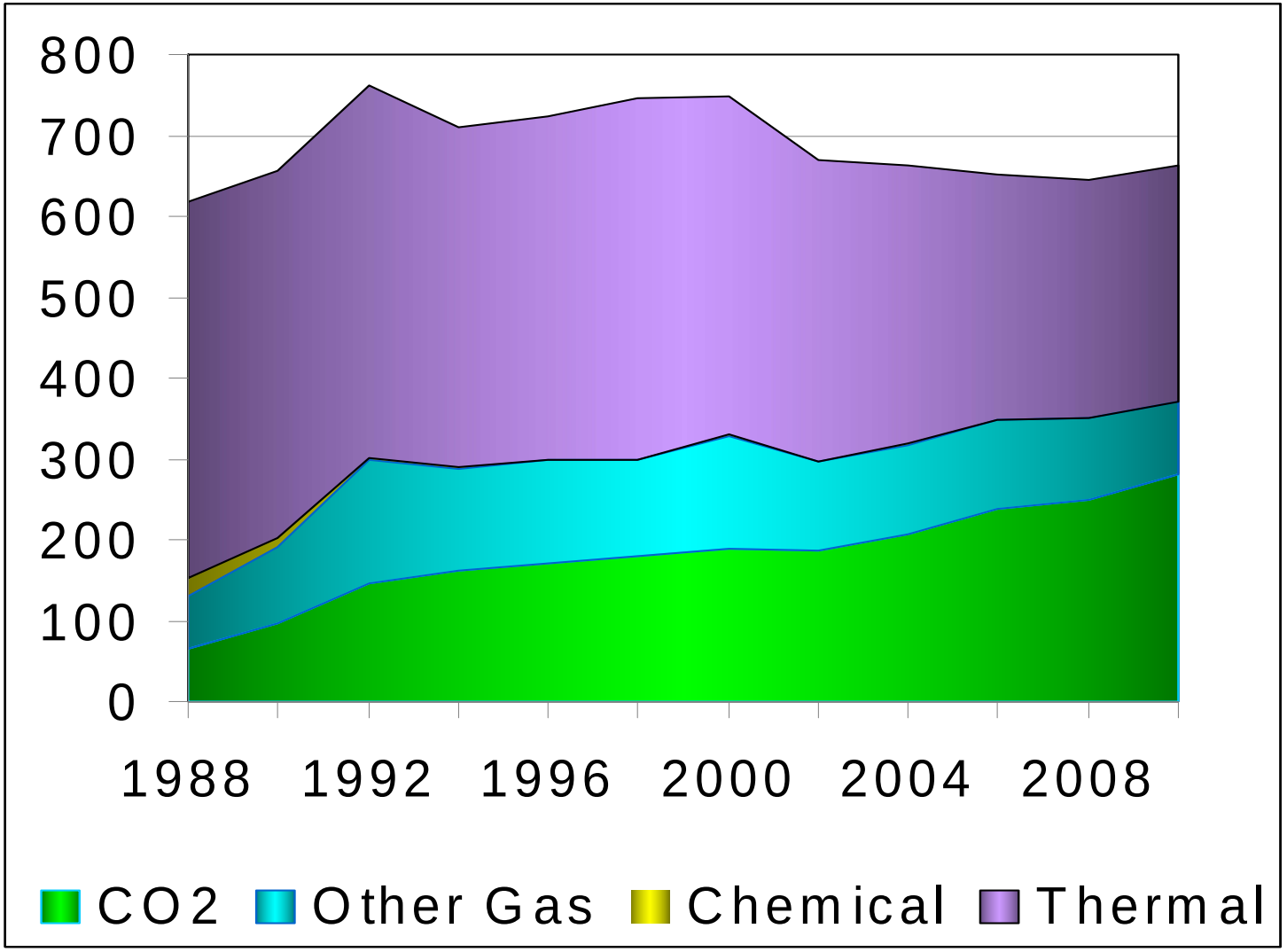
CO_2 EOR – Quite a Story

…and a couple of tall tales

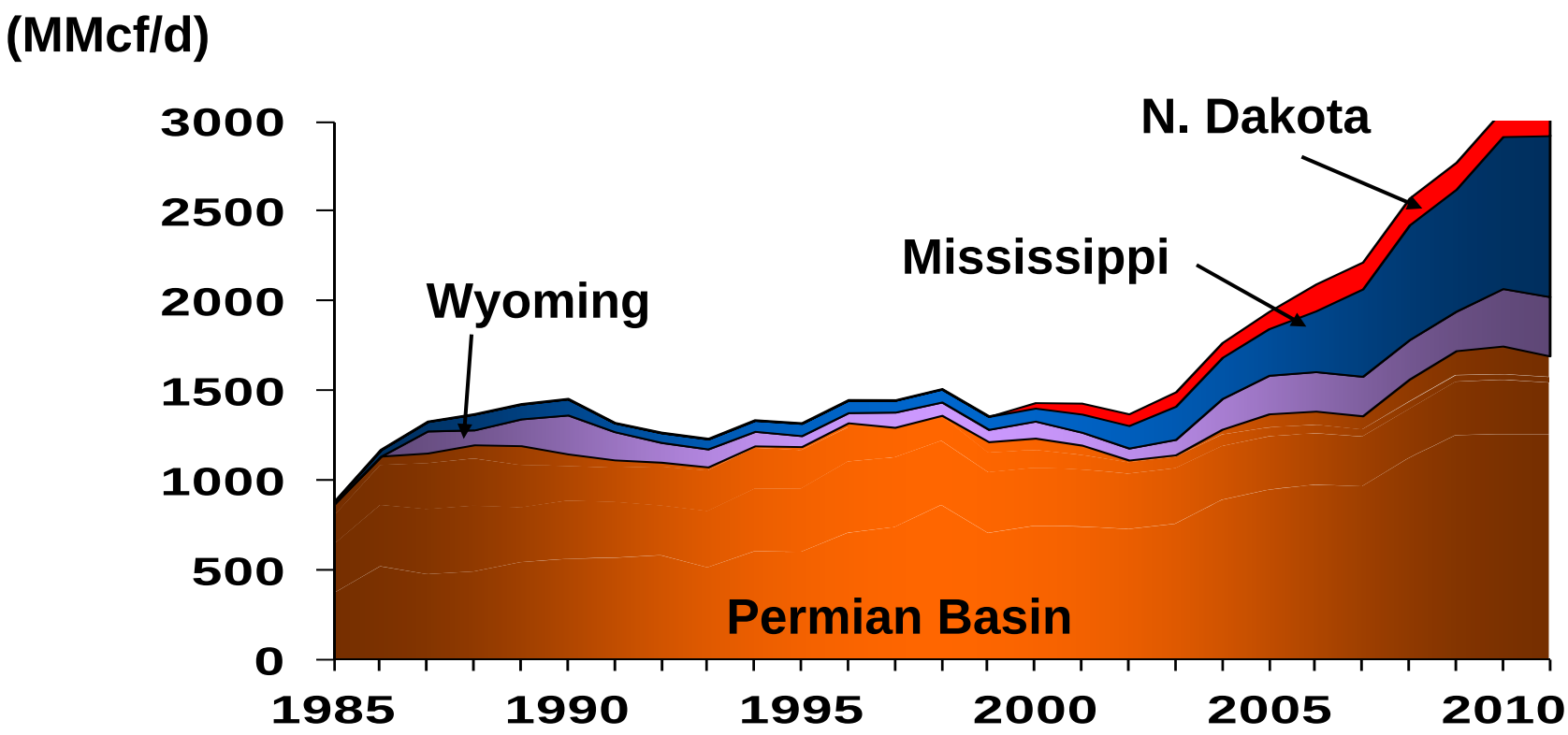
US EOR Production - CO_2 is playing a greater role



Reference: O&GJ

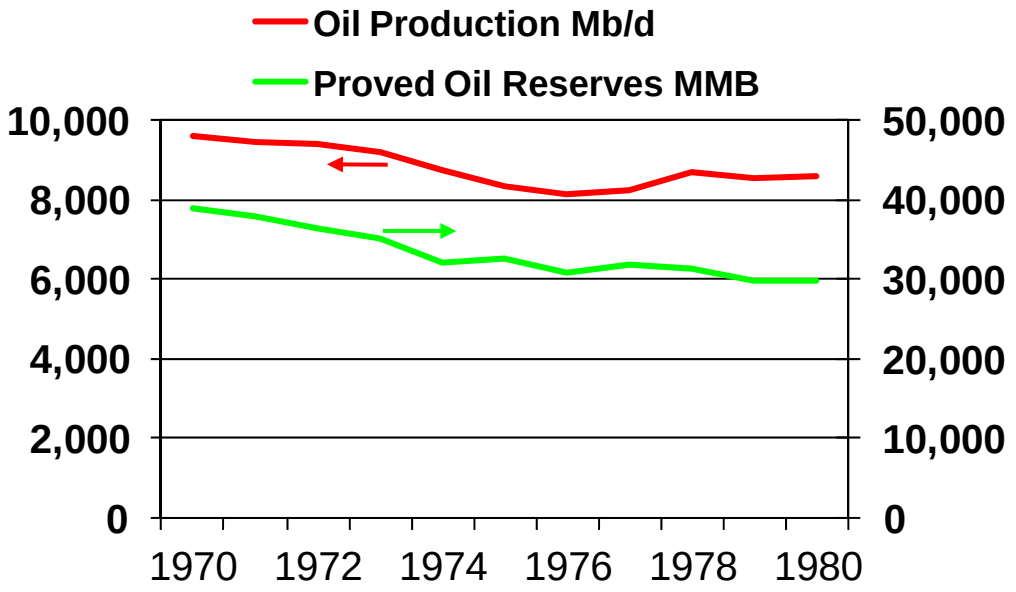
CO_2 Source and Transportation

Business has doubled in size since 2003



Sources: KM estimates, Oil and Gas Journal, EIA, XOM, Dakota Gasification, DRI

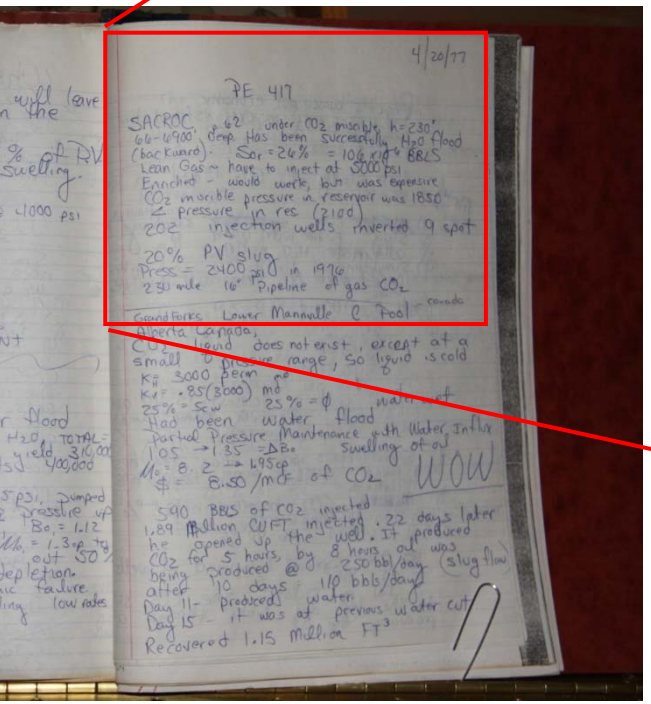
That Seventies Show



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



4/20/77

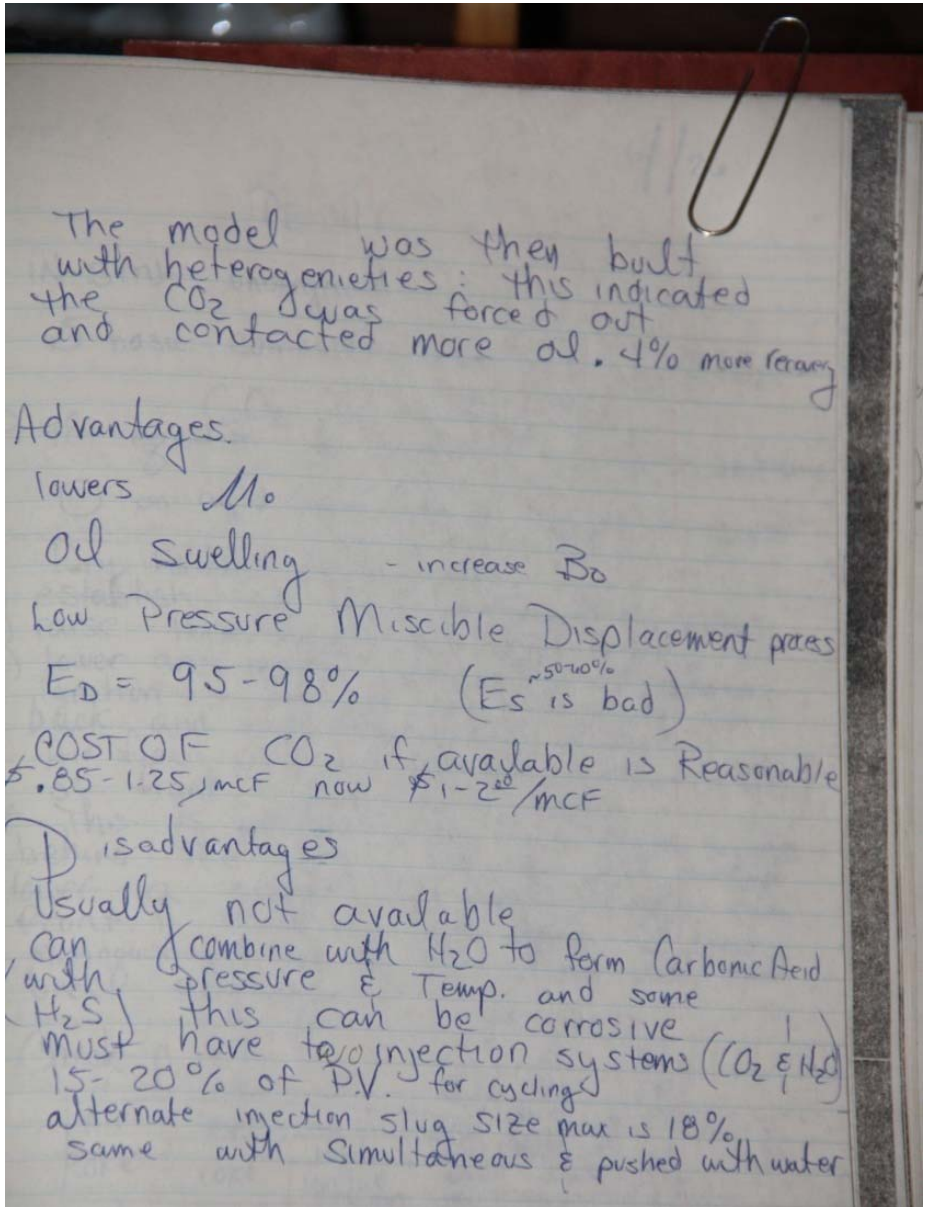
PE 417

SACROC 62 under CO_2 miscible, h=230'
66-6900' Deep. Has been successfully H_2O flood
(backward). S_{or}=26% = 106 x 10^6 BBLS
Lean Gas ~ have to inject at 5000 psi
Enriched - would work, but was expensive
CO_2 miscible pressure in reservoir was 1850
∠ pressure in res. (2100)
202 injection wells inverted 9 spot

