

STORING CO₂ WITH “NEXT GENERATION” ENHANCED OIL RECOVERY

Prepared for:
CO₂-EOR with Carbon Sequestration Forum

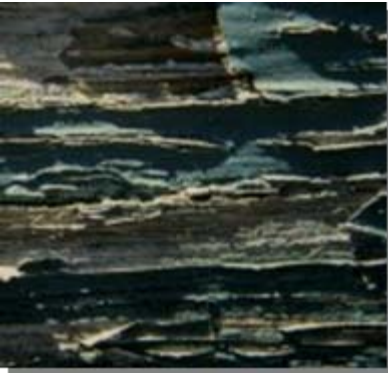
Sponsored by:
**Research Partnership to Secure Energy for America
RPSEA**

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Advanced Resources International, Inc.**

**April 23, 2008
Austin, TX**



BACKGROUND

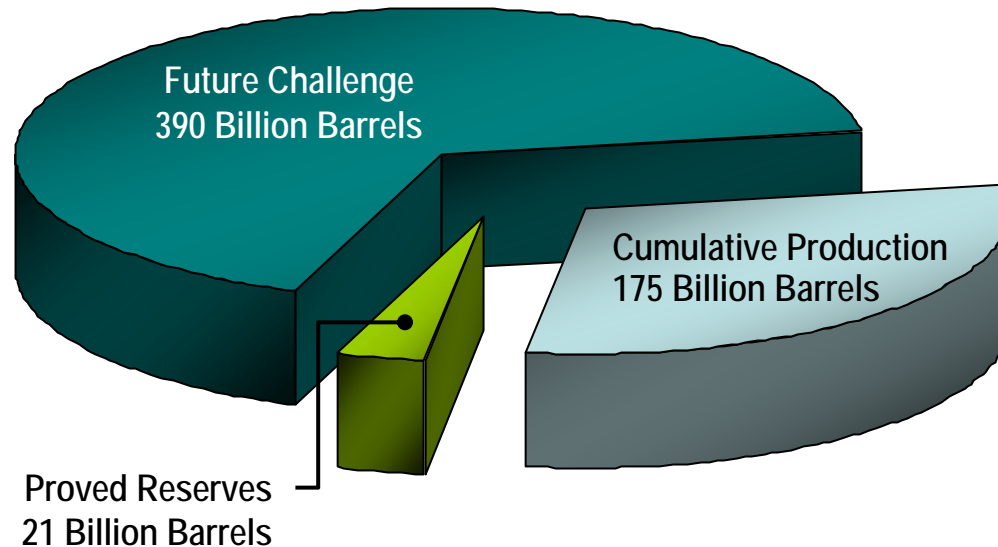


1. **Status and Outlook for CO₂-EOR**
2. **“Game Changer” CO₂-EOR Technology**
 - **Increasing Oil Recovery Efficiency**
 - **Expanding CO₂ Storage Capacity**
3. **“Early Application” of CO₂-EOR**
4. **Summary**

