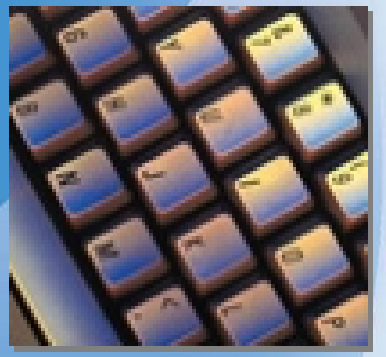

CO_2 Utilization with Enhanced Oil Recovery: The New Paradigm for CO_2 Capture and Storage

Prepared for:
10th Annual Carbon Management Workshop

Prepared By:
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Arlington, VA USA

December 4, 2012
Midland, Texas

Unconventional Resources • Enhanced Recovery • Carbon Sequestration

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Introduction

To better understand the role of CO_2 enhanced oil recovery (CO_2-EOR) as a major carbon management strategy, it is useful to examine four key questions:

(1) *How ready are CO_2-EOR practices and technologies for large-scale CO_2 utilization?*

(2) *To what extent can CO_2-EOR, like wind and solar, provide carbon neutral ("green") energy?*

(3) *What is the "size of the prize?" and*

(4) *To what extent could CO_2-EOR provide a market-driven option for increased application of CO_2 capture?*

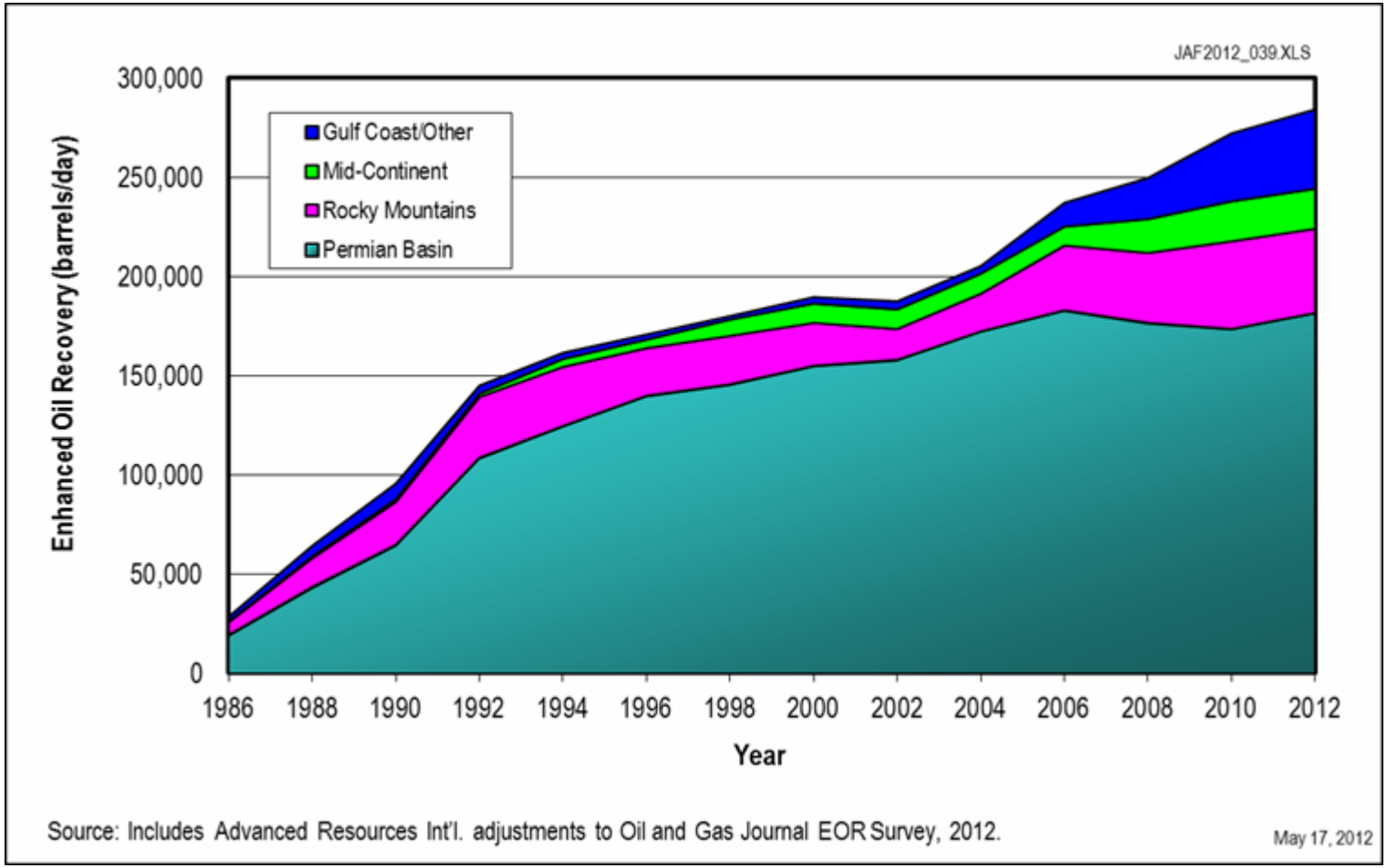
1. How Ready Are CO_2-EOR Practices and Technologies for Large-Scale CO_2 Utilization?