20% PV slug
Press = 2400 psi in 1976
230 mile 16" Pipeline of gas CO_2

Who would have thought…

A pivotal moment in time



The time: 2:30 PM

The date: Wednesday April 20, 1977

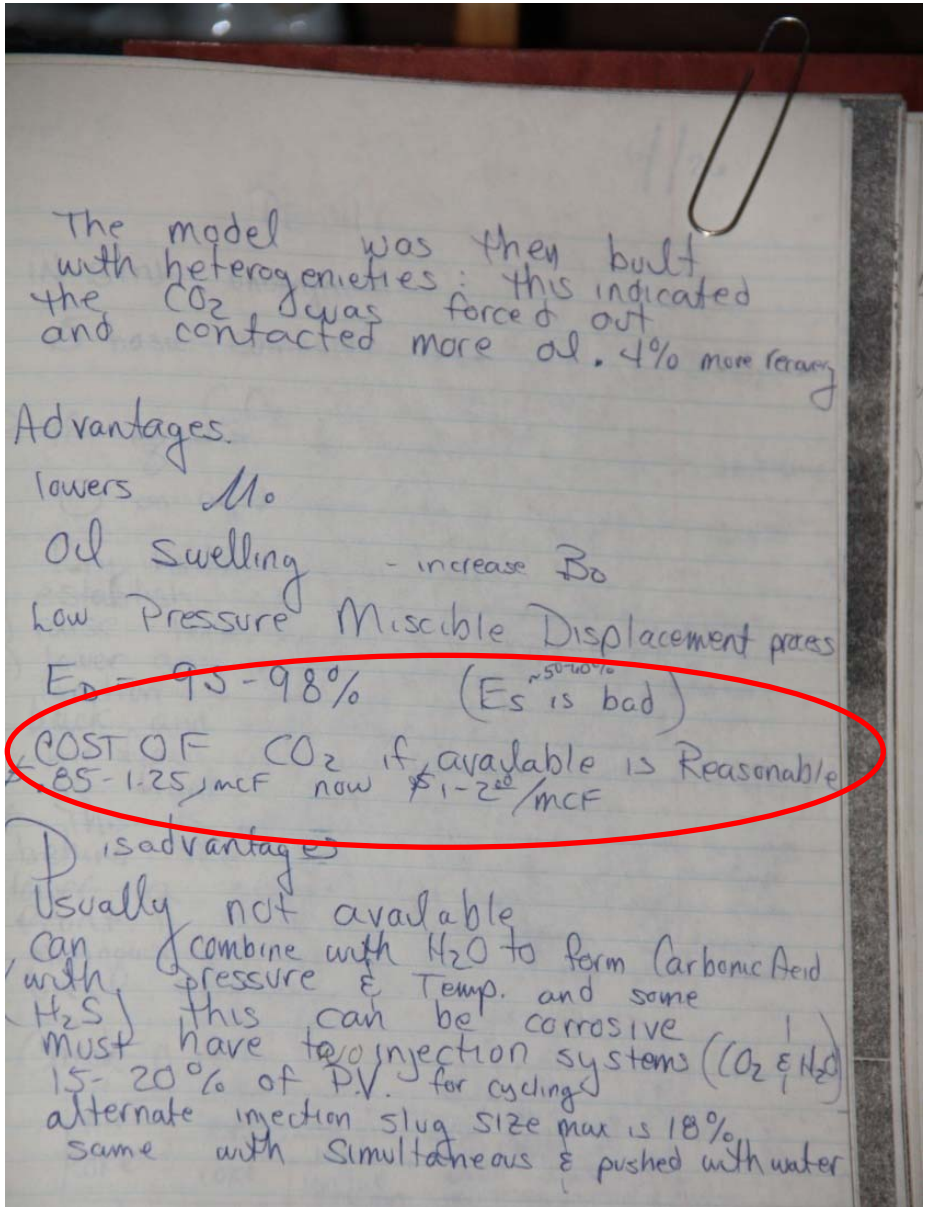
The Class: Petr Eng 417 Recovery Methods

The Instructor: Dr. Len Koederitz

The Conclusion:

1. **CO_2 EOR was what I wanted to do!**

A pivotal moment in time



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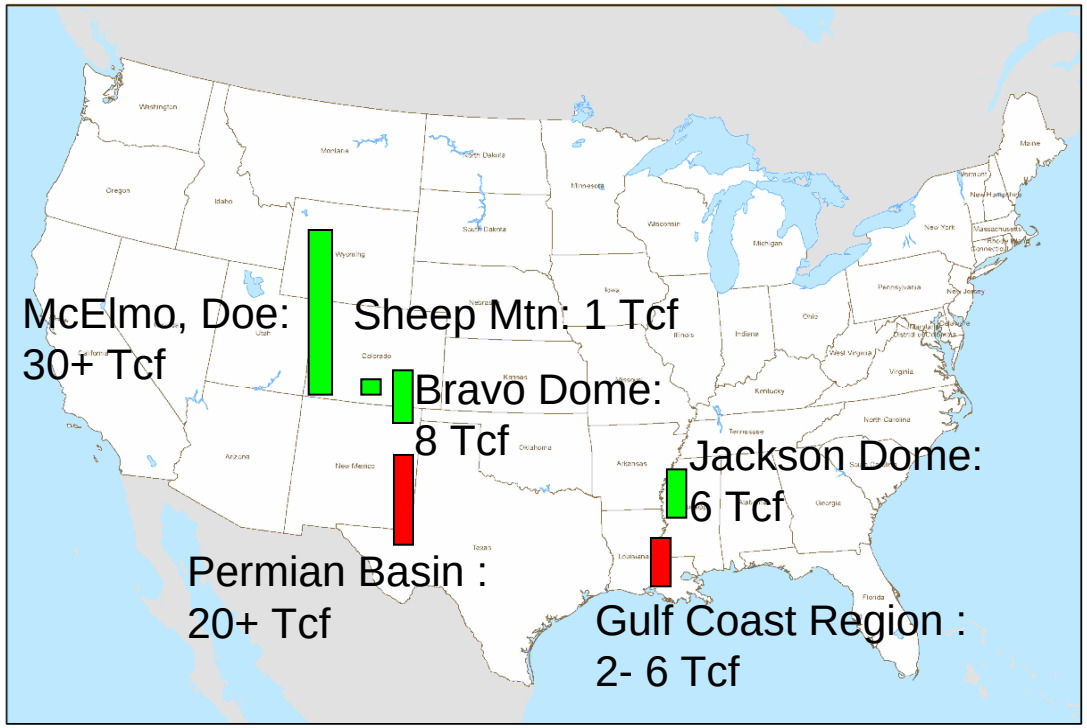
The Conclusion:

1. **CO_2 EOR was what I wanted to do!**
2. **CO_2 price of $1.00-2.00/mcf was reasonable**

Perspectives from the 70's – Source and Pipeline



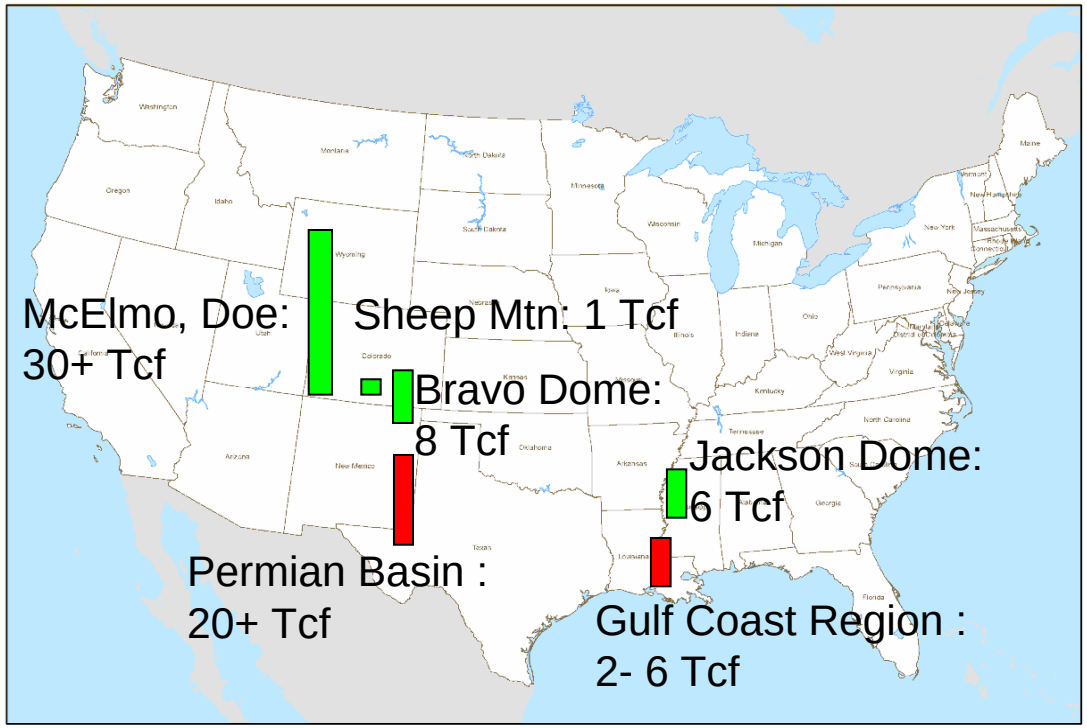
Supply/Demand Studies

- 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



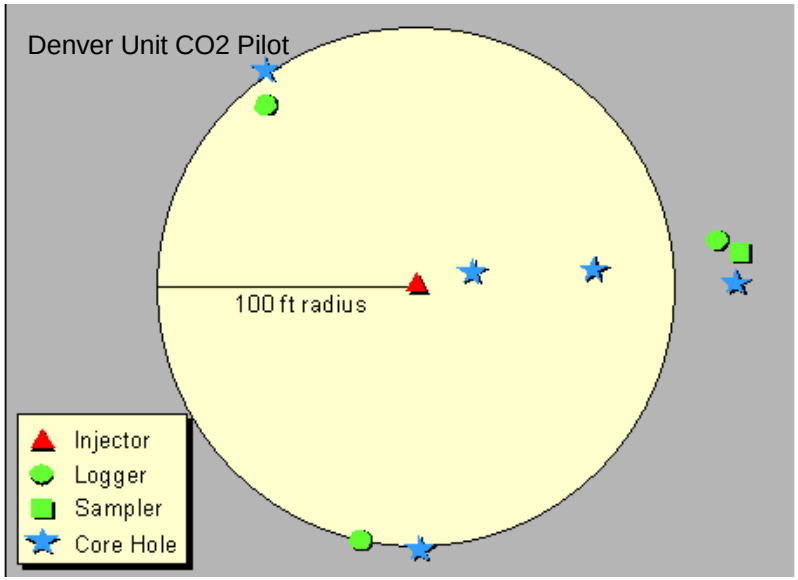
Pipeline concepts were evaluated

- 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

Perspectives from the ’70s – EOR Field



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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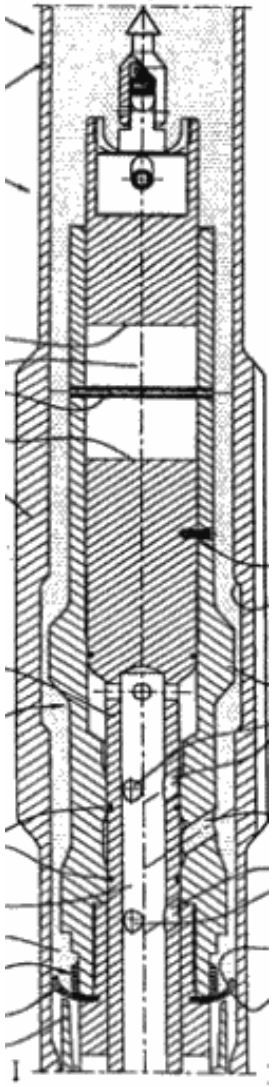

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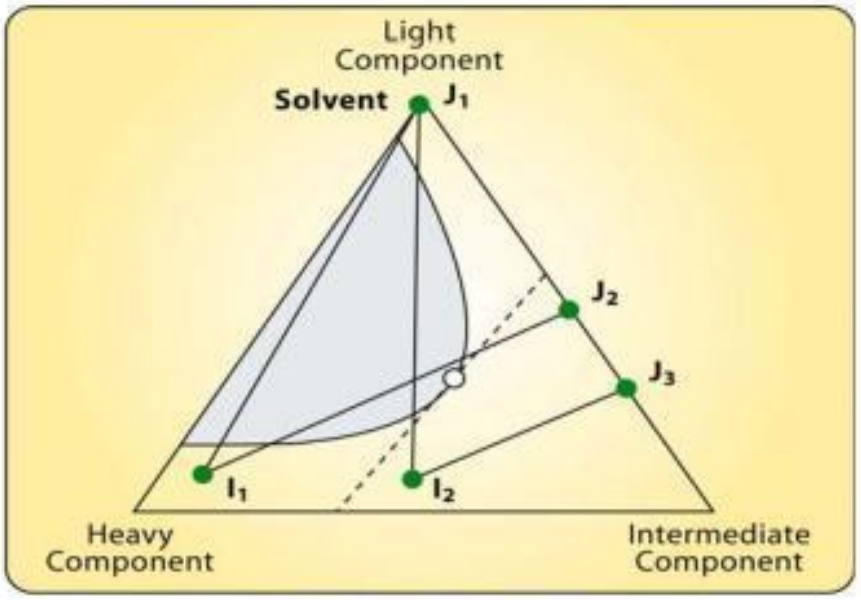