LARGE VOLUMES OF DOMESTIC OIL REMAIN “STRANDED” AFTER PRIMARY/SECONDARY OIL RECOVERY

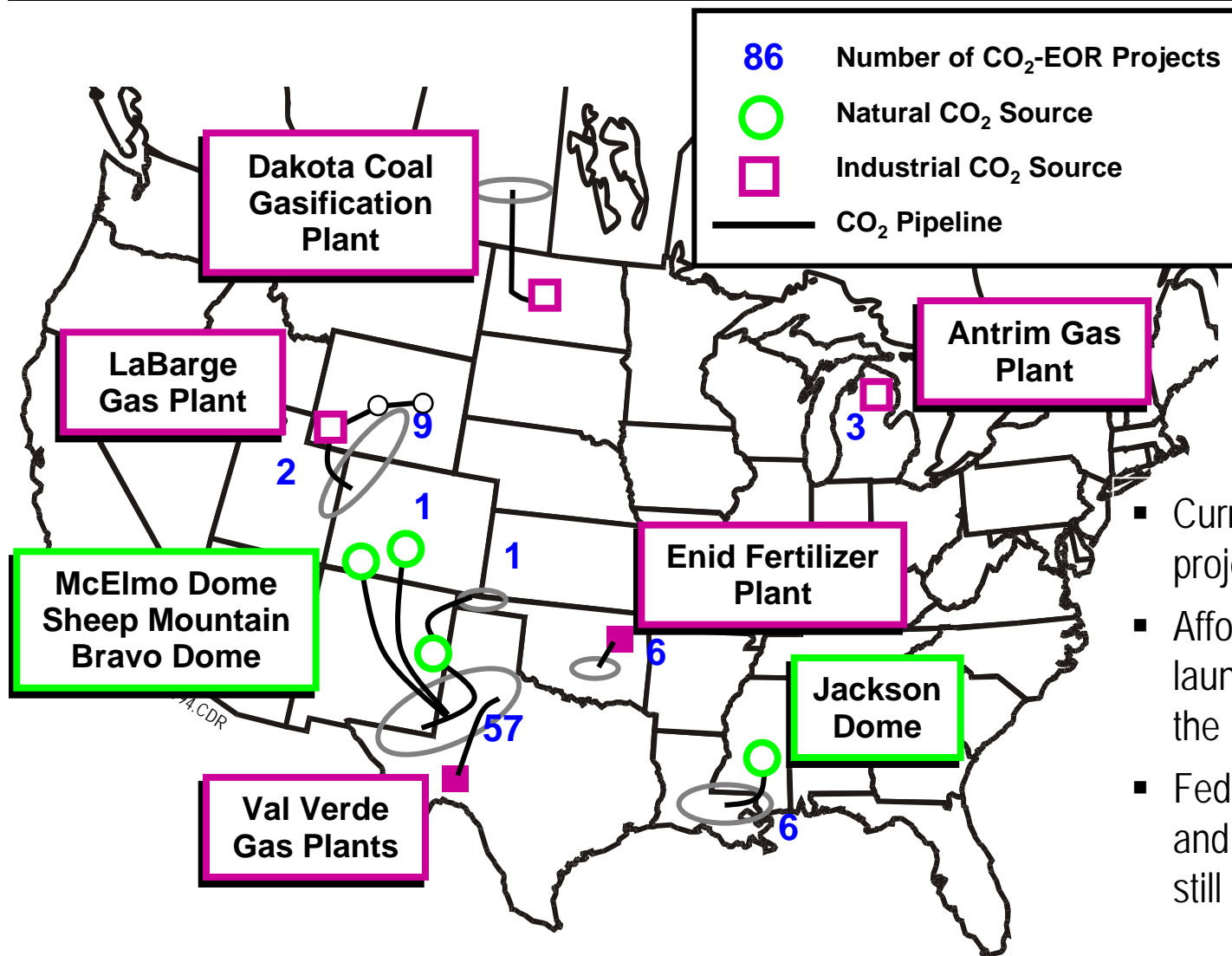
Original Oil In-Place: 596 B Barrels*

“Stranded” Oil In-Place: 400 B Barrels*



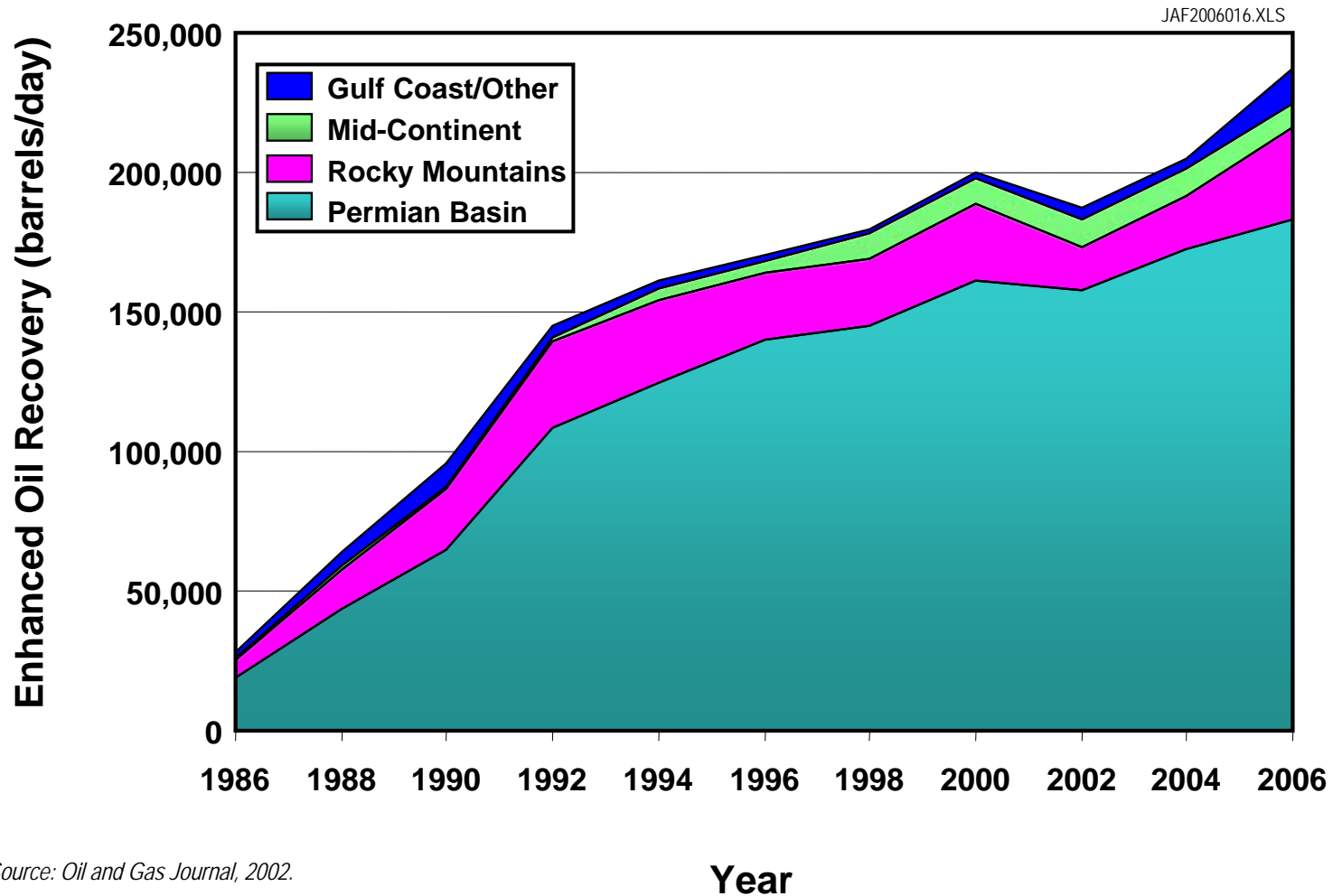
*All domestic basins except the Appalachian Basin.
Source: Advanced Resources Int'l. (2005)

U.S. CO₂-EOR ACTIVITY



- Currently, 86 CO₂-EOR projects provide 237,000 B/D
- Affordable natural CO₂ launched CO₂-EOR activity in the 1980's
- Federal tax credits (Sec.43) and state severance tax relief still encourage CO₂-EOR

GROWTH OF CO₂-EOR PRODUCTION IN THE U.S.



Source: Oil and Gas Journal, 2002.

CO₂- EOR ACTIVITY OUTSIDE OF THE U.S.

	Area	Formation	Depth	Oil Gravity	Viscosity
Canada					
Weyburn Unit	9,900	LS/Dolo	4,660'	28°	3 cp
Joffre	6,625	Sand	4,900'	42°	1 cp
Trinidad					
Forest Reserve	500	Sand	2,000-4,200'	17-25°	10-100+ cp
Oropouche	175	Sand	2,400'	29°	5 cp
Turkey					
Bati Raman	12,890	LS	4,260'	13°	590 cp

Numerous hydrocarbon miscible and nitrogen EOR projects exist in Canada, Libya, UAE, Mexico and Venezuela that would be favorable and convert to CO₂-EOR

In addition, CO₂-EOR has been discussed for oil fields in the North Sea.

OUTLOOK FOR CO₂-EOR

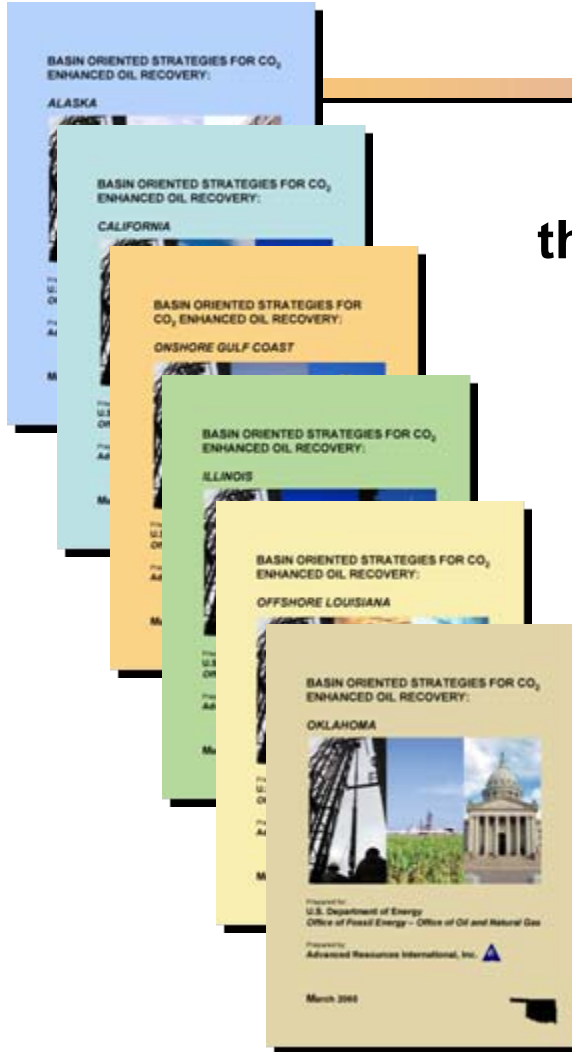
Recently updated study of applying “state-of-the-art” CO₂-EOR in the U.S. indicate:

- 88 billion barrels of technically recoverable resource,
- From 39 to 48 billion barrels of economically recoverable resource, depending on oil price and CO₂ costs.

