering
- Pumping vs. compression
The Initial CO₂ Pipelines –
Several different business approaches were taken

Canyon Reef Carriers
Owned by SACROC Unit

Cortez PL
Partnership – posted tariff

Sheep Mountain PL
JV-Undivided Interest

Bravo PL
JV-Undivided Interest

Choctaw PL
Single Owner

Central Basin PL
Contract Carrier

Wyoming
Single Owner
Early Permian Basin Projects

Denver Unit, Wasson ODC, Willard, Cornell, Mahoney, Means, Seminole

San Andres Dolomite, ~5200’ deep
- Initial slug size
- Wag or continuous, wag ratio, tapered wag
- Flumping wells
- Gas processing
- H₂S treating: sulferox, selexol

Initial contracting for supply
Volumes
Pricing
In-kind deliveries, balancing
Take-or-Pay/Project Failure
Early Mississippi CO2 Projects

Little Creek, W. Mallalieu, Olive

Tuscaloosa Sand, ~10,000’ deep, ~30’ of pay

• Strongly water wet
• Gravity Over-ride
• Continuous CO$_2$ Injection
• Sand Control
• Continuous Inhibition
Weeks Island Gravity-Stable CO$_2$ Flood

Pilot
CO$_2$ injection in pilot effectively mobilized waterflood residual oil

Liquids
Watered-out Zones
Strong Aquifer
Gas Cap

CO$_2$

Large Gas Cap

Commercial Project

Ref: Holtz Case Studies
Early Rockies EOR Projects

Rangley, Lost Soldier, Wertz
Early CO$_2$ Contract Price vs Oil Price
Delivered at the Field

Reference: KMCO2 records, based on current Cortez PL tariff
The early 1980’s – pretty heady times
...and a lot of gutsy investments made
Perspectives on 1986 - 2000

What goes up with great expectations, often comes down.

In February 1986 oil prices collapsed.
Perspectives on 1986 – 2000
A lot of projects under water

Retrenchment
Cost Control
Business Process Redesign

Active US CO2 EOR Projects

Courtesy: Bart Simpson
Persistent Focus on all Costs

Supply Contract Challenges

- Project economic failure
- Volumes above TOP
- Parsing language, provisions

The Dean of CO₂ Contracting

- Jim Hefley – Amerada Hess

New CO₂ Marketing Strategies Emerged

- Blanket supply arrangements
- Trading CO₂ for participation in projects
- Industrial gas customer demand

Suddenly a heated exchange broke out between the King and the moat contractor.

Courtesy: Larsen
Early Attempts to Expand CO\textsubscript{2} Market
Early Attempts to Expand CO$_2$ Market
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Early Attempts to Expand CO$_2$ Market
Shell CO₂ Company, Ltd. formed March 1998
…and then Kinder Morgan buys Shell’s 80% interest in 2000

Best move I ever made
(That’s Bill Morgan on the left)
The ‘90’s was a decade of learning – projects don’t always work as originally drawn on paper.

‘Scotty, we need more compression now!’

‘Captain, the vessels are too small...the facility is going to blow up!’
CO₂ EOR - It's not all just about the subsurface...
It takes an integrated team to make it work

- Subsurface/Geosciences
- Facilities engineering
- Well engineering
- Operators
- Mechanics
- Commercial
- Financial staff
- Management
2000 to Present

Oil prices began to steadily rise, finally, and the industry expanded.
CO$_2$ EOR Industry has been quite busy
Despite changing ~90% of the players

![Active US CO2 EOR Projects](image-url)

Courtesy O&GJ
An evolving business – The industry changes hands

CO₂ Source and PL Operators - the 80’s
An evolving business – The industry changes hands

CO₂ Source and PL Operators - Present
Clarke’s Third Law:
Any sufficiently advanced technology is indistinguishable from magic

What we now take for granted:
• Residual Oil Saturation to WF
• MMP testing, developed miscibility
• Elastomers
• Corrosion management
  • Chemicals
  • Liners for Tubing
  • Non-metallic pipe
• Pumping, ESPs vs. compression
• Membrane Separation
CO₂ EOR Production/Injection History and Forecast
A solid track record and a promising future.

References: AEO 2011 Forecast, O&GJ, Personal Knowledge
Can we do it?
It depends...
We need continued advances in technology

Improve results + lower risk + reduce costs = more opportunities
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Improve results + lower risk + reduce costs = more opportunities
We need professional help

Our country is not educating enough science and engineering students

Courtesy: National Science Foundation
We need a mandate

When will the people pulling against us get tired of $4+/gallon gasoline?
We need to restore public confidence

Education

Compliance

Operational Excellence
We have a noble mission

“Every new CO₂ project saves a town”
- Chuck Fox

Snyder, Texas
Rich Kinder of Kinder Morgan:

“Good things come to those who waiteth, if you work like hell while you waiteth.”