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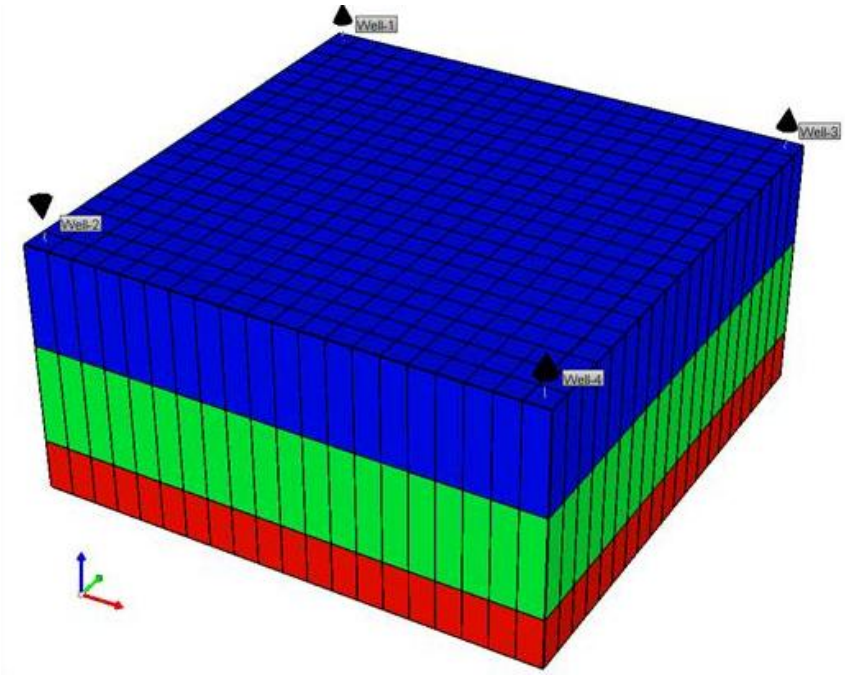

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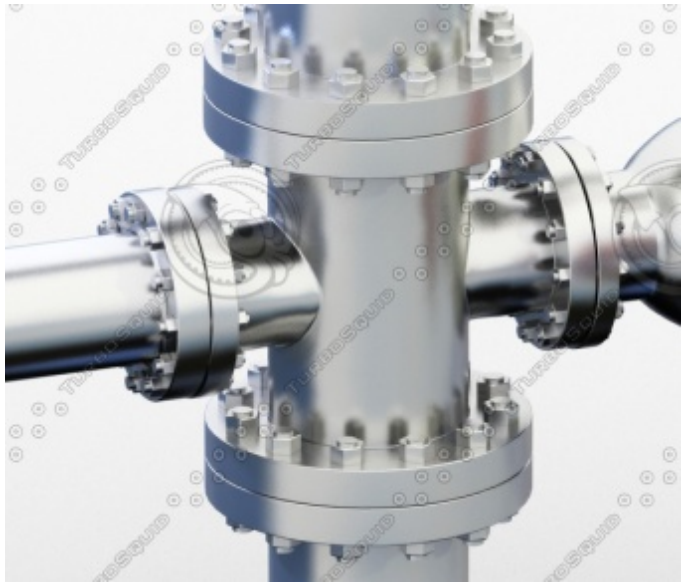

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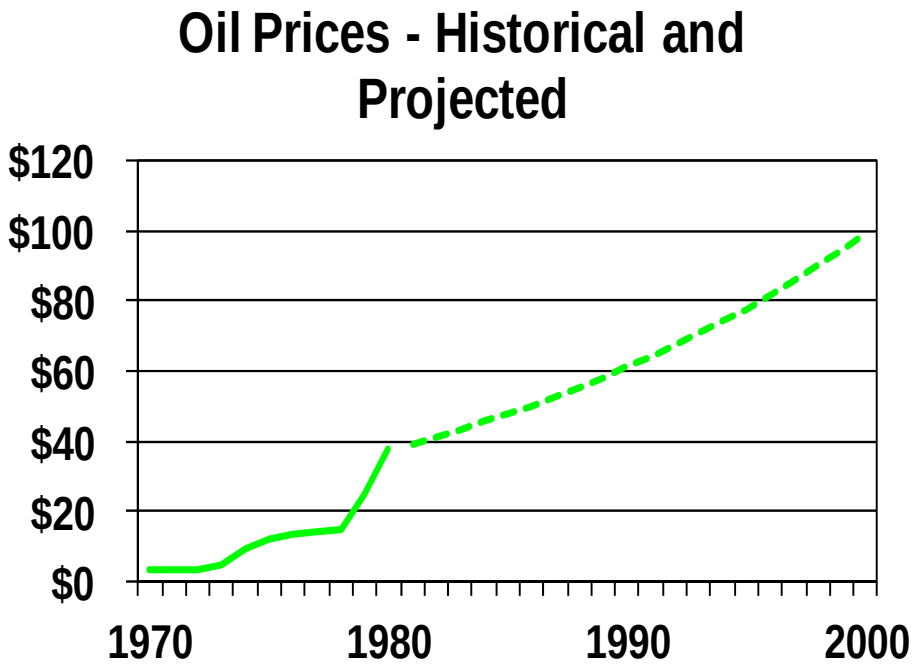
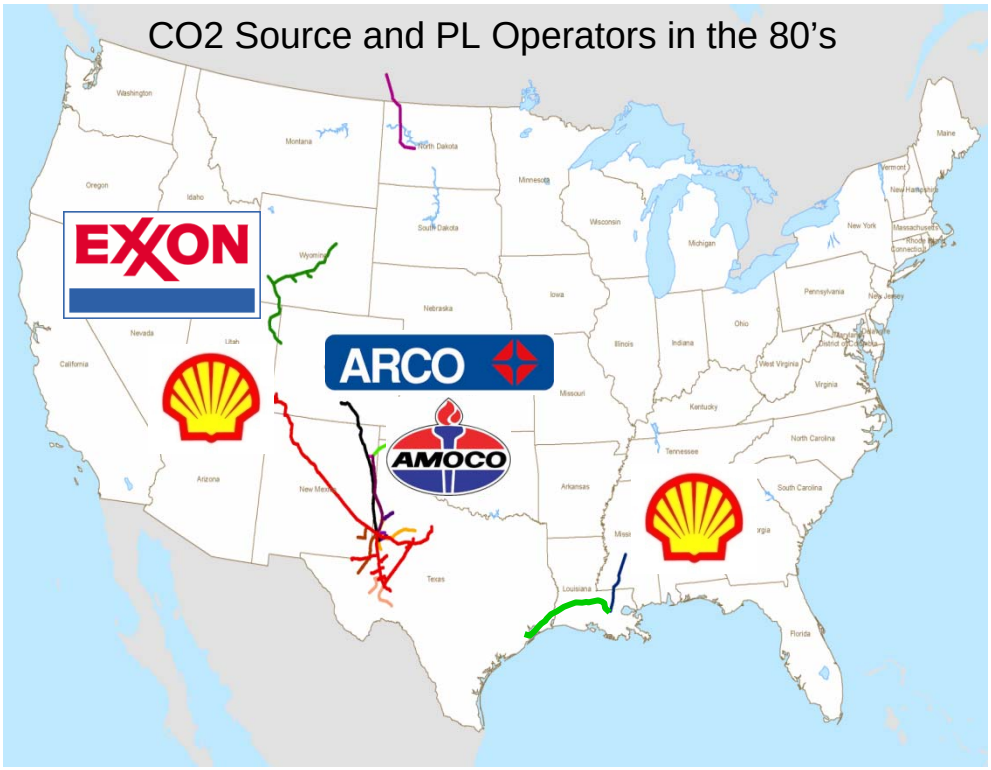
The ’80s



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

Perspectives from the 80's – Source and Pipeline



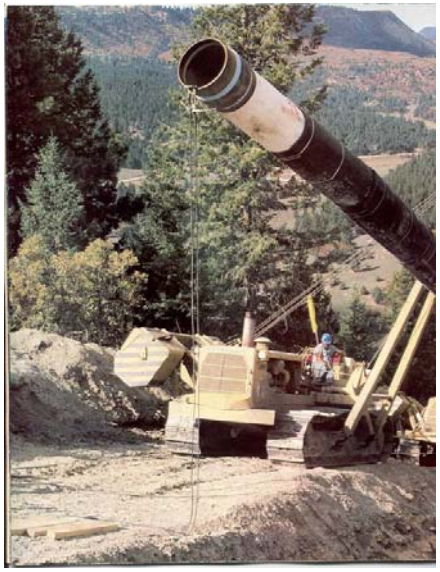
Source Field Developments

- 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:

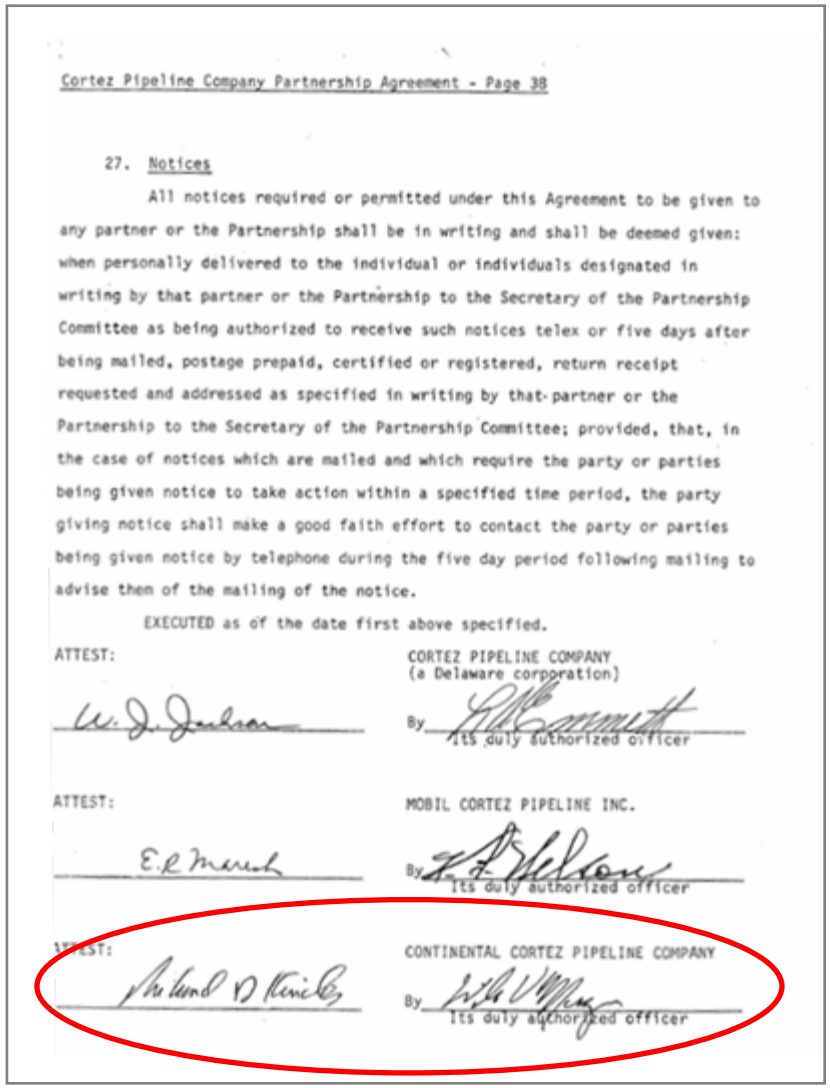
- Flow vs ESP
- Fiberglass Tubing
- Stainless Steel Flowlines
- Operating Pressures, Temperatures
- Dehydration with glycol and glycerol



Pipelines:

- Crack arrestors
- Water content spec
- Metering
- Pumping vs. compression

The Initial CO_2 Pipelines –
Several different business approaches were taken



Cortez Pipeline Company Partnership Agreement - Page 38

27. Notices

All notices required or permitted under this Agreement to be given to any partner or the Partnership shall be in writing and shall be deemed given: when personally delivered to the individual or individuals designated in writing by that partner or the Partnership to the Secretary of the Partnership Committee as being authorized to receive such notices telex or five days after being mailed, postage prepaid, certified or registered, return receipt requested and addressed as specified in writing by that partner or the Partnership to the Secretary of the Partnership Committee; provided, that, in the case of notices which are mailed and which require the party or parties being given notice to take action within a specified time period, the party giving notice shall make a good faith effort to contact the party or parties being given notice by telephone during the five day period following mailing to advise them of the mailing of the notice.

EXECUTED as of the date first above specified.

ATTEST:

CORTEZ PIPELINE COMPANY
(a Delaware corporation)

By _____
Its duly authorized officer

ATTEST:

MOBIL CORTEZ PIPELINE INC.

By _____
Its duly authorized officer

ATTEST:

CONTINENTAL CORTEZ PIPELINE COMPANY

By _____
Its duly authorized officer

Canyon Reef Carriers
- Owned by SACROC Unit

Cortez PL
- Partnership – posted tariff

Sheep Mountain PL
- JV-Undivided Interest

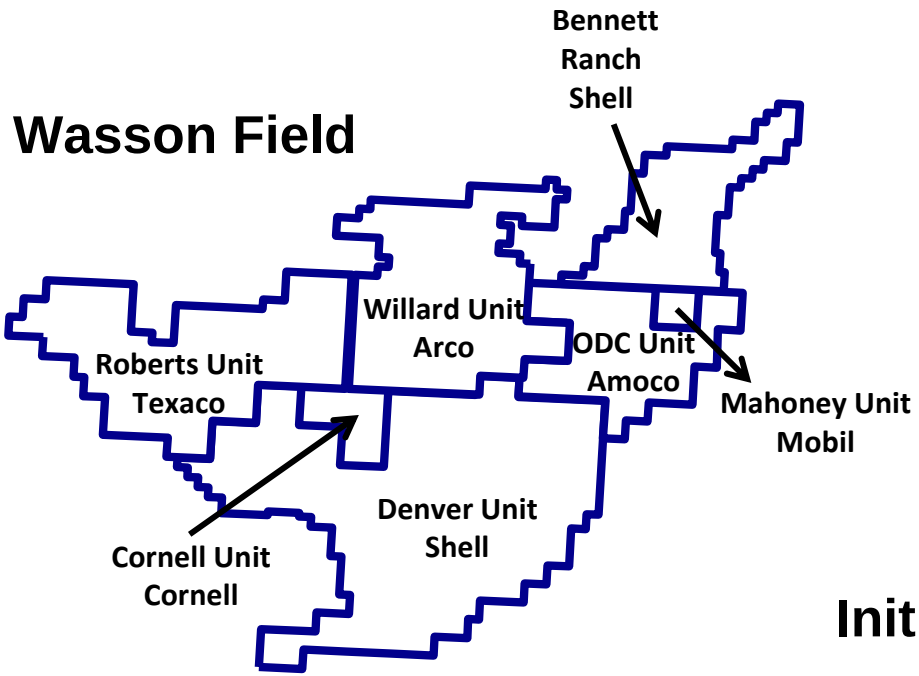
Bravo PL
- JV-Undivided Interest

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

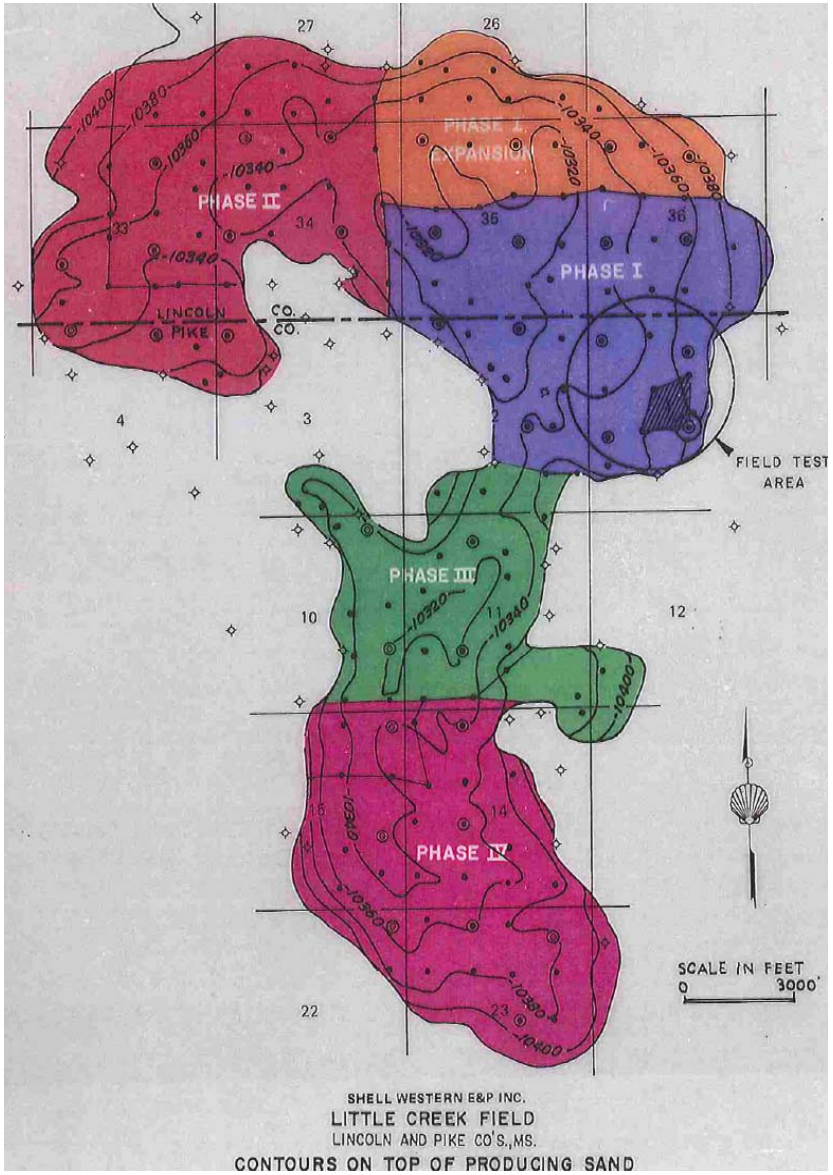
San Andres Dolomite, ~5200' deep

- **Initial slug size**
- **Wag or continuous, wag ratio, tapered wag**
- **Flumping wells**
- **Gas processing**
- **H_2S treating: sulferox, selexol**

Initial contracting for supply

Volumes
Pricing
In-kind deliveries, balancing
Take-or-Pay/Project Failure

Early Mississippi CO2 Projects

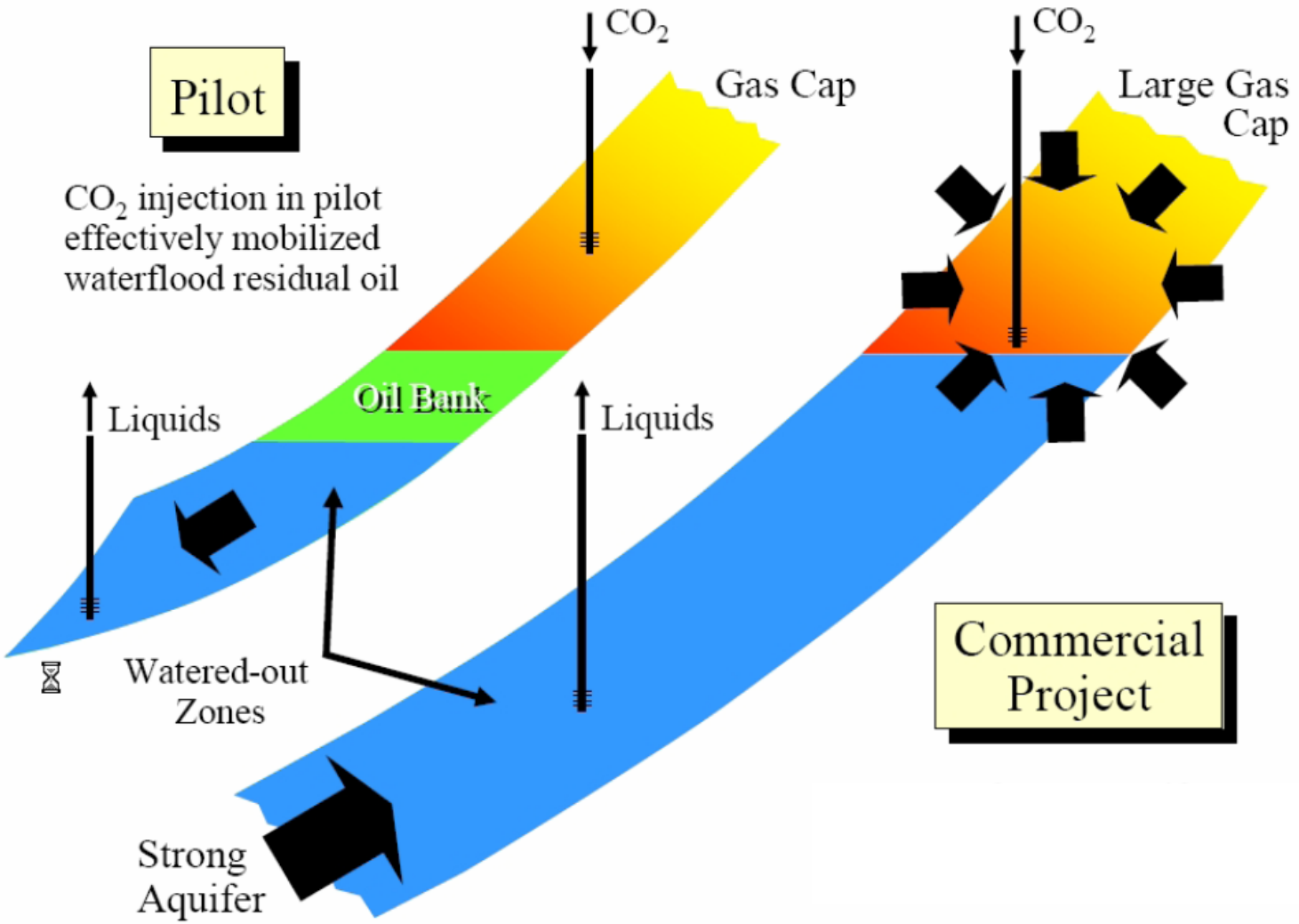


Little Creek, W. Mallalieu, Olive

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

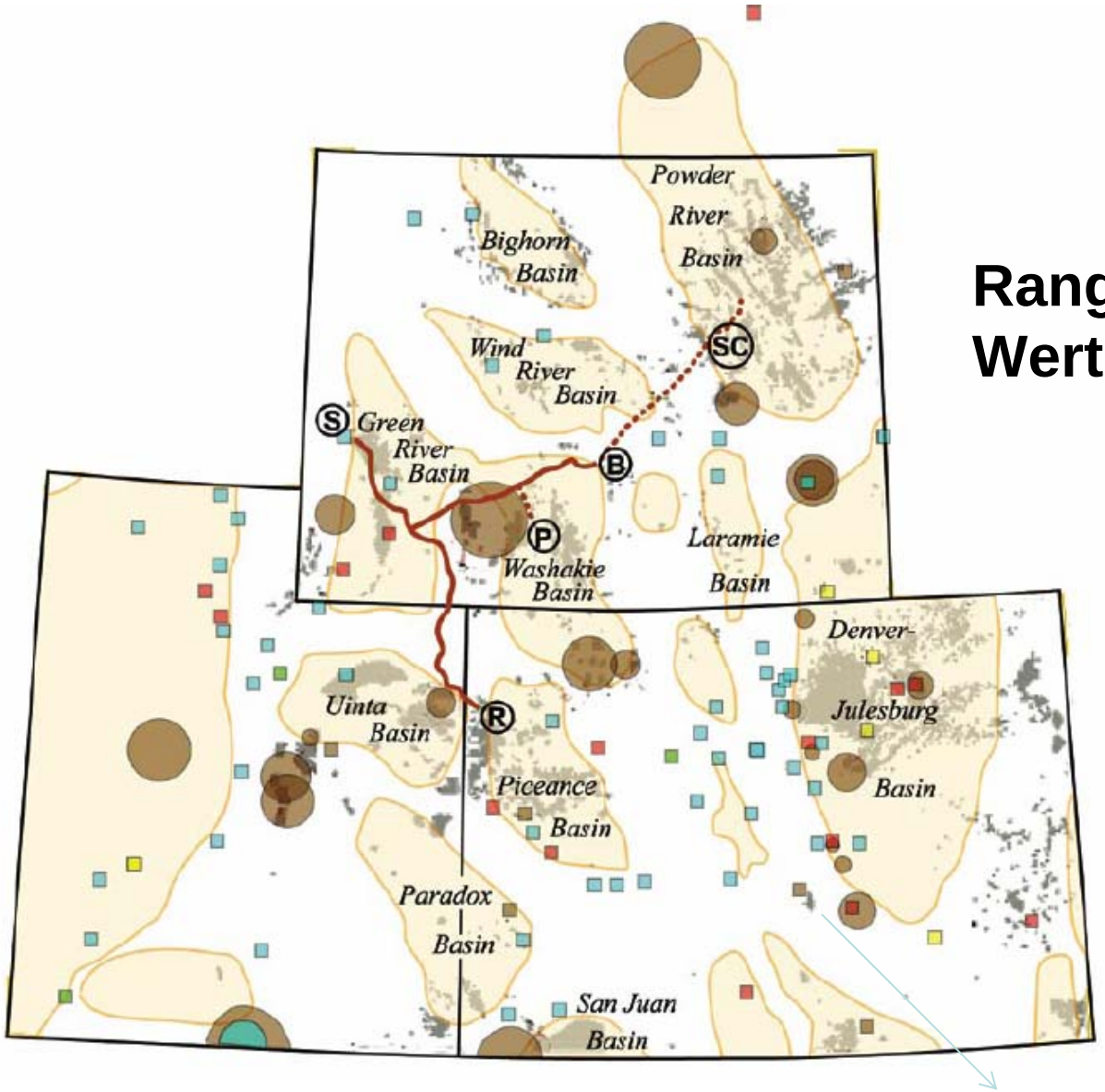
- **Strongly water wet**
  - **Gravity Over-ride**
  - **Continuous CO_2 Injection**
- **Sand Control**
- **Continuous Inhibition**