CO_2-based enhanced oil recovery, using state-of-the-art (SOA) technology, is already being implemented in the U.S.:

- CO_2-EOR currently provides about 284,000 barrels of oil per day.
- A total of 62 million metric tons of CO_2 was used by EOR last year with 13 million metric tons from industrial sources, natural gas processing plants, and hydrocarbon conversion facilities.
- A robust network of pipelines in the Permian Basin, the Gulf Coast and the Rockies transports this CO_2 to oil fields from natural CO_2 deposits, industrial sources and gas processing plants.

U.S. Oil Production from CO_2-EOR

With increased access to CO_2 supplies, CO_2-EOR production is expanding in the Gulf Coast and Rockies.



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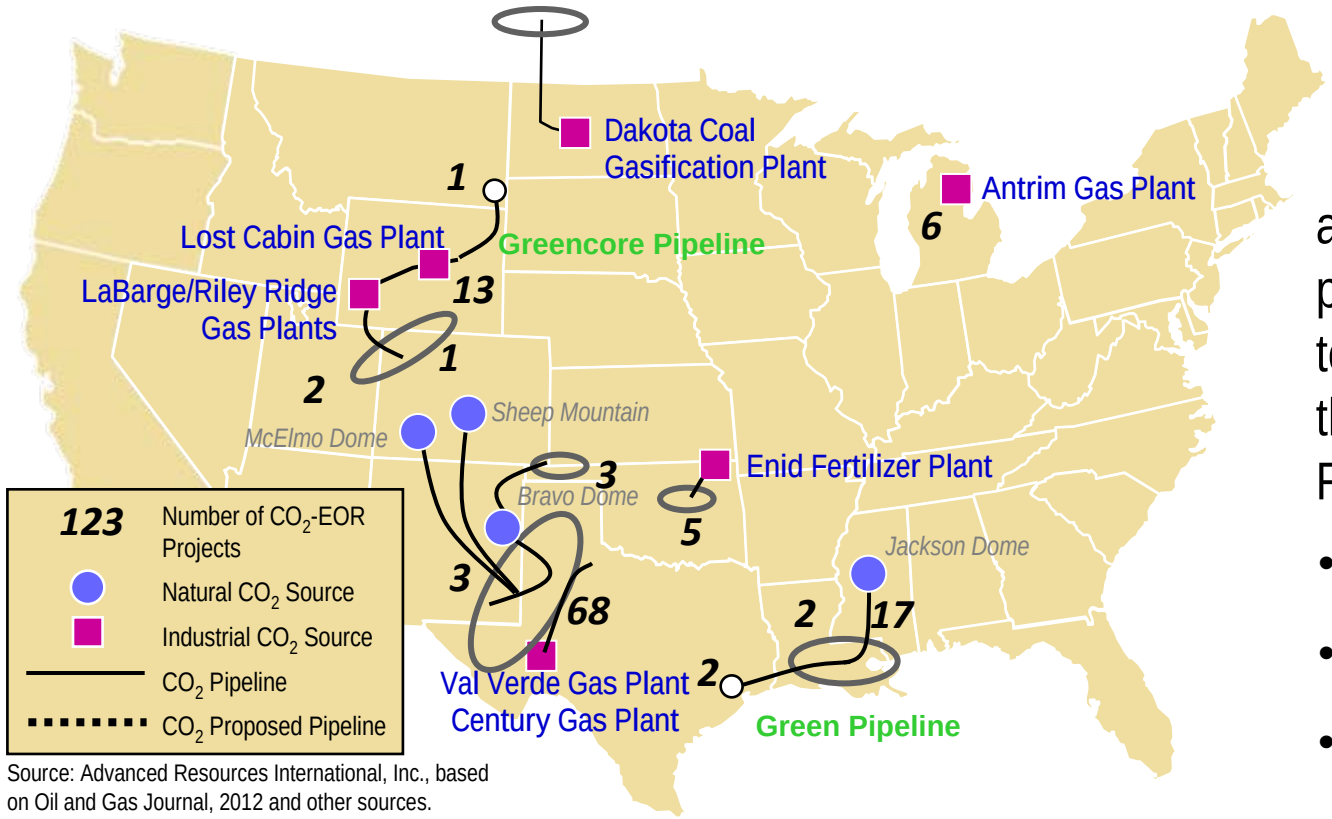
Significant Volumes of Anthropogenic CO_2 Are Already Being Injected for EOR

Location of Oil Fields	Location of CO_2 Sources	CO_2 Supply	
		Geologic	Anthropogenic
Texas, New Mexico, Oklahoma, Utah	Geologic (CO, NM) and Gas Processing, Fertilizer Plant (TX)	1,600	190
Colorado, Wyoming	Gas Processing (Wyoming)	-	300
Mississippi	Geologic (Mississippi)	930	-
Michigan	Gas Processing (Michigan)	-	10
Oklahoma	Fertilizer Plant (Oklahoma)	-	35
Saskatchewan	Coal Gasification (North Dakota)	-	150
TOTAL (Million cfd)		2,530	685
TOTAL (Million metric tons/ year)		49	13

* Source: Advanced Resources International, 2012

**MMcfd of CO_2 can be converted to million metric tons per year by first multiplying by 365 (days per year) and then dividing by 18.9 * 10^3 (Mcf per metric ton)

U.S. CO_2-EOR Activity and Infrastructure



Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2012 and other sources.

New CO_2 pipelines and gas processing plants are delivering CO_2 to CO_2-EOR projects in the Gulf Coast and the Rockies.

- Green Pipeline
- Greencore CO_2 Pipeline
- Century Gas plant
- Lost Cabin Gas Plant