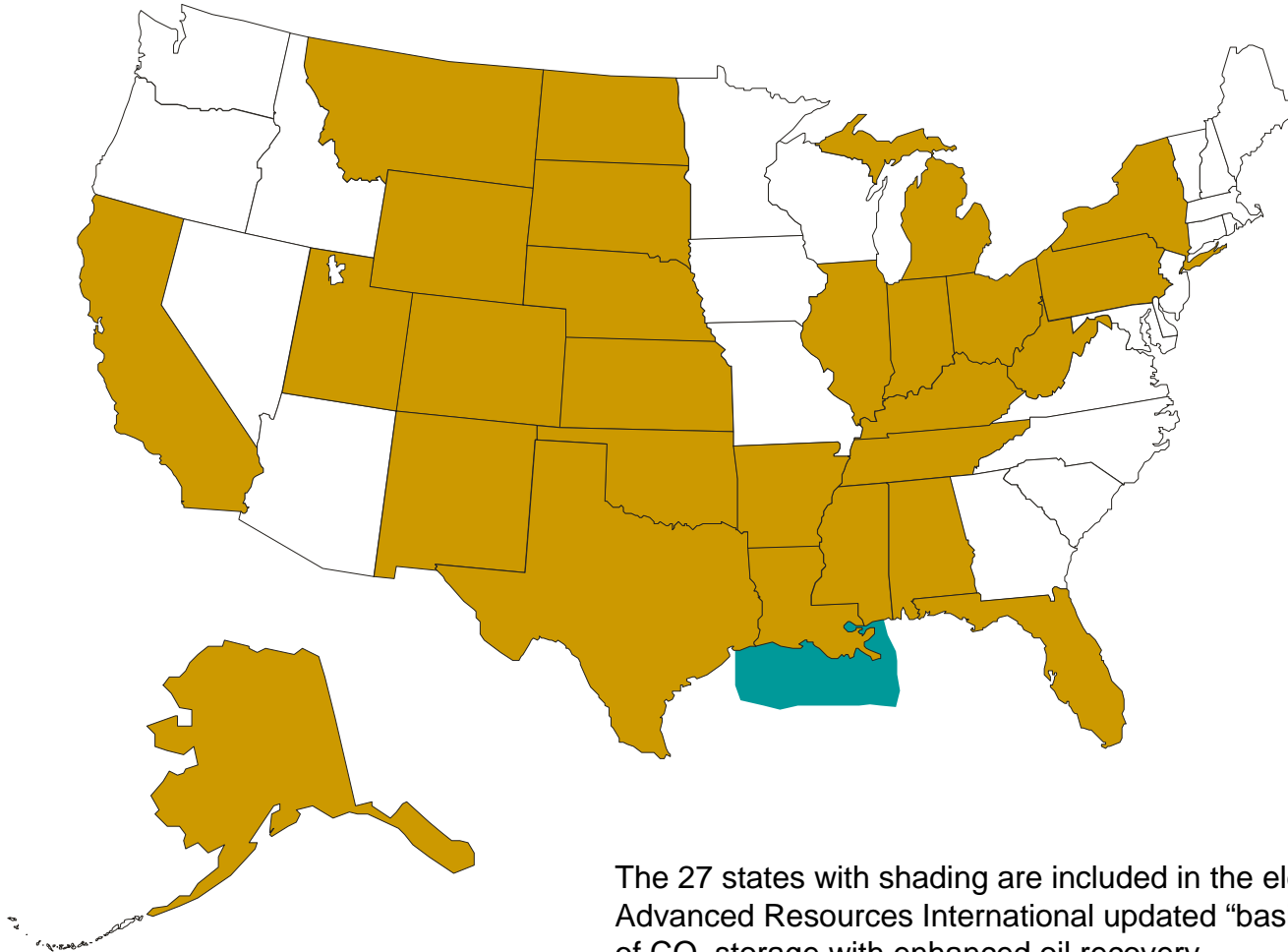
Results are based on applying streamline reservoir simulation to 2,012 large oil reservoirs (74% of U.S. oil production).

Previous version of the “basin studies” are available on the U.S. DOE web site.

http://www.fe.doe.gov/programs/oilgas/eor/Ten_Basin-Oriented_CO2-EOR_Assessments.html



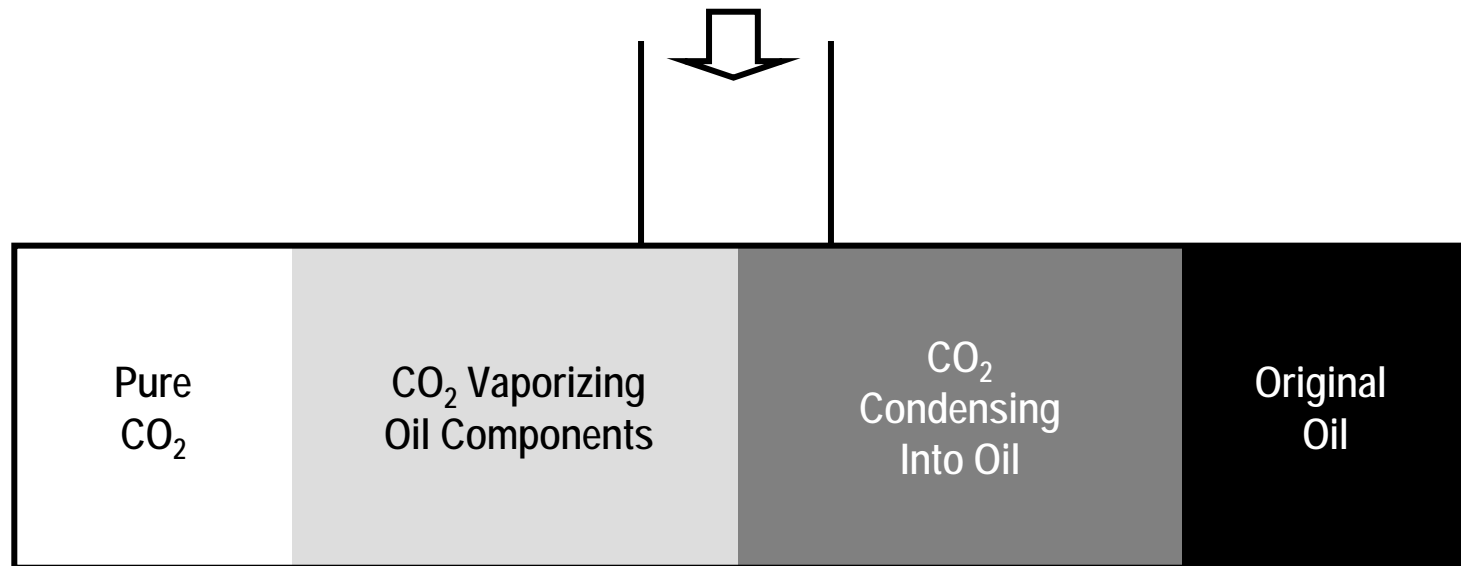
U.S. BASINS/REGIONS STUDIED FOR CO₂ STORAGE AND ENHANCED OIL RECOVERY



The 27 states with shading are included in the eleven Advanced Resources International updated “basin studies” of CO₂ storage with enhanced oil recovery.