Weeks Island Gravity-Stable CO_2 Flood



Ref: Holtz Case Studies

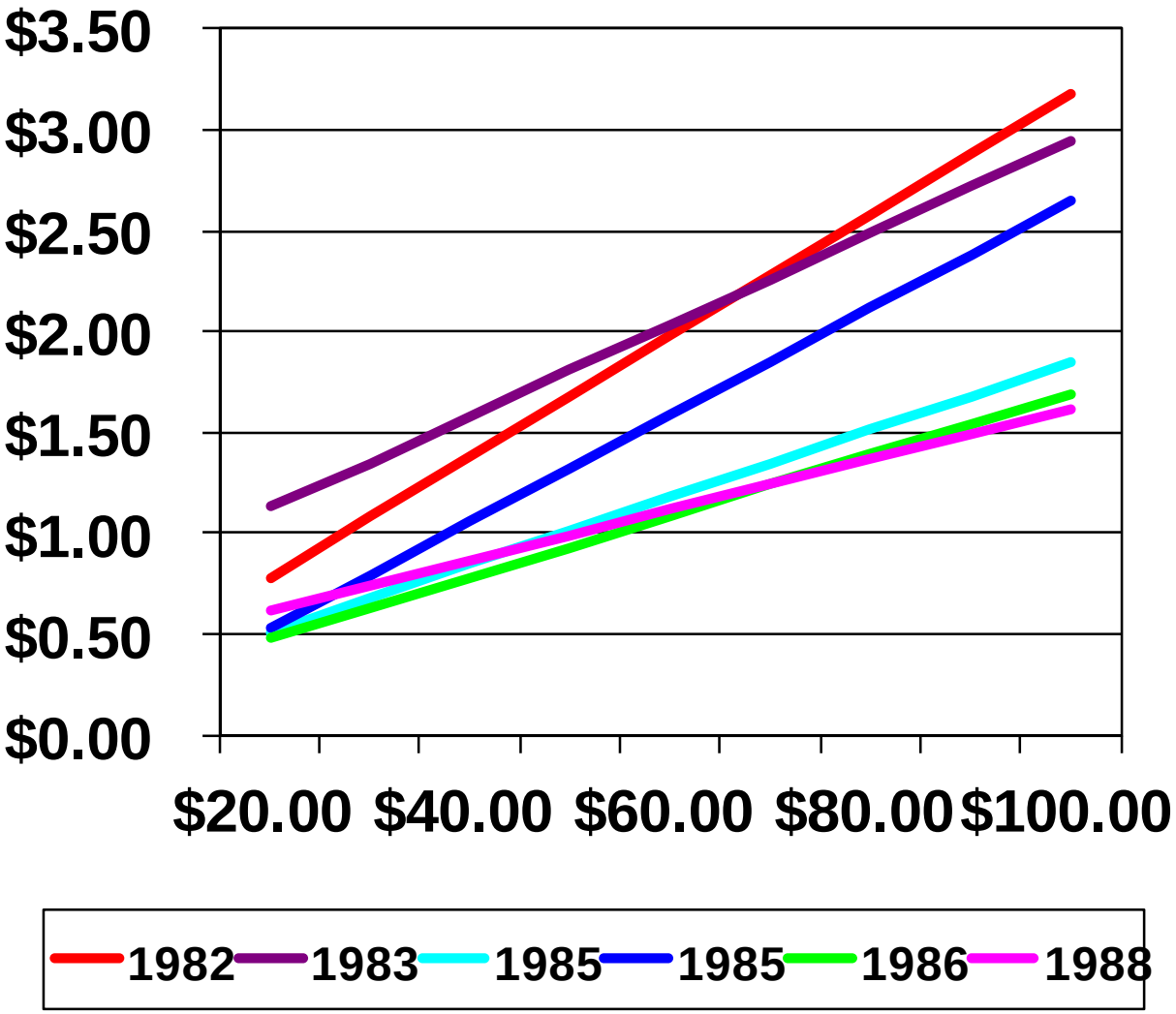
Early Rockies EOR Projects



Rangley, Lost Soldier, Wertz

Early CO_2 Contract Price vs Oil Price

Delivered at the Field



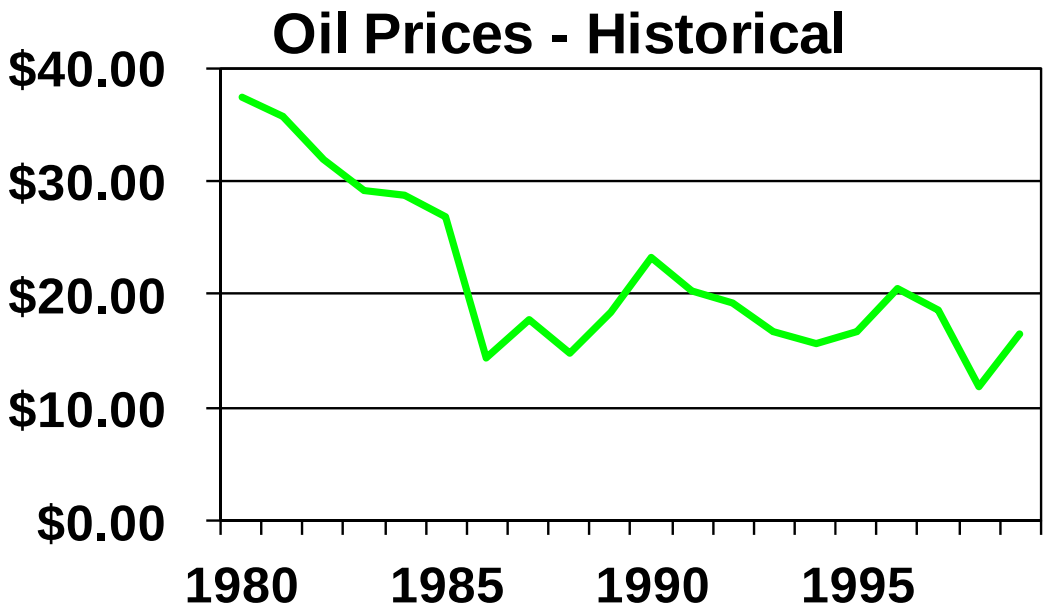
Reference: KMCO2 records, based on current Cortez PL tariff

The early 1980's – pretty heady times

…and a lot of gutsy investments made

Courtesy: Raiders of the Lost Arc

Perspectives on 1986 - 2000

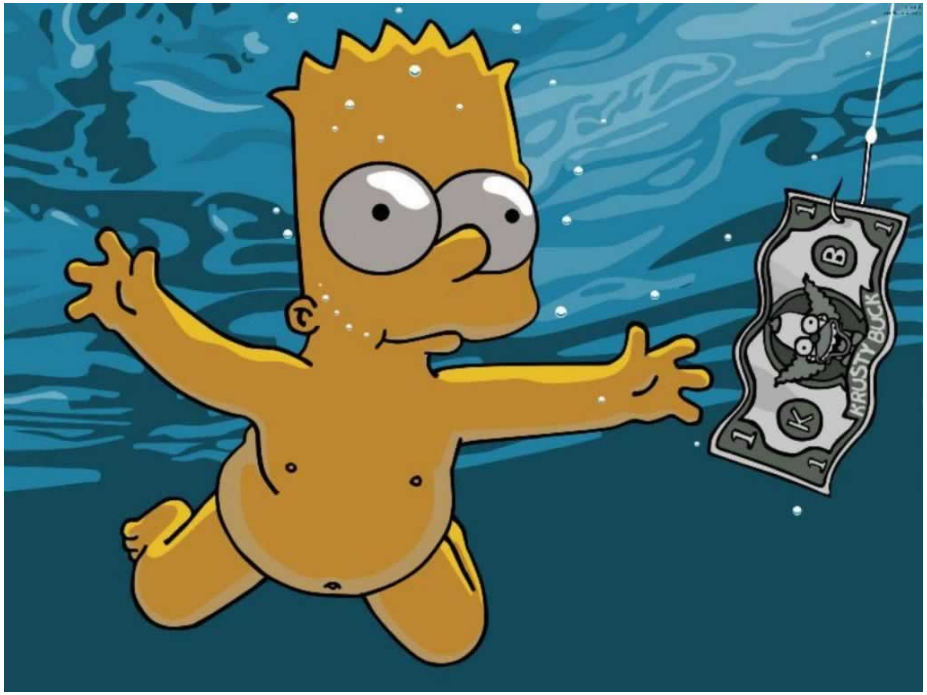


What goes up with great expectations, often comes down.

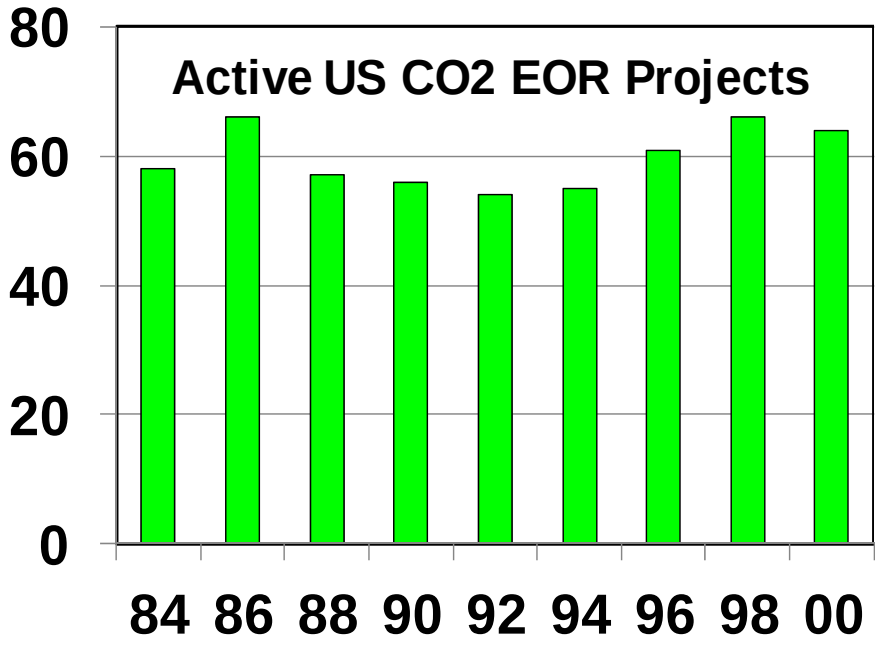
In February 1986 oil prices collapsed.

Perspectives on 1986 – 2000

A lot of projects under water

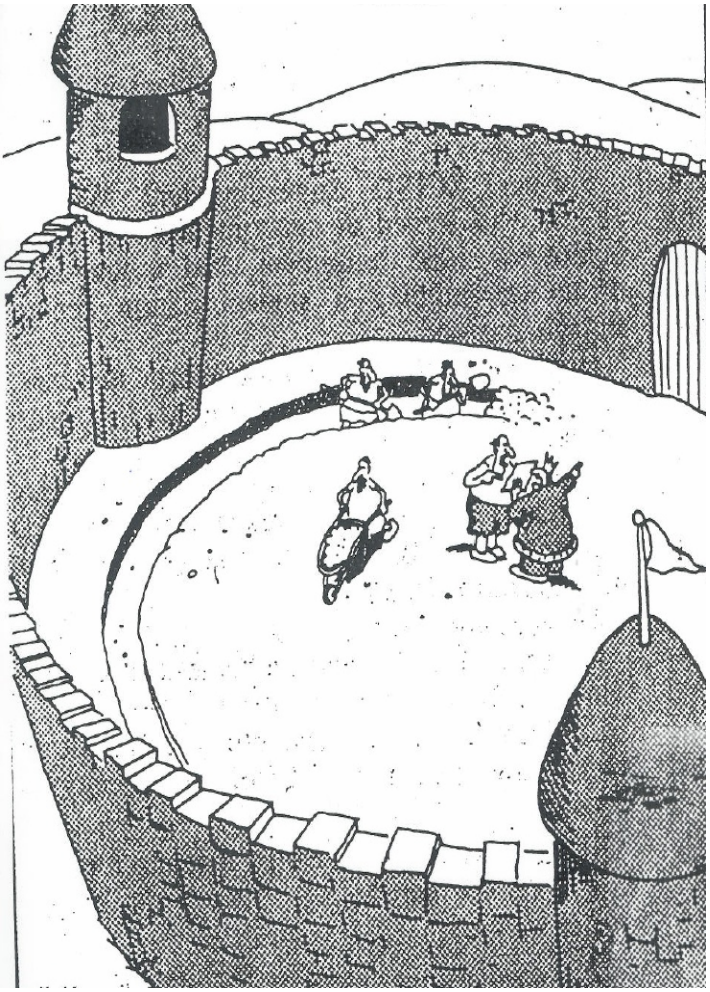


Courtesy: Bart Simpson



Retrenchment
Cost Control
Business Process Redesign

Persistent Focus on all Costs



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

Courtesy: Larsen

Supply Contract Challenges

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

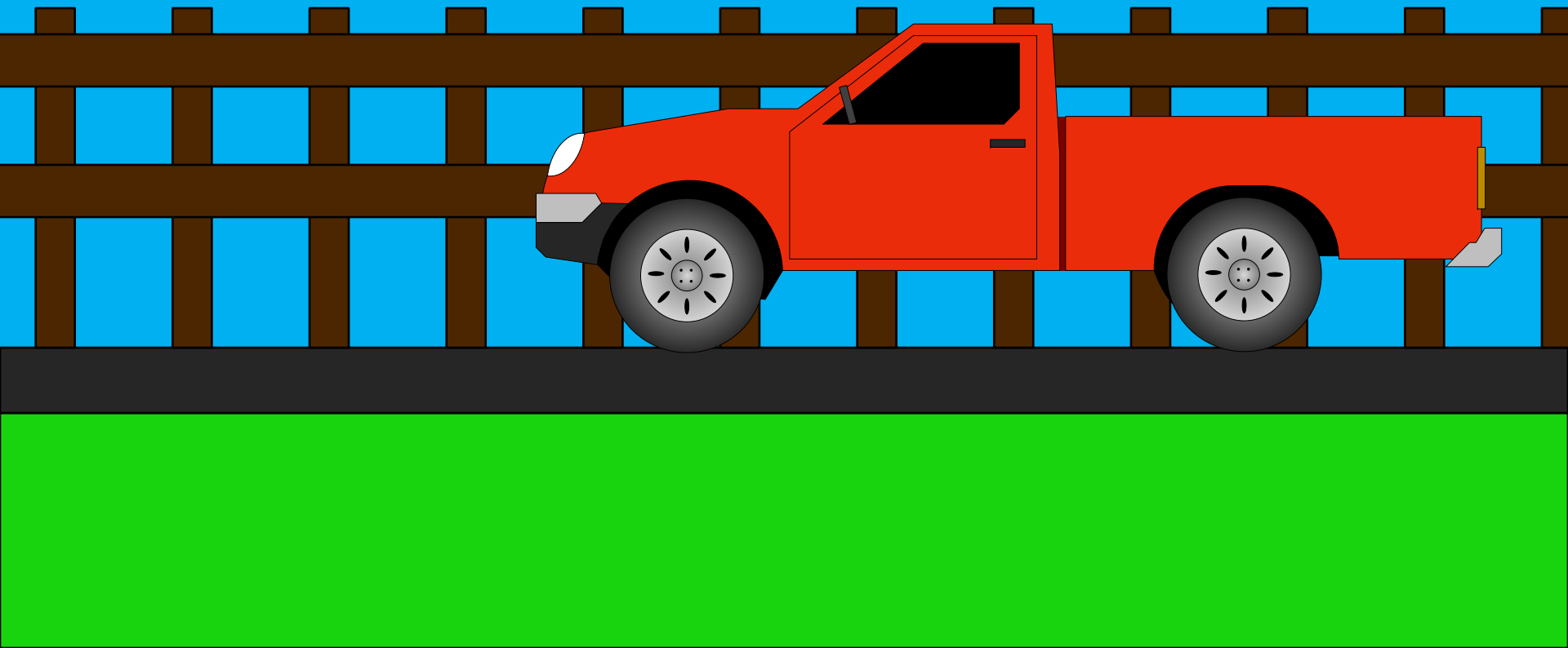
The Dean of CO_2 Contracting

- Jim Hefley – Amerada Hess

New CO_2 Marketing Strategies Emerged

- Blanket supply arrangements
- Trading CO_2 for participation in projects
- Industrial gas customer demand

Early Attempts to Expand CO_2 Market



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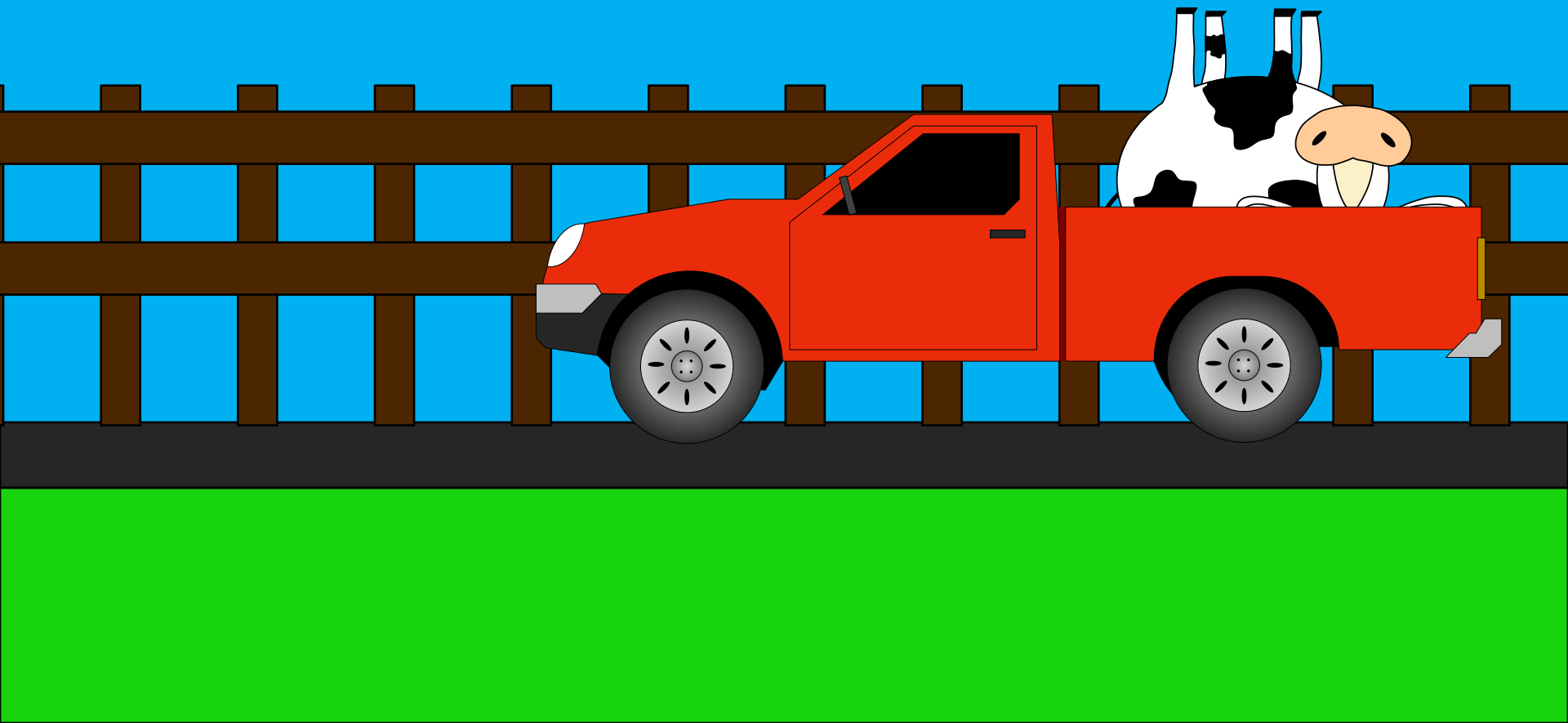