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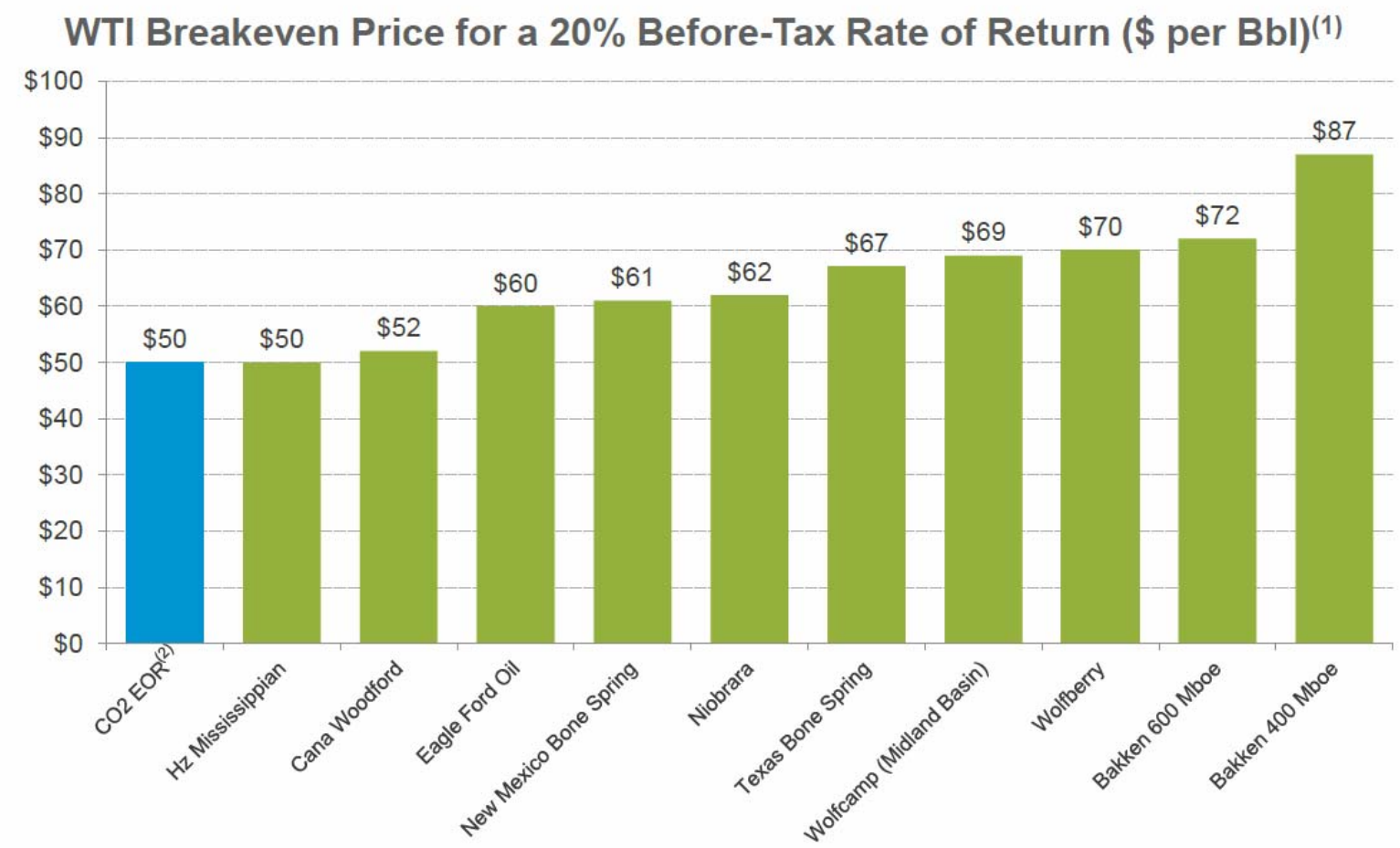
CO_2-EOR – Compelling Economics



(1) Source: KeyBanc as of 10/17/12, Defined as the threshold WTI oil price necessary to generate a 20% before-tax rate of return. Excludes acreage costs.
(2) Internal estimate for indicative large CO_2 EOR development project in the Gulf Coast Region.