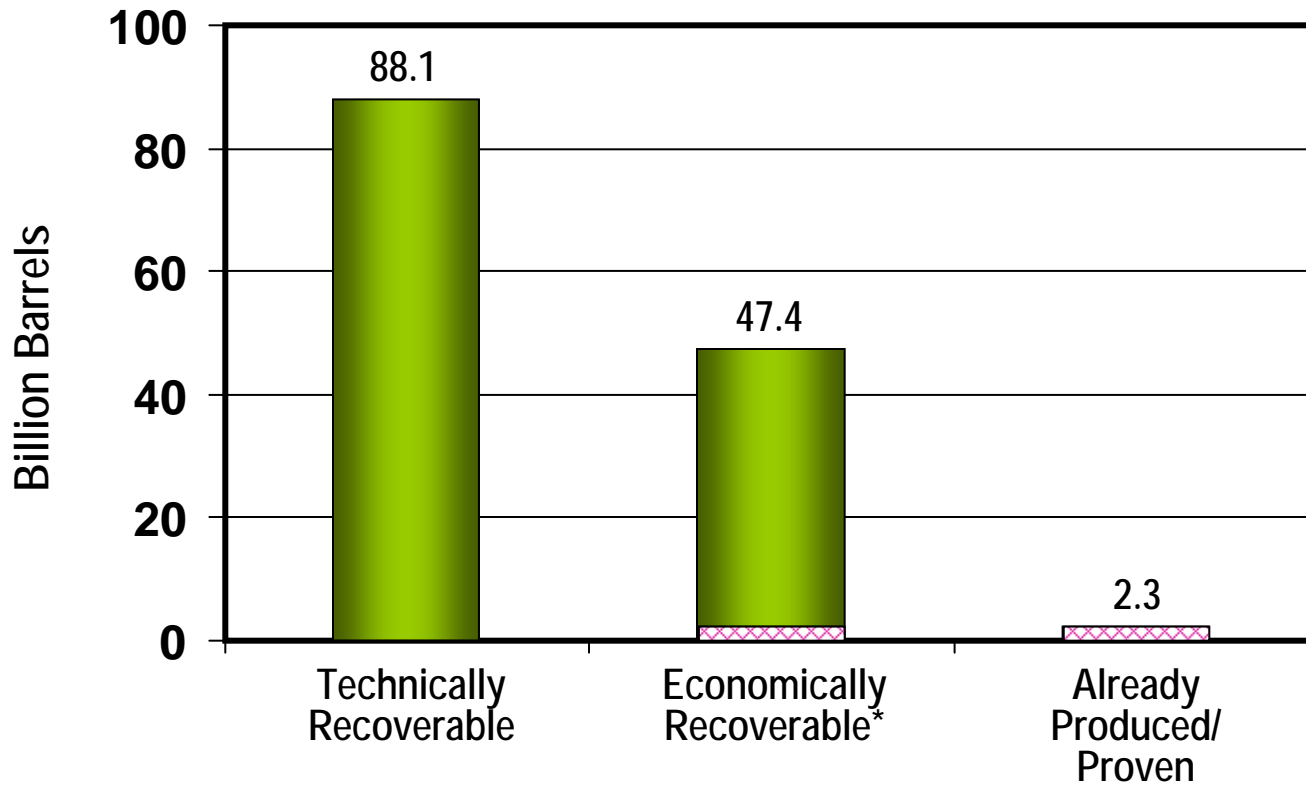
ONE-DIMENSIONAL SCHEMATIC OF THE CO₂ MISCIBLE PROCESS

*Miscibility is Developed in This Region
(CO₂ and Oil Form Single Phase)*



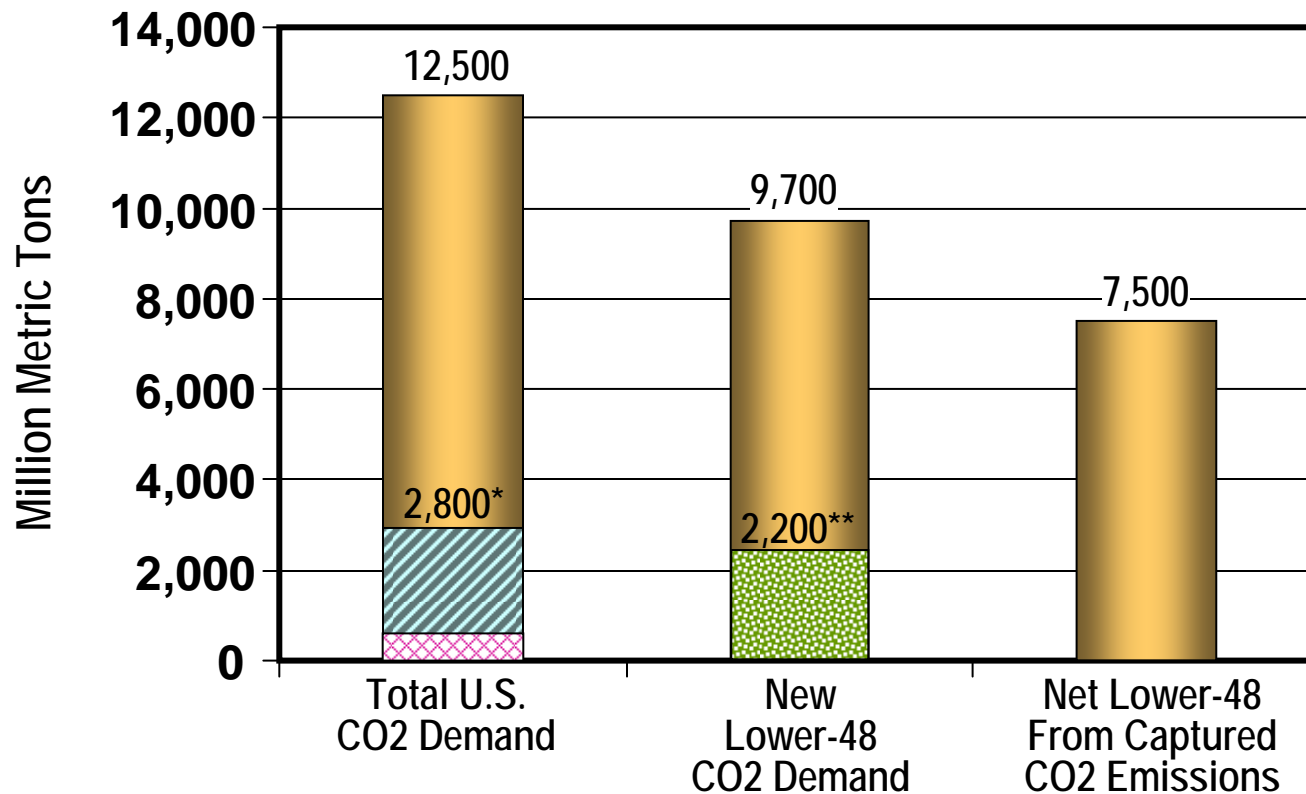
Direction of Displacement 

DOMESTIC OIL RESOURCES TECHNICALLY AND ECONOMICALLY RECOVERABLE W/CO₂-EOR



*Assuming oil price of \$70/B (real); CO₂ costs (delivered to field at pressure) of \$45/metric ton (\$2.38/Mcf); investment hurdle rate (15%, real).

MARKET DEMAND FOR CO₂ BY THE ENHANCED OIL RECOVERY INDUSTRY⁽¹⁾



*CO₂ demand in Alaska is already being met by on-going CO₂-EOR projects

**CO₂ demand that can be met by natural CO₂ and already being captured CO₂ emissions.

(1) Economic CO₂ market demand for EOR at oil price of \$70/B (real), CO₂ cost of \$45/mt, and ROR of 15% (real).