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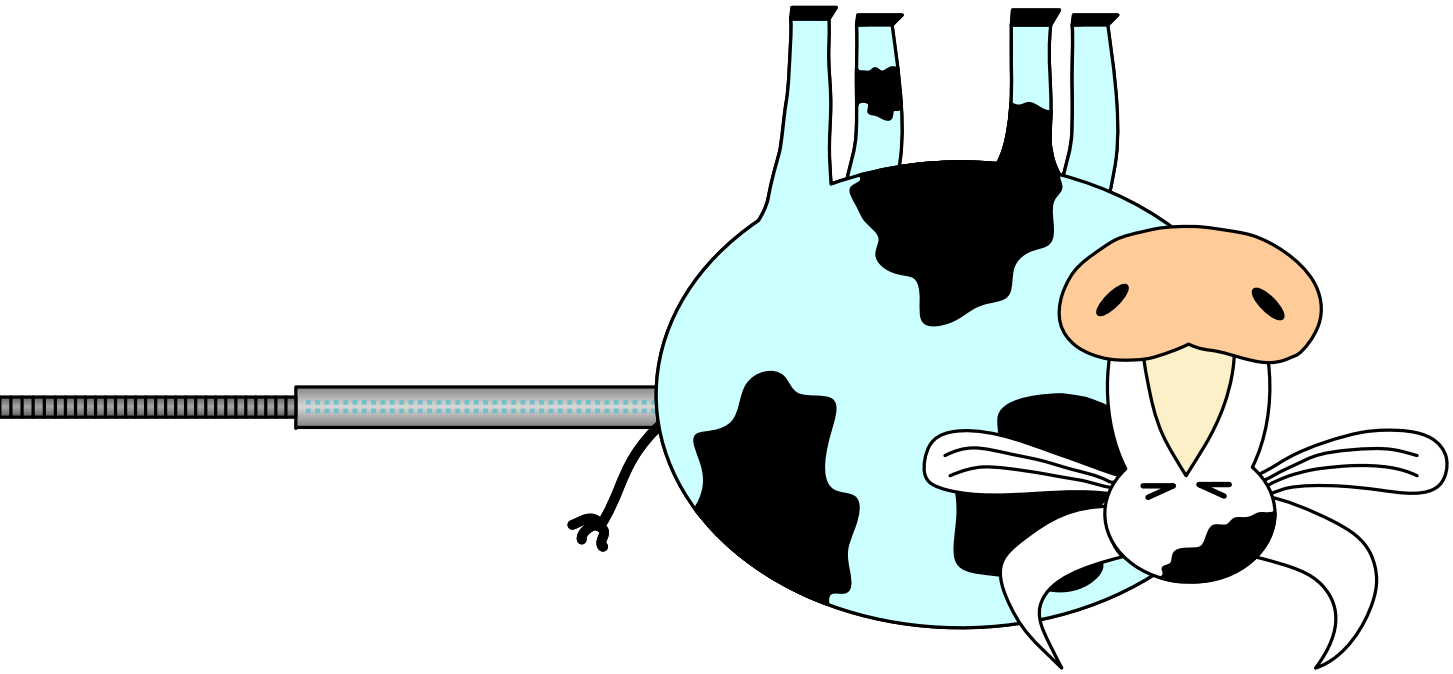

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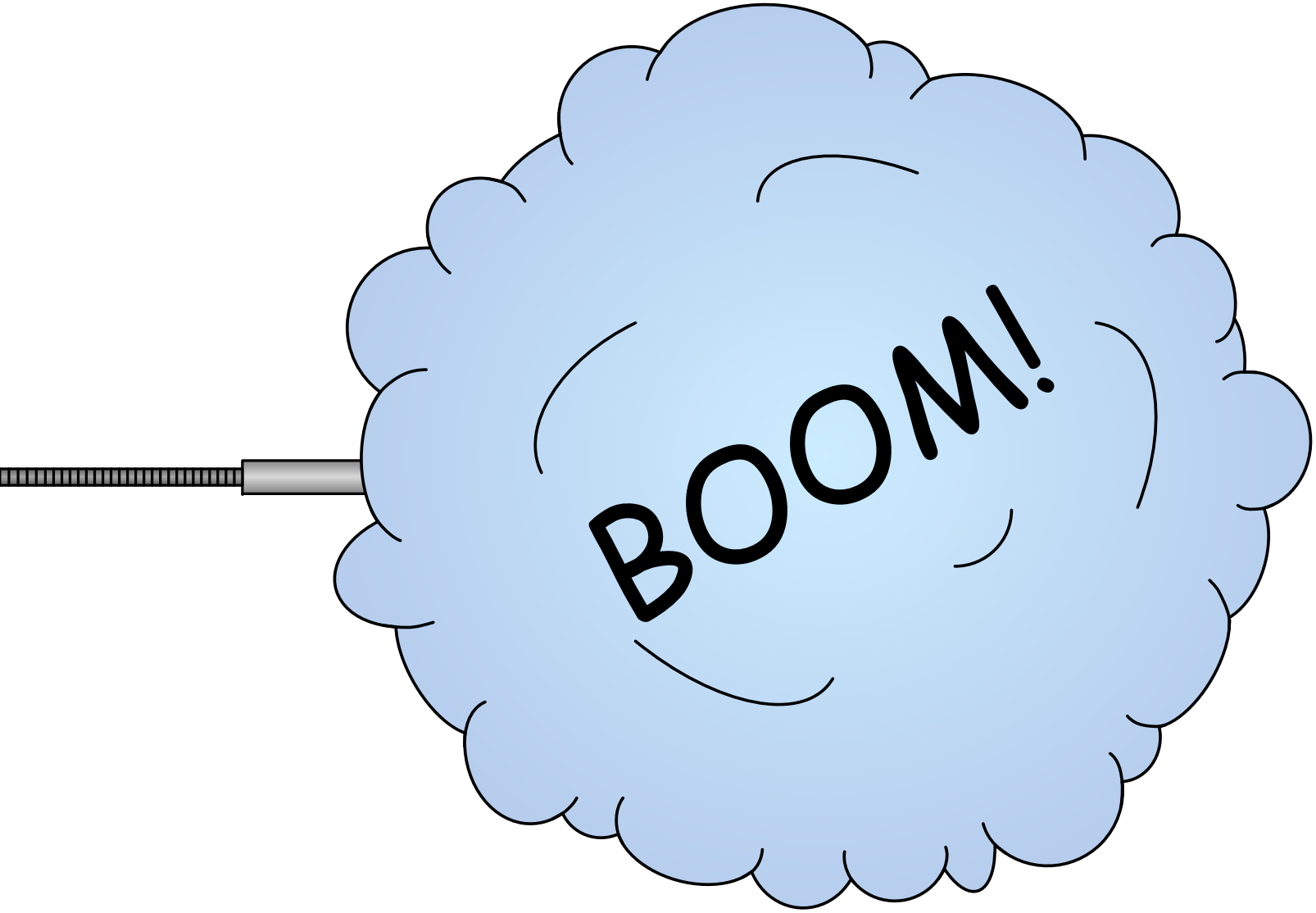


Shell CO_2 Company, Ltd. formed March 1998

…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!’

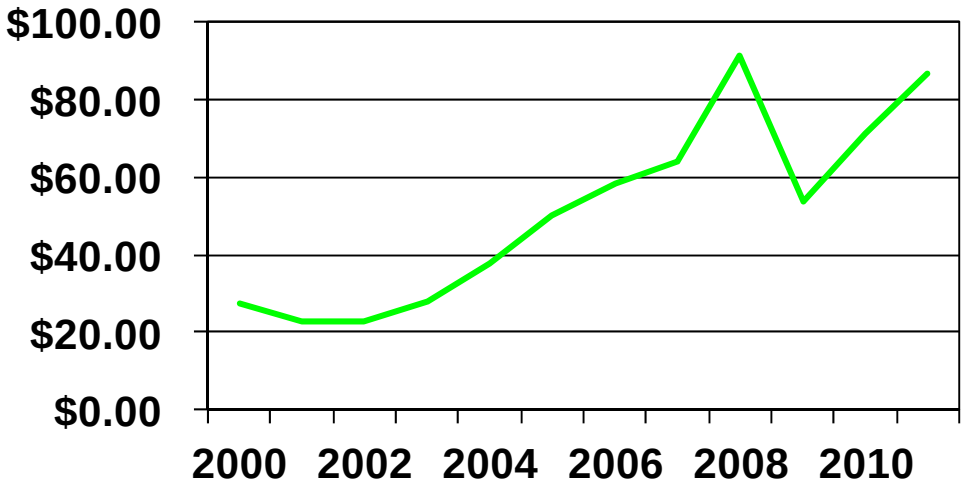
CO_2 EOR - Its not all just about the subsurface…

It takes an integrated team to make it work

- Subsurface/Geo-sciences
- Facilities engineering
- Well engineering
- Operators
- Mechanics
- Commercial
- Financial staff
- Management

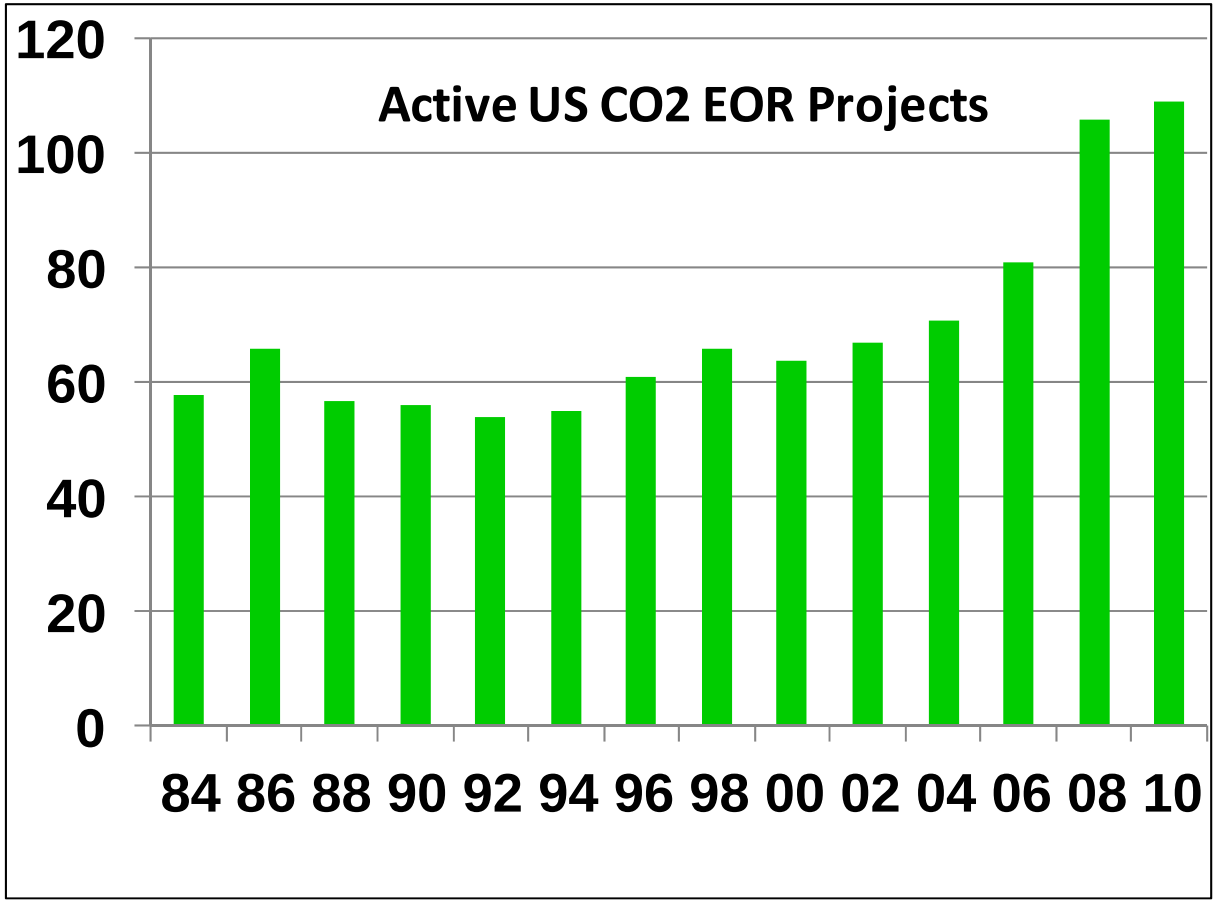
2000 to Present

Oil Prices – Historical



Oil prices began to steadily rise, finally, and the industry expanded.