Source: Denbury Resources (2012)

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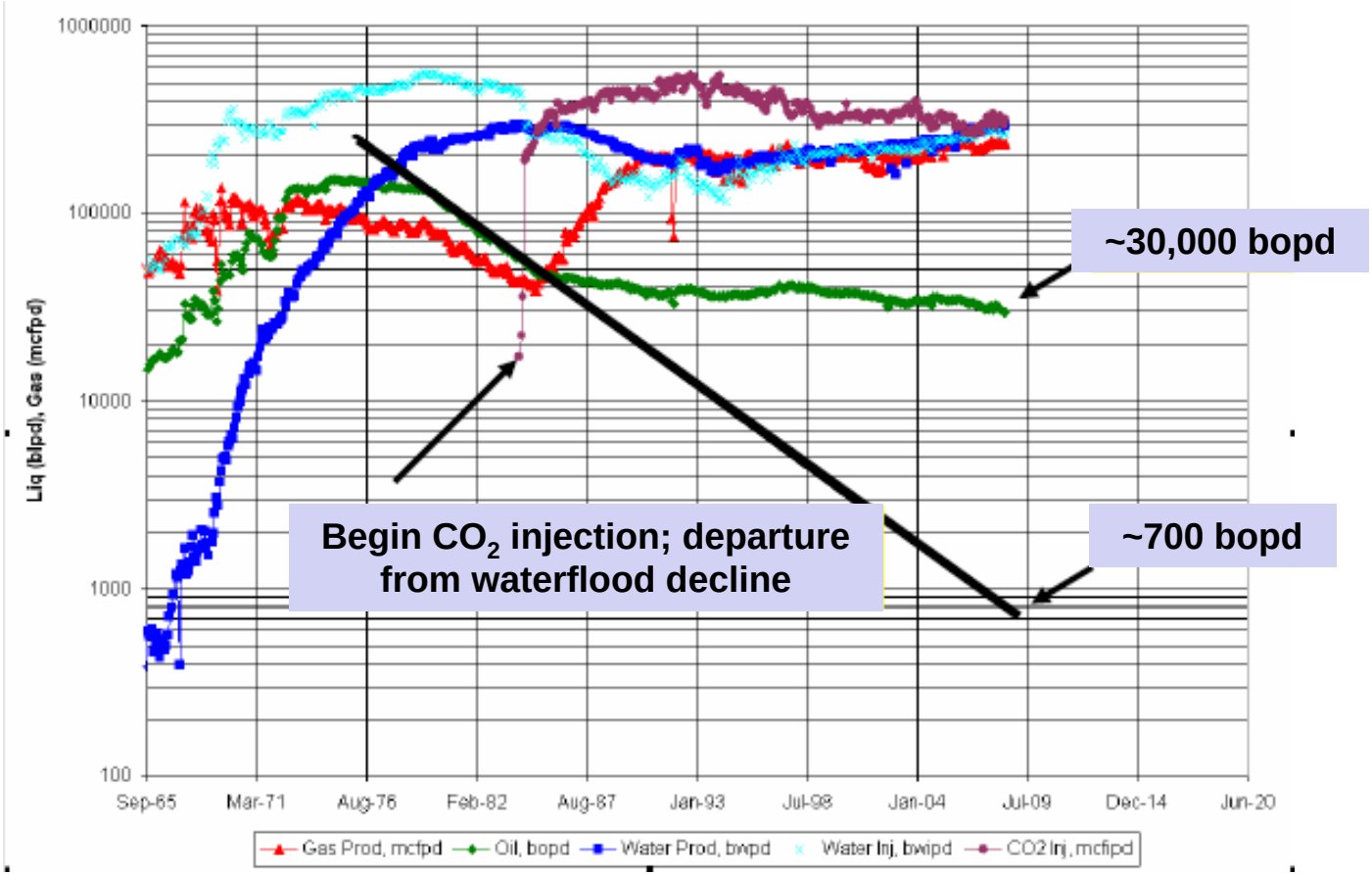
Permian Basin CO_2-EOR Case Study

"What Does a Successful CO_2-EOR Project Look Like?"