SOURCES OF CO₂

State/ Province (storage location)	Source Type (location)	CO ₂ Supply MMcfd**	
		Natural	Anthropogenic
Texas-Utah-New Mexico- Oklahoma	Geologic (Colorado-New Mexico) Gas Processing (Texas)	1,700	110
Colorado-Wyoming	Gas Processing (Wyoming)	-	340
Mississippi	Geologic (Mississippi)	400	-
Michigan	Ammonia Plant (Michigan)	-	15
Oklahoma	Fertilizer Plant (Oklahoma)	-	35
Saskatchewan	Coal Gasification (North Dakota)	-	145
TOTAL		2,100	645

* Source: 12th Annual CO₂ Flooding Conference, Dec. 2006

** MMcfd of CO₂ can be converted to million metric tons per year by first multiplying by 365 (days per year) and then dividing by 18.9 * 10³ (Mcf per metric ton).

“NEXT GENERATION” CO₂-EOR TECHNOLOGY

Reservoir modeling and selected field tests show that high oil recovery efficiencies are possible with innovative applications of CO₂-EOR.

So far, except for a handful of cases, the actual performance of CO₂-EOR has been less than optimum due to:

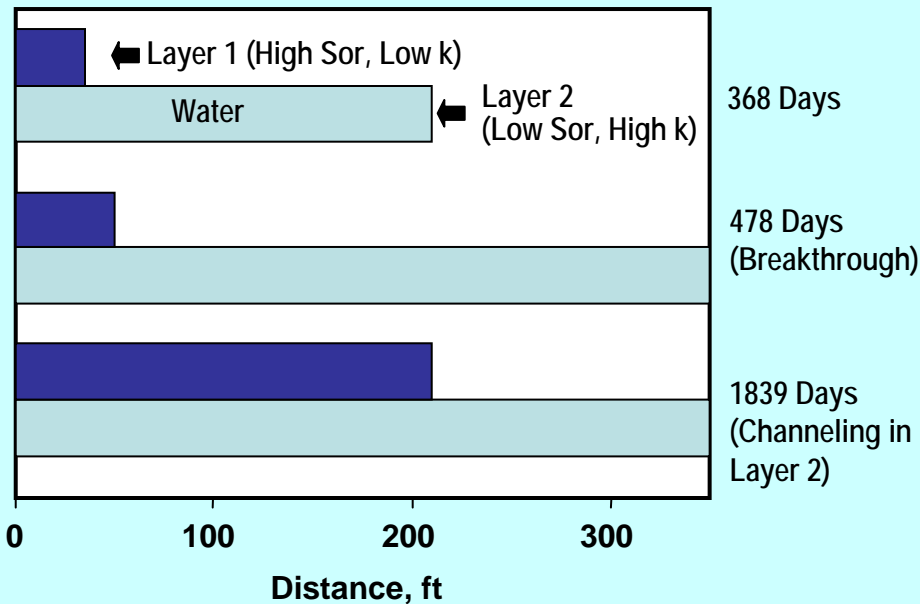
- **Geologically complex reservoirs**
- **Limited process control**
- **Insufficient CO₂ injection**

IMPACT OF GEOLOGIC COMPLEXITY ON CO₂-EOR PERFORMANCE

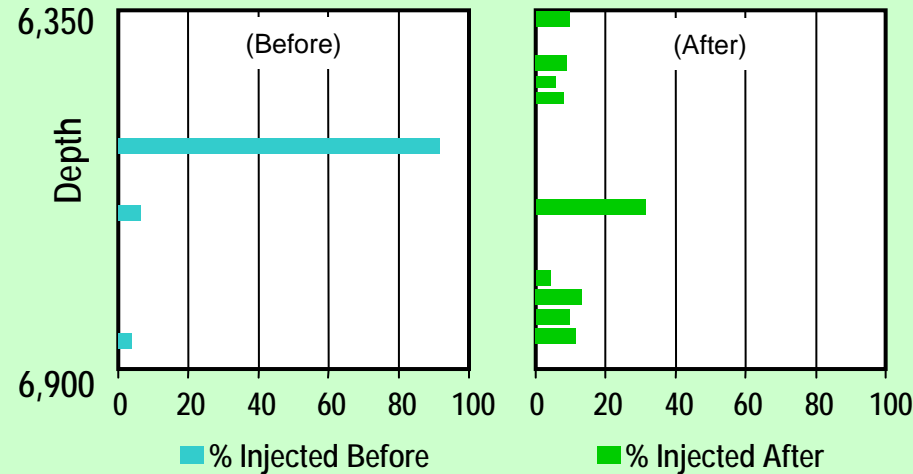
Inability to target injected CO₂ to reservoir strata with high residual oil saturation.

- Higher oil saturation portion of reservoir is inefficiently swept;
- CO₂ channeling reduced with well workover.

Relative Location of the Water Front



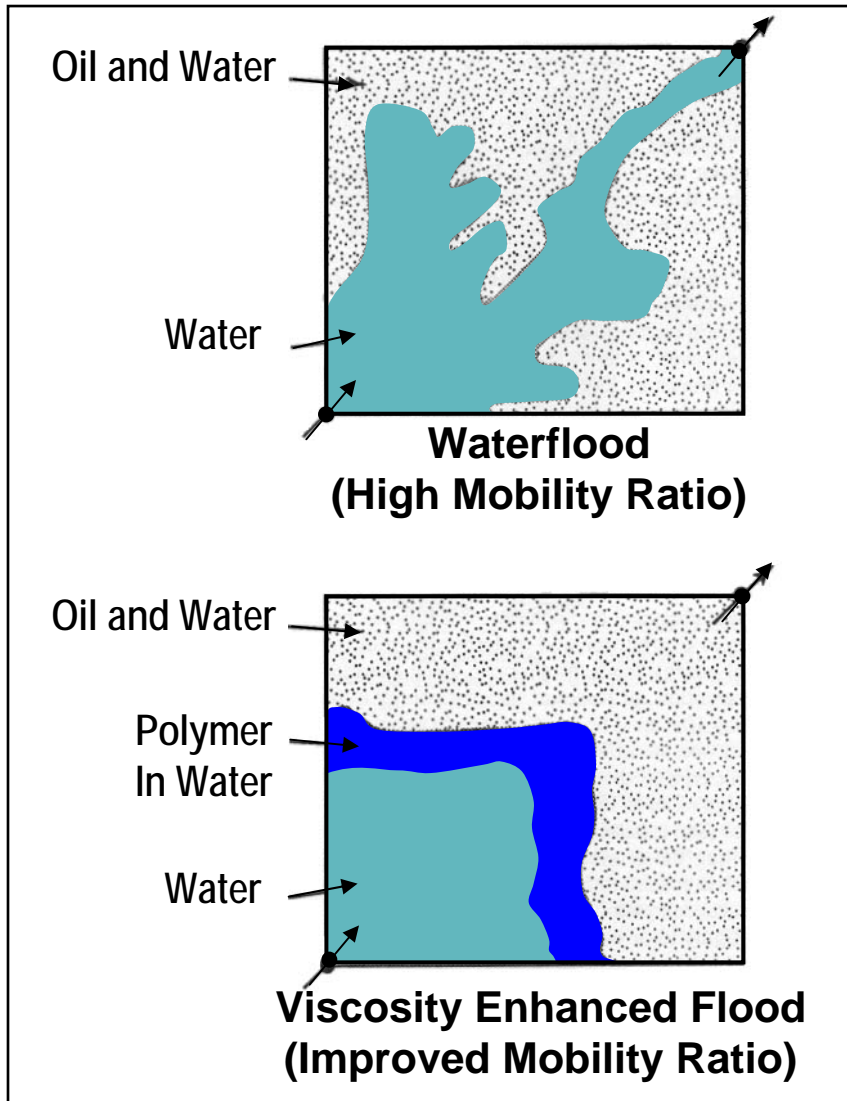
Well 27-6 Injection Profile



Source: Adapted by Advanced Resources Int'l from "Enhanced Oil Recovery", D.W. Green and G. P. Willhite, SPE, 1998.