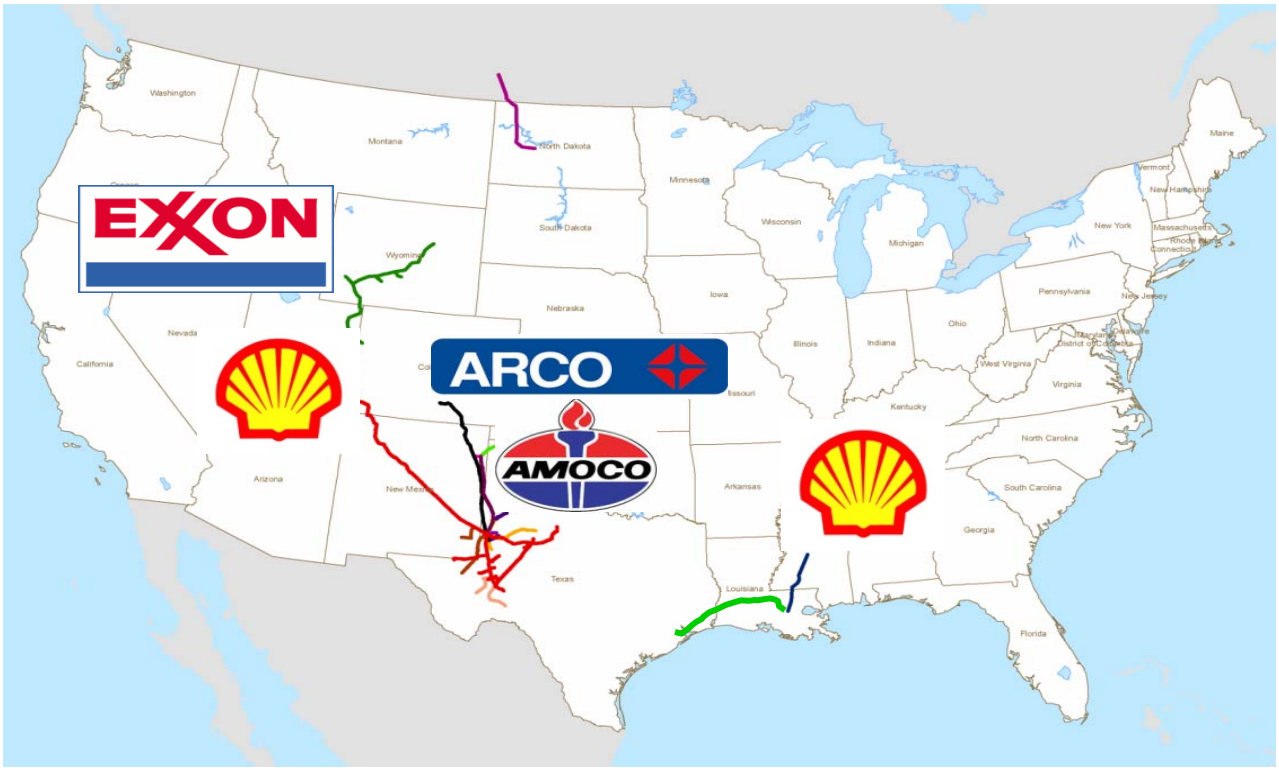
CO_2 EOR Industry has been quite busy
Despite changing ~90% of the players



Courtesy O&GJ

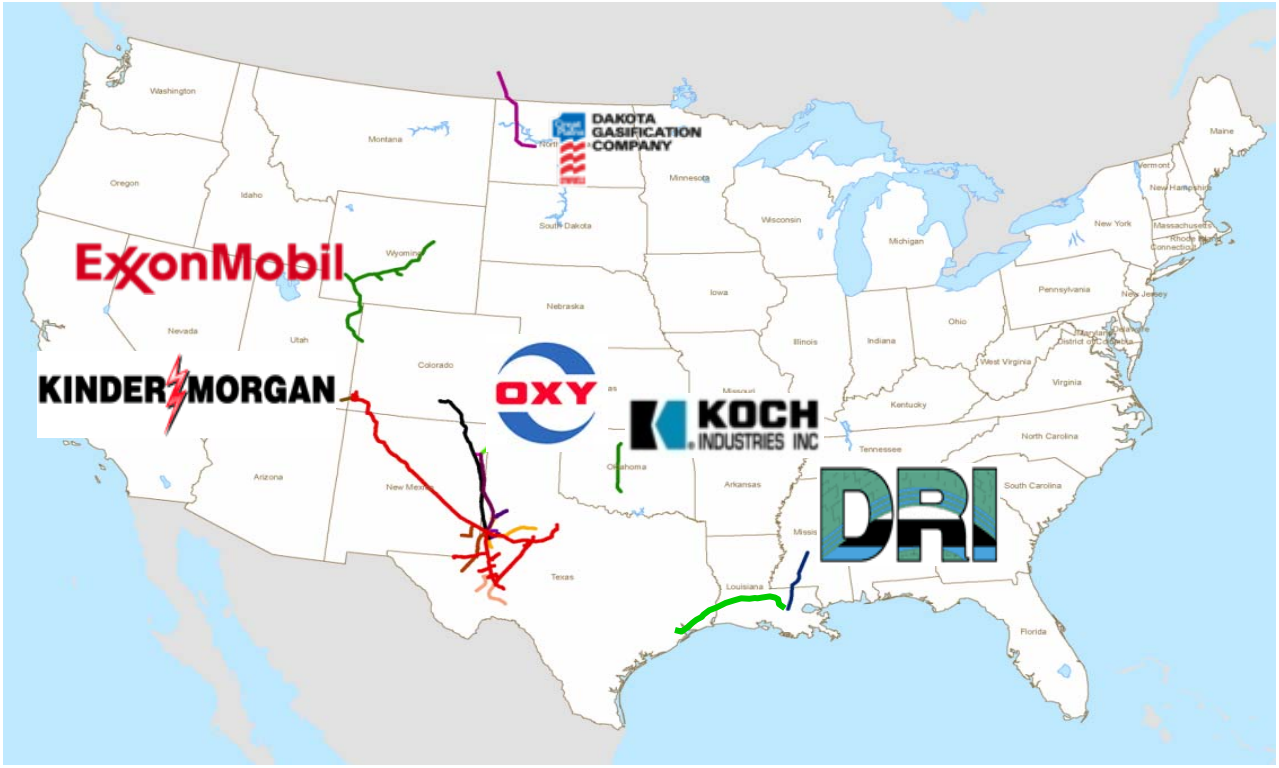
An evolving business – The industry changes hands

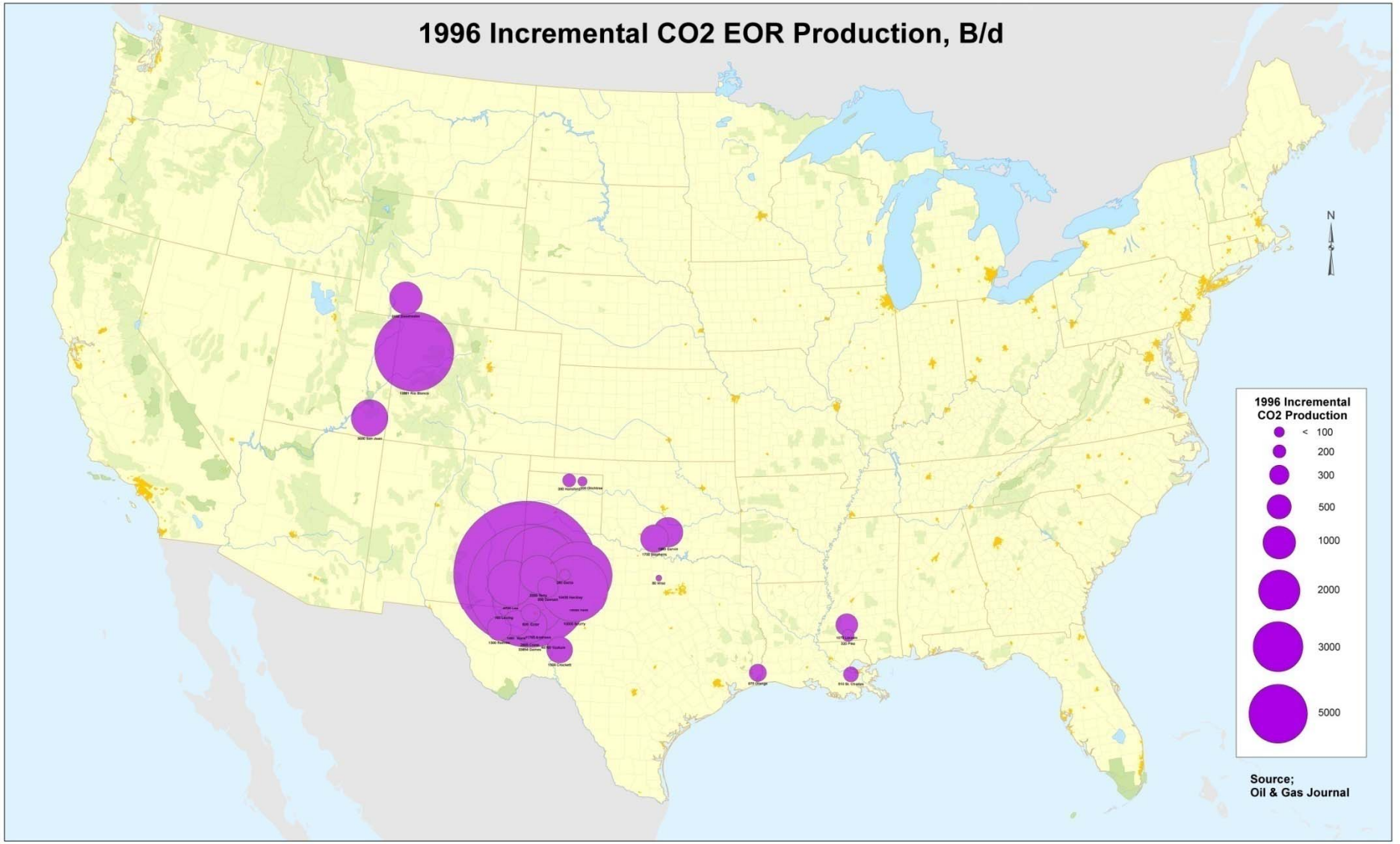
CO_2 Source and PL Operators - the 80's



An evolving business – The industry changes hands

CO_2 Source and PL Operators - Present





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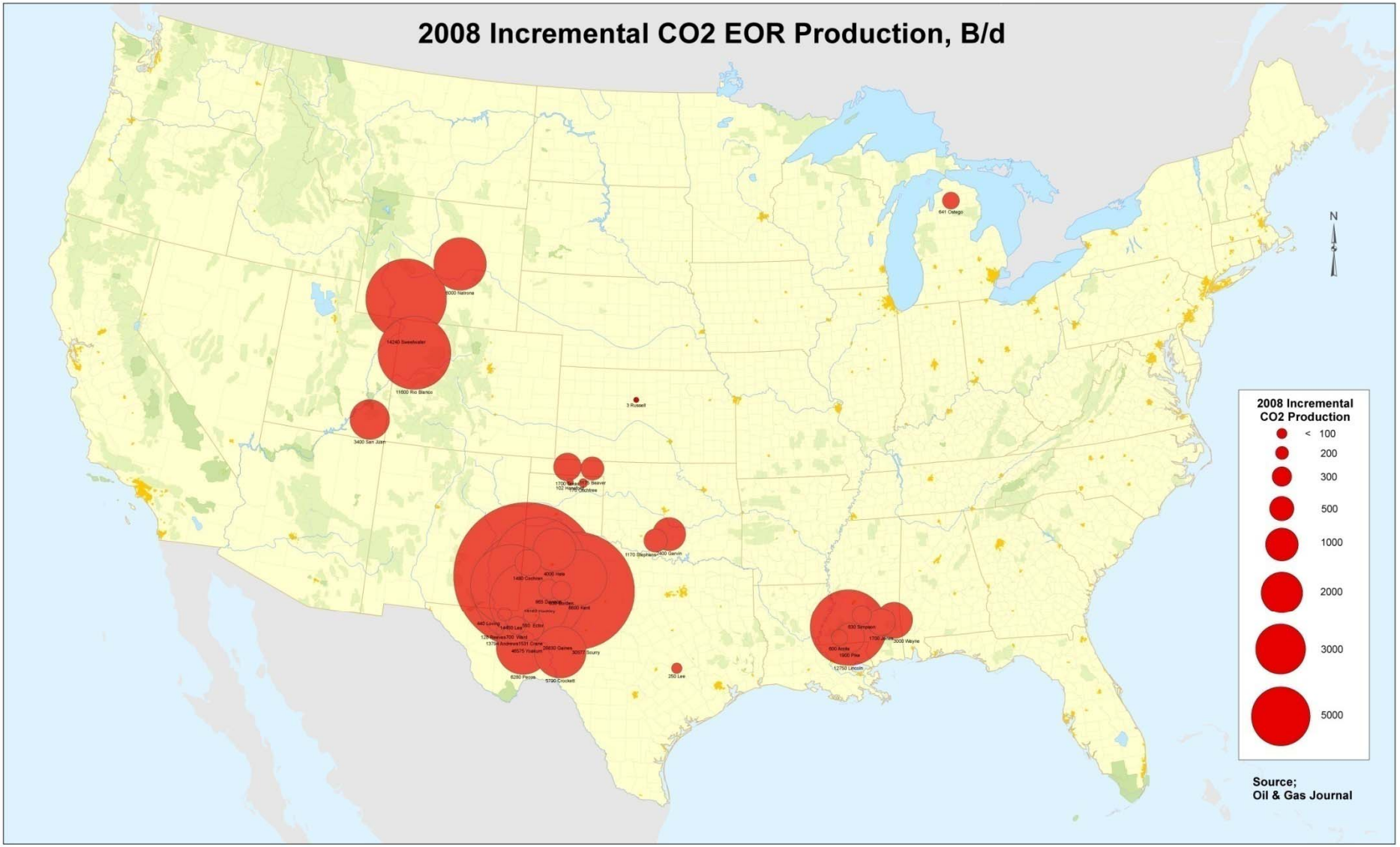
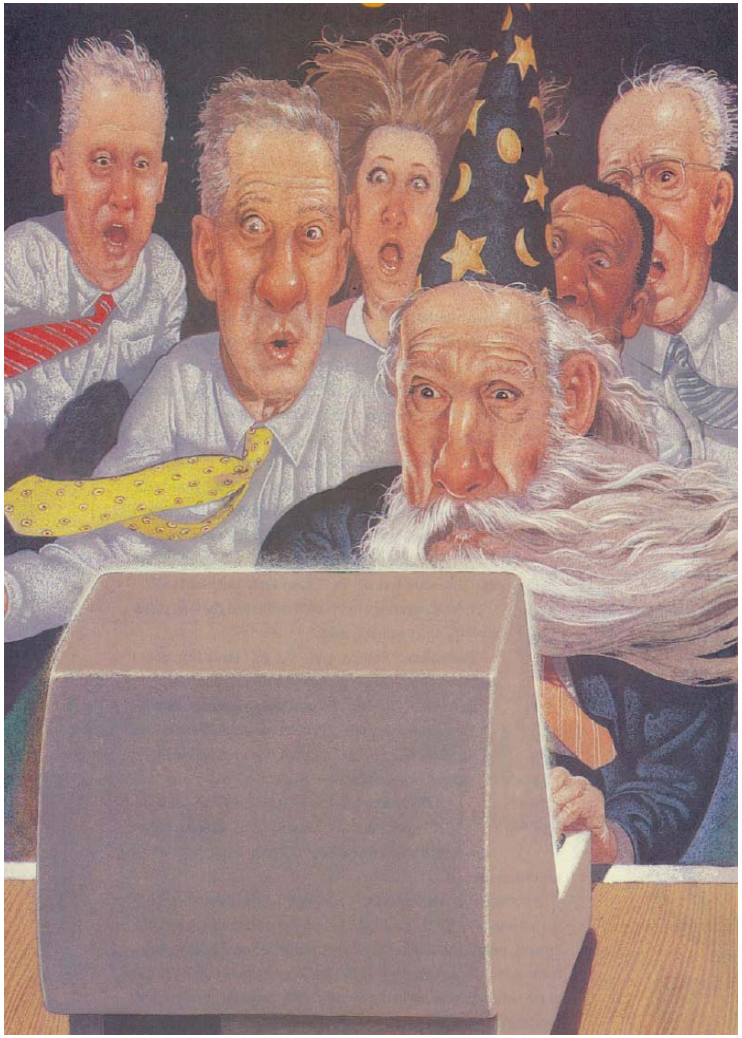