Source: "SACROC Unit CO₂ Flood: Multidisciplinary Team Improves Reservoir Management and Decreases Operating Costs", J.T. Hawkins, et al., SPE Reservoir Engineering, August 1996.

IMPACT OF LIMITED PROCESS CONTROL ON CO₂-EOR PERFORMANCE



Injected CO₂ achieves only limited contact with the reservoir due to:

- Viscous fingering
- Gravity override

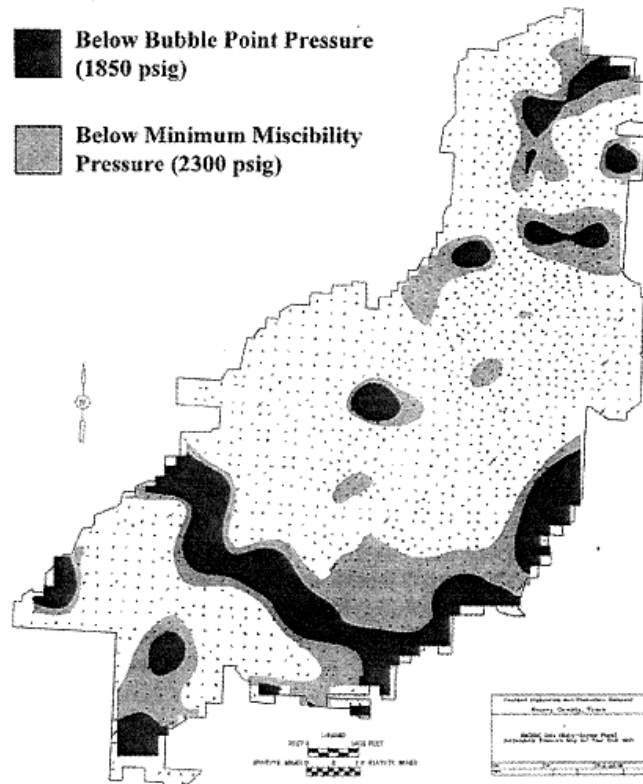
Addition of viscosity enhancers would improve mobility ratio and reservoir contact.

Use of “smart fluids”, as reported by ARAMCO and BP, offer promise.

Source: Adapted by Advanced Resources Int'l from “Enhanced Oil Recovery”, D.W. Green and G. P. Willhite, SPE, 1998.

IMPACT OF LIMITED PRESSURE CONTROL ON CO₂-EOR PERFORMANCE

SACROC Unit 1992 Pressure Contour Map.



Analysis of past CO₂ floods also shows that, in many cases, the CO₂-EOR project was operated below miscibility pressure in positions of the reservoir.

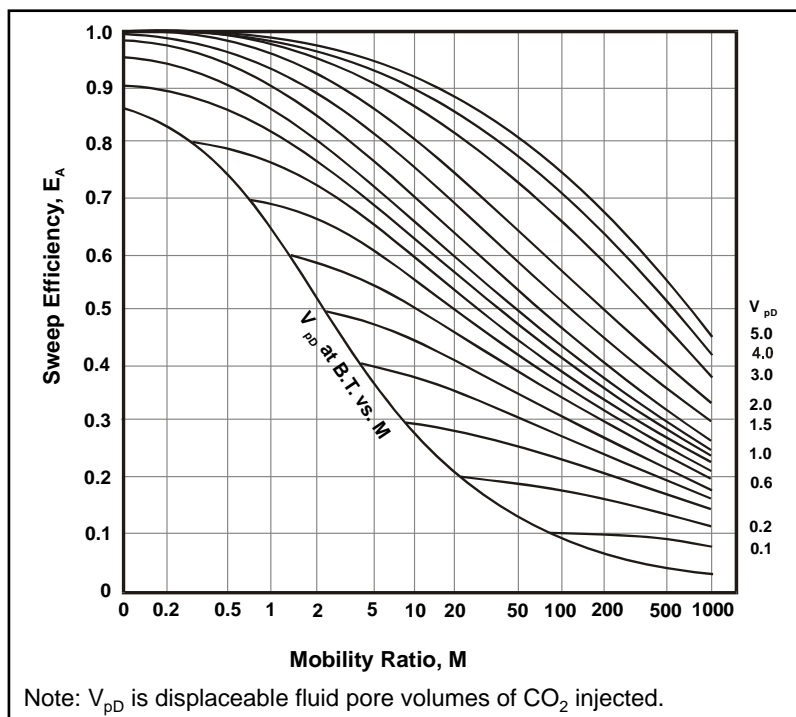
This was caused by low well operating pressures, too few injection wells, and failure to maintain a favorable fluid balance.

Crosshatch shading indicates areas below MMP (2,300 psig) and solid shading indicates areas below bubblepoint pressure (1,850 psig).

IMPACT OF INSUFFICIENT CO₂ INJECTION ON CO₂-EOR PERFORMANCE

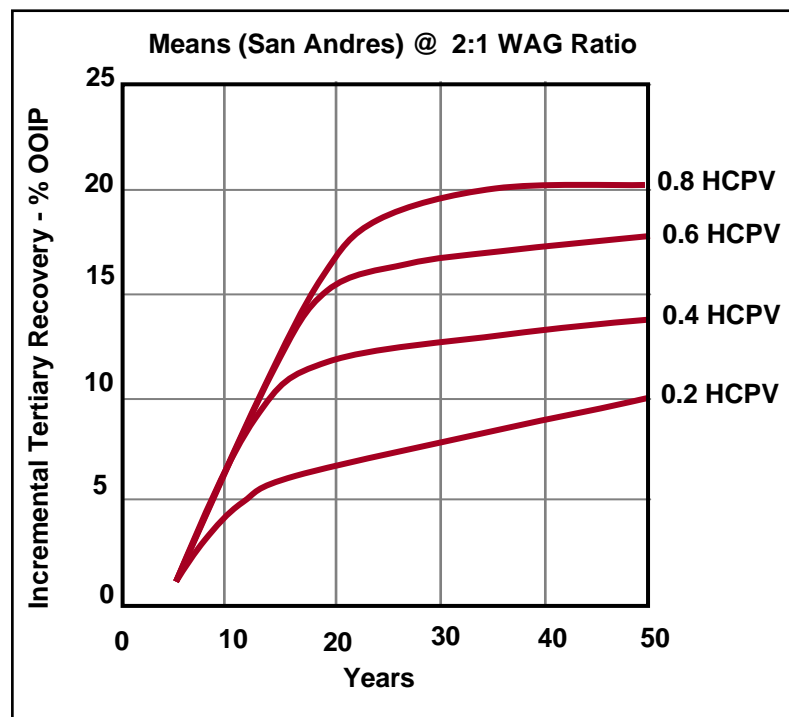
Because of high CO₂ costs and lack of process control, most older CO₂ floods used too little CO₂.

Sweep Efficiency in Miscible Flooding



Source: Claridge, E.L., "Prediction of Recovery in Unstable Miscible Displacement", SPE (April 1972).

Injected CO₂ vs Oil Recovery



Source: SPE 24928 (1992)

EVOLUTION OF “INDUSTRY STANDARD” FOR VOLUME CO₂ INJECTION (“SLUG SIZE”)

Eastern Denver Unit (Wasson Oil Field) CO₂-EOR Project

Started

Start of CO₂ injection in EDU with 40% slug size

1984

Non performing FIA patterns stopped (~20% slug size)

1992

EDU 40% to 60% CO₂ slug size increase approved

1994

EDU 60% to 80% CO₂ slug size increase approved

1996

EDU 80% to 100% CO₂ slug size increase approved

2001

Source: OXY Permian 2006

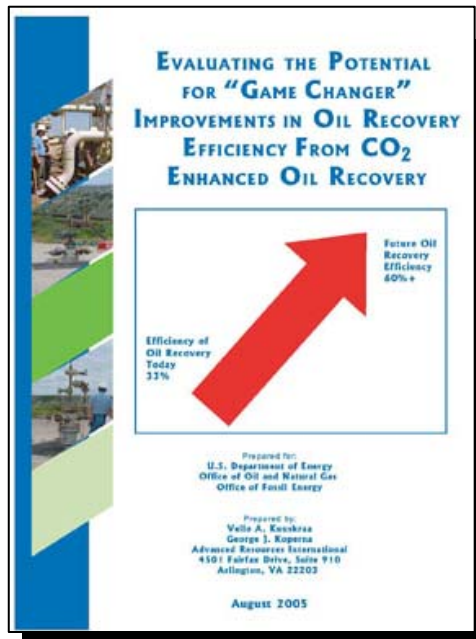
“NEXT GENERATION” CO₂-EOR TECHNOLOGY

Over coming these technical barriers requires
“next generation” CO₂-EOR technology:

- **Innovative Flood Design and Well Placement.** Adding horizontal production wells and vertical CO₂ injection wells, enabling CO₂ to contact residual oil from poorly swept portions of the reservoir.
- **Viscosity and Miscibility Enhancement.** Adding mobility control with viscosity enhancers and lowering MMP with miscibility enhancers.
- **Increased Volume of CO₂ Injection.** Injecting up to 1.5 HCPV of CO₂.
- **Flood Performance Diagnostics and Control.** Fully staffed technical team. Uses instrumented observation wells and downhole sensors to monitor progress. Conducts periodic 4-D seismic and pressure plus zone-by-zone flow tests (among others) to “manage and control” the CO₂ flood.

“NEXT GENERATION” CO₂-EOR TECHNOLOGY (Cont'd)

The DOE report, ***“Evaluating the Potential for “Game Changer” Improvements in Oil Recovery Efficiency from CO₂-Enhanced Oil Recovery”***:



- Reviews performance of past CO₂-EOR floods.
- Sets forth theoretically and scientifically possible advances in technology for CO₂-EOR.
- Examines how much “Next Generation” CO₂-EOR technology would increase oil recovery and CO₂ storage capacity.

Available on the U.S. DOE web site.

http://www.fe.doe.gov/programs/oilgas/publications/eor_co2/Game_Changer_Document.pdf

DOMESTIC OIL RESOURCES TECHNICALLY RECOVERABLE W/”NEXT GENERATION” CO₂-EOR

“Next Generation” CO₂-EOR would significantly improve domestic oil recovery efficiency.

Basin Studies	OOIP (BBbls)	Favorable Reservoirs (#)	Technically Recoverable	
			State-of-the-Art (BBbls)	Next Generation (BBbls)
Six Basins*	309	553	43.3	83.7
Eleven Basins**	596	1,111	88.1	?

*"Evaluating the Potential for "Game Changer" Improvements in Oil Recovery Efficiency from CO₂ Enhanced Oil Recovery", Advanced Resources International, report prepared for the U.S. DOE, Office of Oil and Natural Gas, Office of Fossil Energy, August 2005. http://www.fe.doe.gov/programs/oilgas/eor/Game_Changer_Oil_Recovery_Efficiency.html.

**"Storing CO₂ with Enhanced Oil Recovery" Advanced Resources International, report prepared for U.S. DOE/NETL, Office of Systems, Analyses and Planning, DOE/NETL-402/1312/02-07-08, February 7, 2008. http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20EOR_FINAL.pdf.

INTEGRATING CO₂-EOR AND CO₂ STORAGE

Expanding CO₂ Storage Capacity: A Case Study. Large Gulf Coast oil reservoir with 340 million barrels (OOIP) in the main pay zone.

- Primary/Secondary Oil Recovery: 153 million barrels (45% of OOIP)
- Main Pay Zone:
 - Depth - - 14,000 feet
 - Oil Gravity - - 33°API
 - Porosity - - 29%
 - Net Pay - - 325 feet
 - Initial Pressure - - 6,620 psi
 - Miscibility Pressure - - 3,250 psi

Another 100 million barrels (OIP) in the underlying 130 feet of residual oil zone and an underlying saline reservoir 195 feet thick.

Theoretical CO₂ storage capacity: 2,710 Bcf (143 million tonnes)