Courtesy O&GJ

Clarke's Third Law:

Any sufficiently advanced technology is indistinguishable from magic

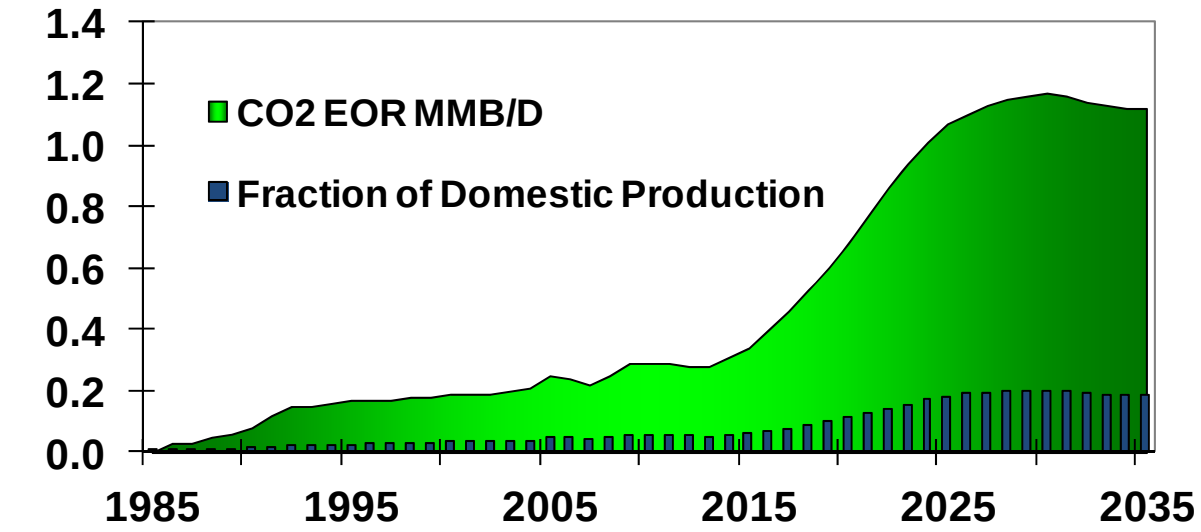


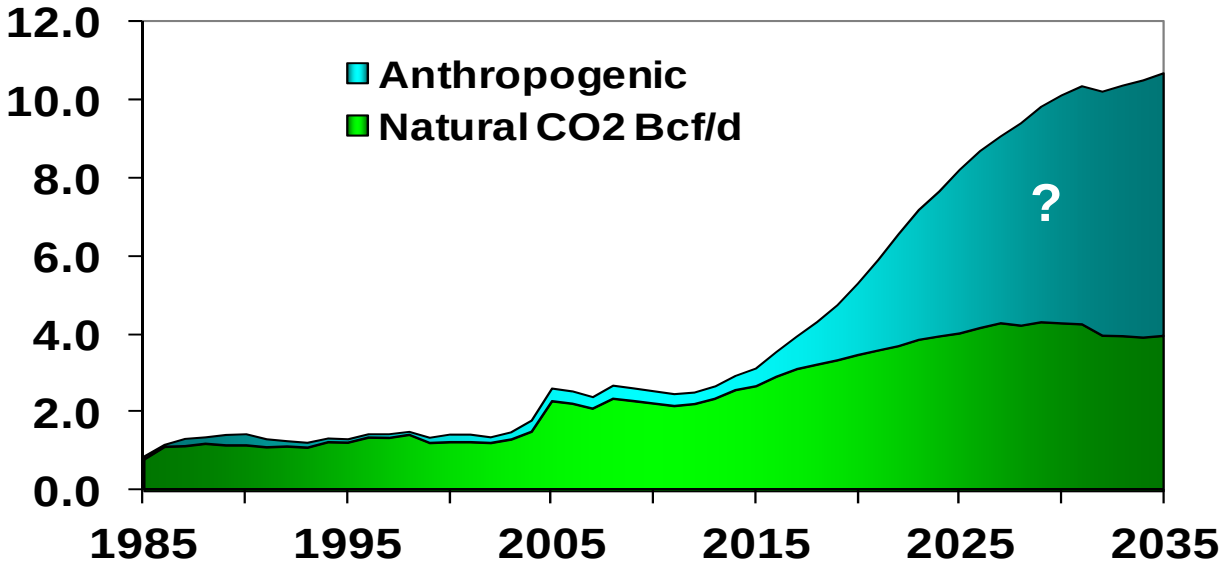
What we now take for granted:

- 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

CO_2 EOR Production/Injection History and Forecast

A solid track record and a promising future.



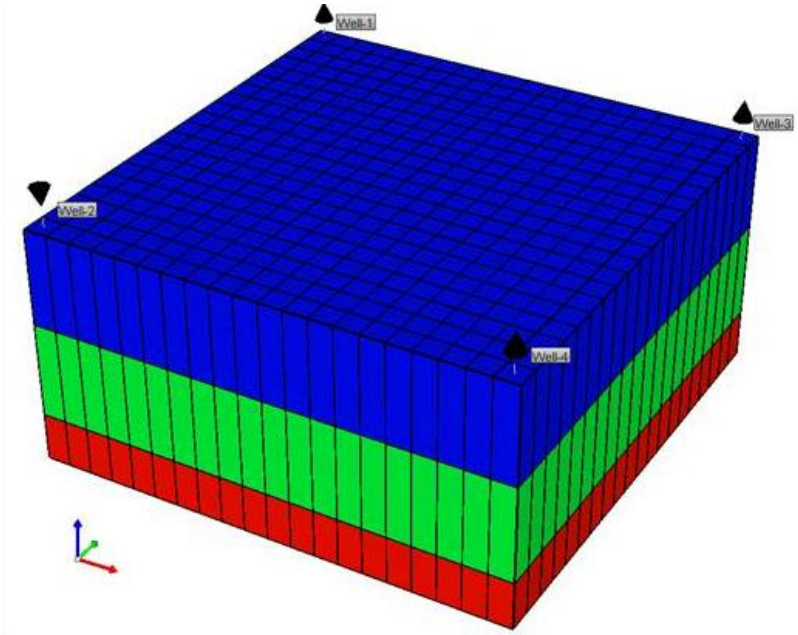


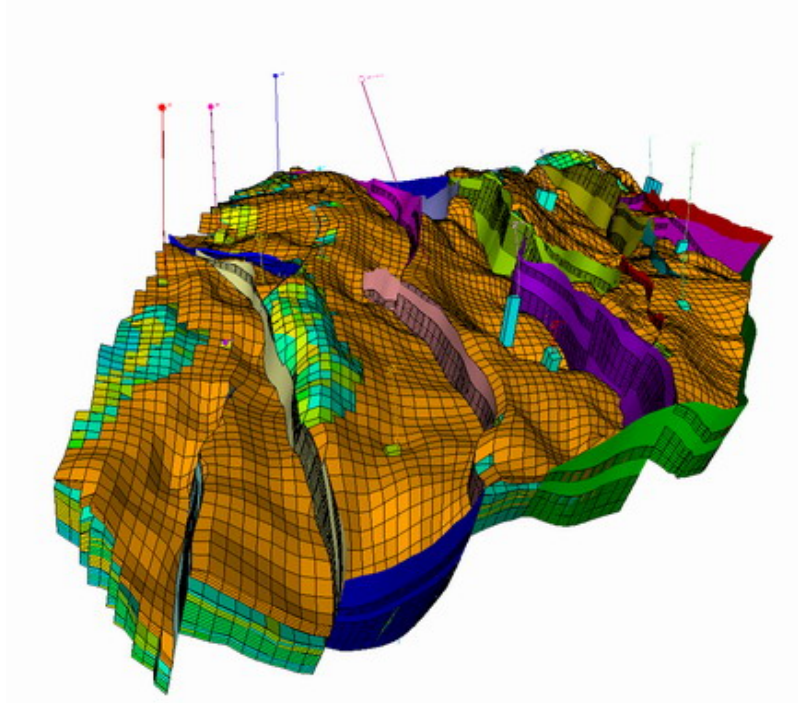
References: AEO 2011 Forecast, O&GJ, Personal Knowledge

Can we do it?

It depends…

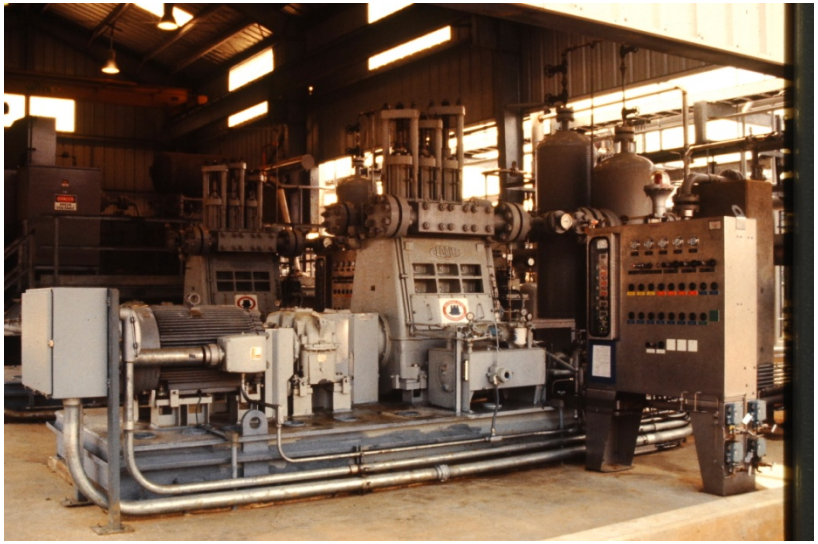
We need continued advances in technology





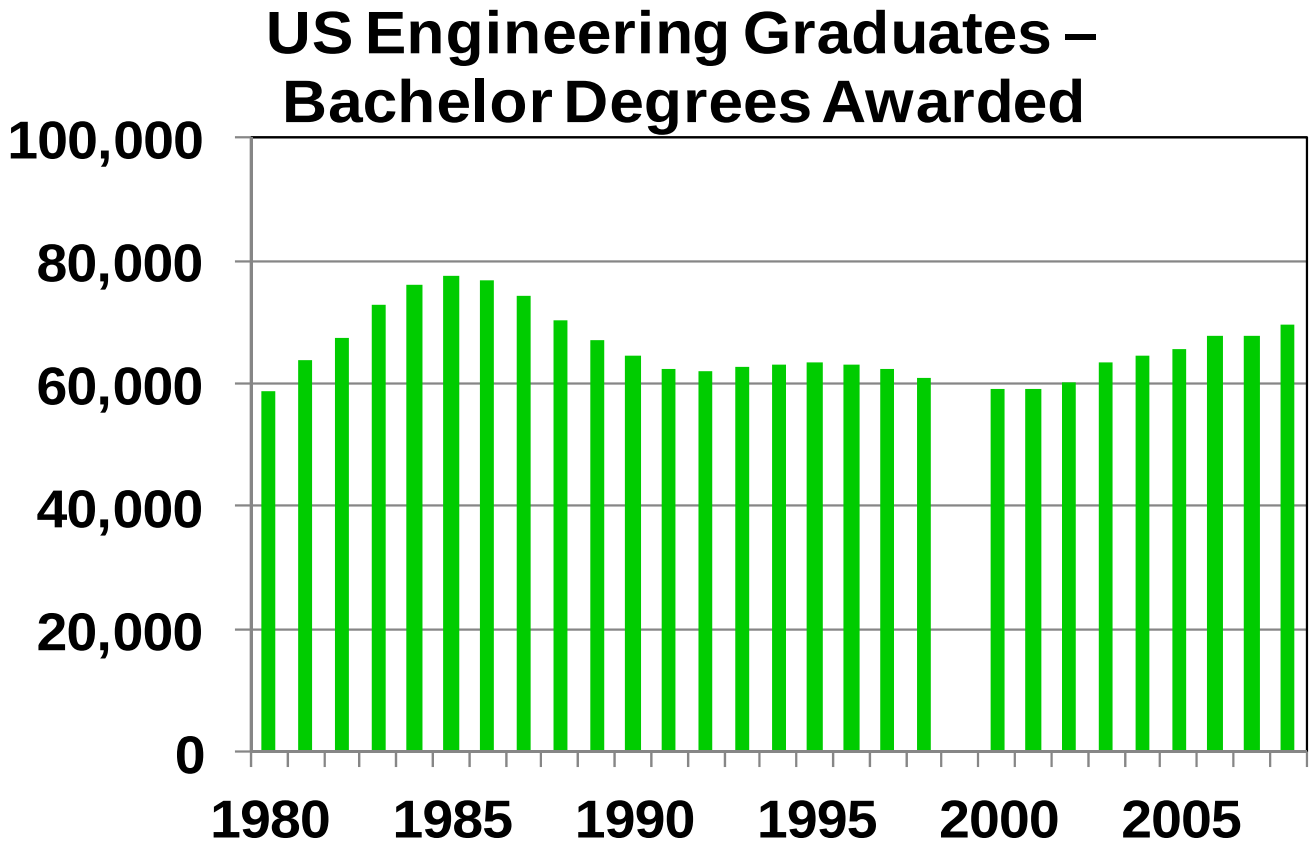
Improve results + lower risk + reduce costs = more opportunities

We need continued advances in technology



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

Snyder, Texas

“Every new CO_2 project saves a town”
- Chuck Fox

From someone who knows a lot about the energy business

Houston Business Journal Feb 16-22, 2001

Rich Kinder of Kinder Morgan:

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