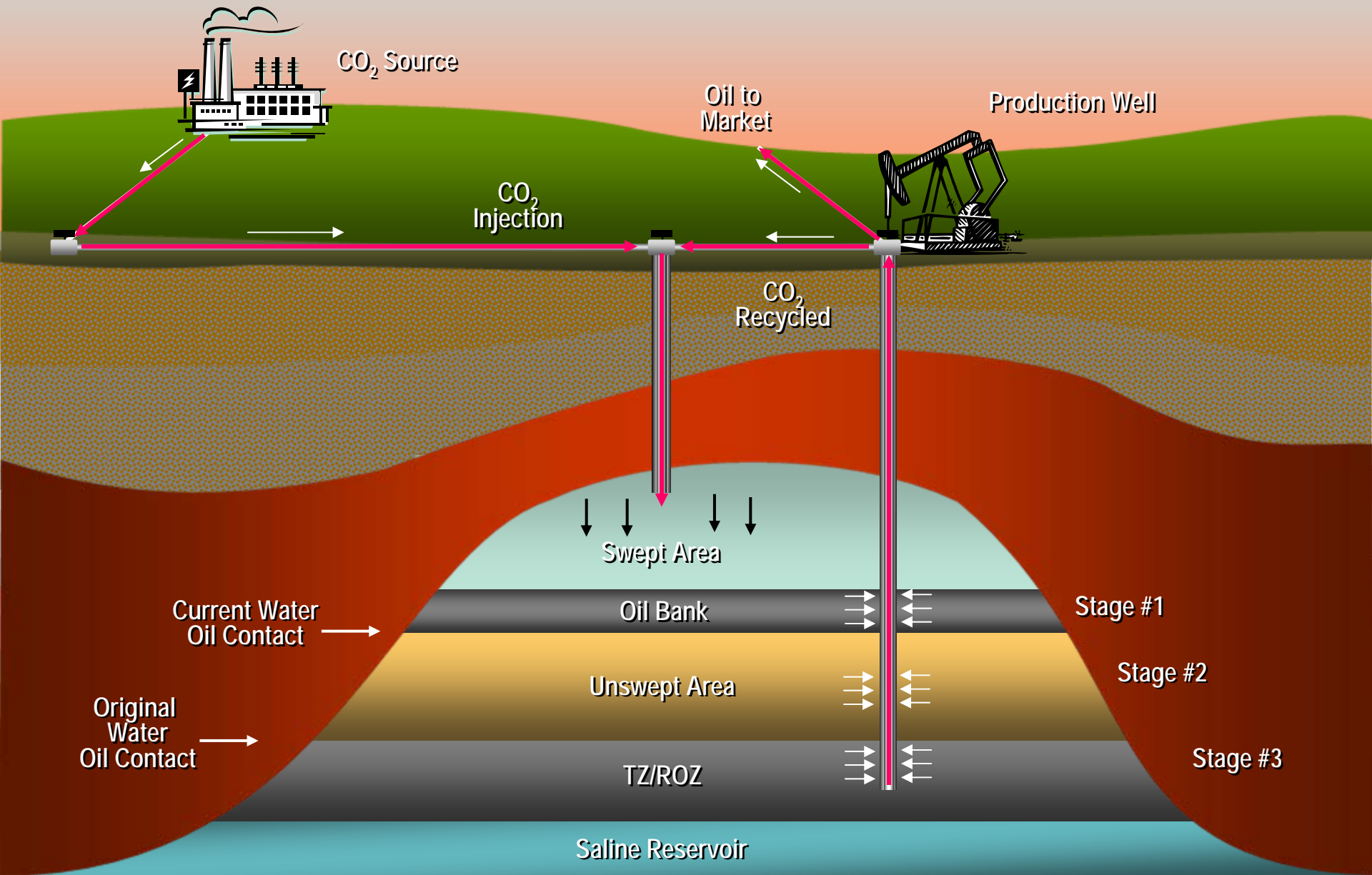
INTEGRATING CO₂-EOR STORAGE

First, this Gulf Coast oil reservoir is produced using “state-of-the-art” CO₂-EOR project design - - vertical wells, 1 HCPV of CO₂ (purchased and recycled CO₂), and a 1:1 WAG.

Next, this Gulf Coast oil reservoir is produced using “next generation” CO₂-storage and CO₂-EOR project design.

- Gravity-stable, vertical CO₂ injection with horizontal wells.
- Targeting the main pay zone, plus the transition/residual oil zone and the underlying saline aquifer.
- Injecting continuous CO₂ (no water) and continuing to inject CO₂ after completion of oil recovery.

INTEGRATING CO₂-EOR AND CO₂ STORAGE (Cont'd)



INTEGRATING CO₂-EOR AND CO₂ STORAGE

Integrating CO₂-EOR and CO₂ Sequestration shows that much more CO₂ can be stored, making the additional oil produced “GREEN OIL”*.

	“State of the Art”	“Next Generation”		
	(millions)	EOR	Seq.	Total
CO ₂ Storage (tonnes)	19	76	33	109
Storage Capacity Utilization	13%	52%	24%	76%
Oil Recovery (barrels)	64	180	-	180
% Carbon Neutral (“Green Oil”)	70%	100%	-	160%

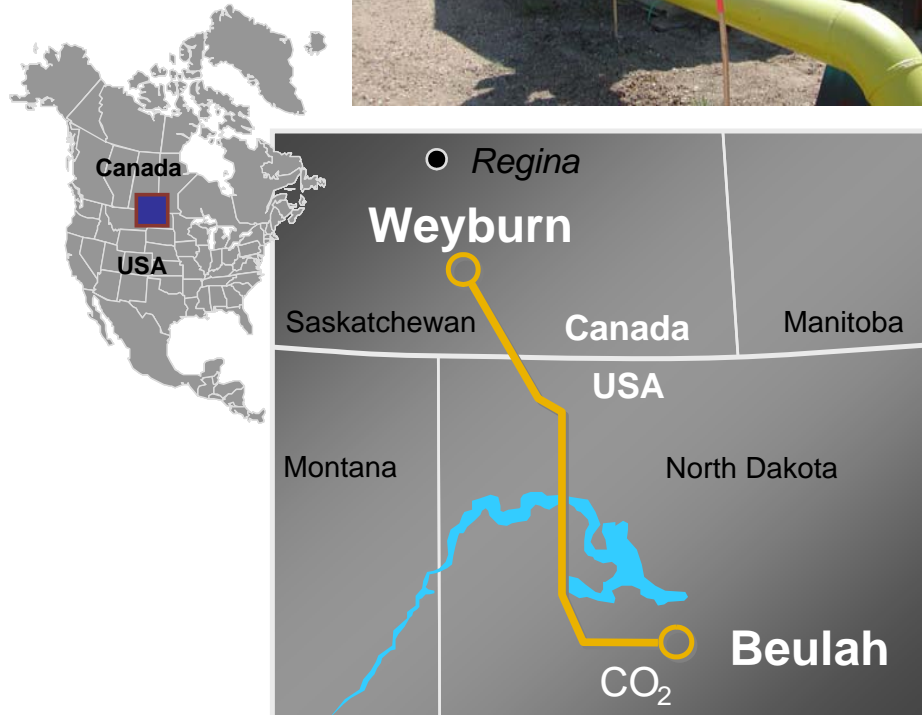
*“Green Oil” means that more CO₂ is injected and stored underground than the volume of CO₂ contained in the produced oil, once burned.

Weyburn Enhanced Oil Recovery Project

(An Operating Project Maximizing Oil Recovery and CO₂ Storage)



- Largest CO₂ EOR project in Canada:
 - OOIP 1.4 Bbbls
 - 155 Mbbls incremental
- Outstanding EOR response
- World's largest geological CO₂ sequestration project
 - 2.4 MMt/year (current)
 - 7 MMt to date
 - 23 MMt with EOR
 - 55 MMt with EOR/sequestration

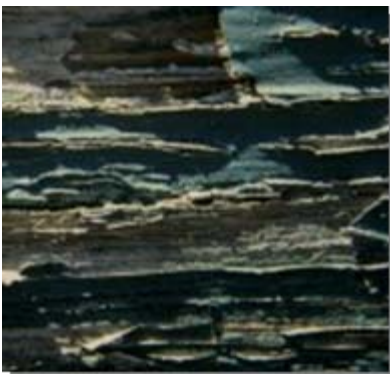


Source: EnCana, 2005





SUMMARY

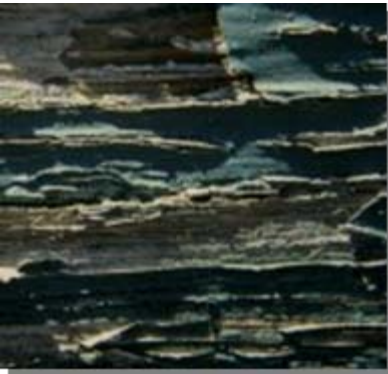


1. CO₂ enhanced oil recovery, while still an emerging industry, has the potential to add significant volumes of future oil supply, in the U.S. and worldwide.
2. Thirty years of experience shows that CO₂-EOR is a technically sophisticated and challenging process, but one that can be successful if “managed and controlled”, not just “operated”.
3. “Next Generation” CO₂-EOR technologies, incorporating scientifically possible but not yet fully developed advances, could significantly increase oil recovery efficiency.



SUMMARY (Cont'd)

4. Wide-scale application of CO₂-EOR is constrained by lack of sufficient “EOR-Ready” CO₂ supplies. A mutually beneficial link exists between CO₂-EOR and new industrial sources of CO₂.
5. Under a “carbon constrained world”, productively using industrial CO₂ emissions for CO₂-EOR will become a winning strategy.





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