- CO_2 injection into the Denver Unit of the giant Wasson (San Andres) oil field began in 1985.
- Before the start of CO_2-EOR, oil production had declined from 90,000 B/D to 40,000 B/D and was on pace to decline to below 1,000 B/D in the next 20 years.
- After the CO_2 flood, oil production rebounded to 50,000 B/D.
- Today, twenty four years later, the Denver Unit still produces 30,000 B/D.

CO_2-EOR Results at the Denver Unit of the Wasson Oil Field



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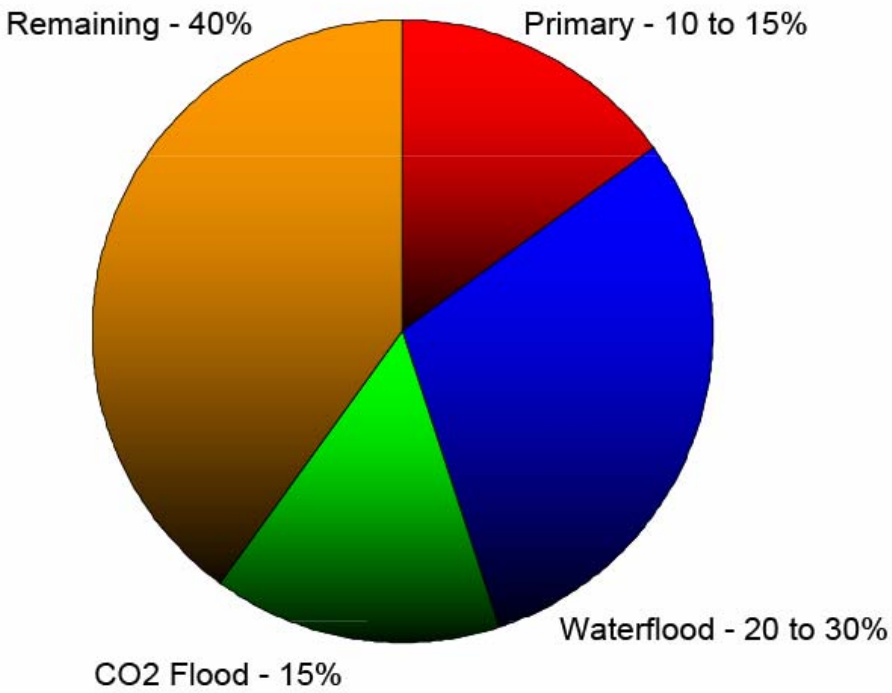
Oil Recovery Performance From Permian Basin San Andres Formation

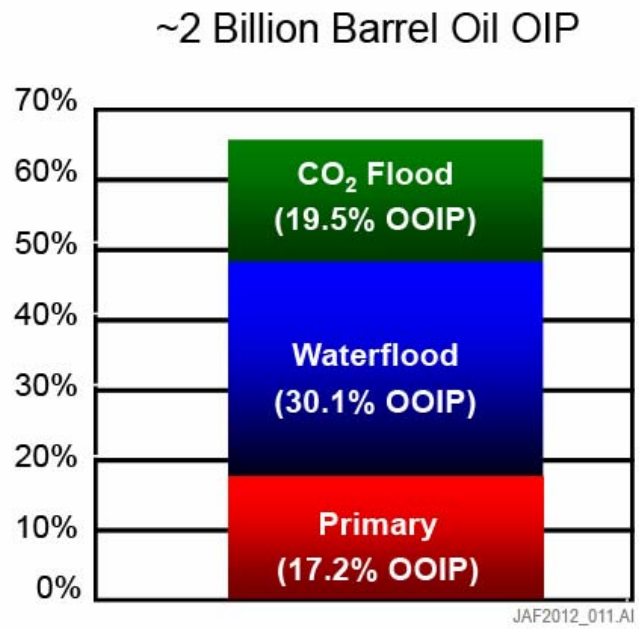
Permian Basin Typical Oil Recovery



Modified from Oxy (2009)

*Wasson Field: 2 Billion Barrels OOIP

Denver Unit, Wasson Field* Oil Recovery



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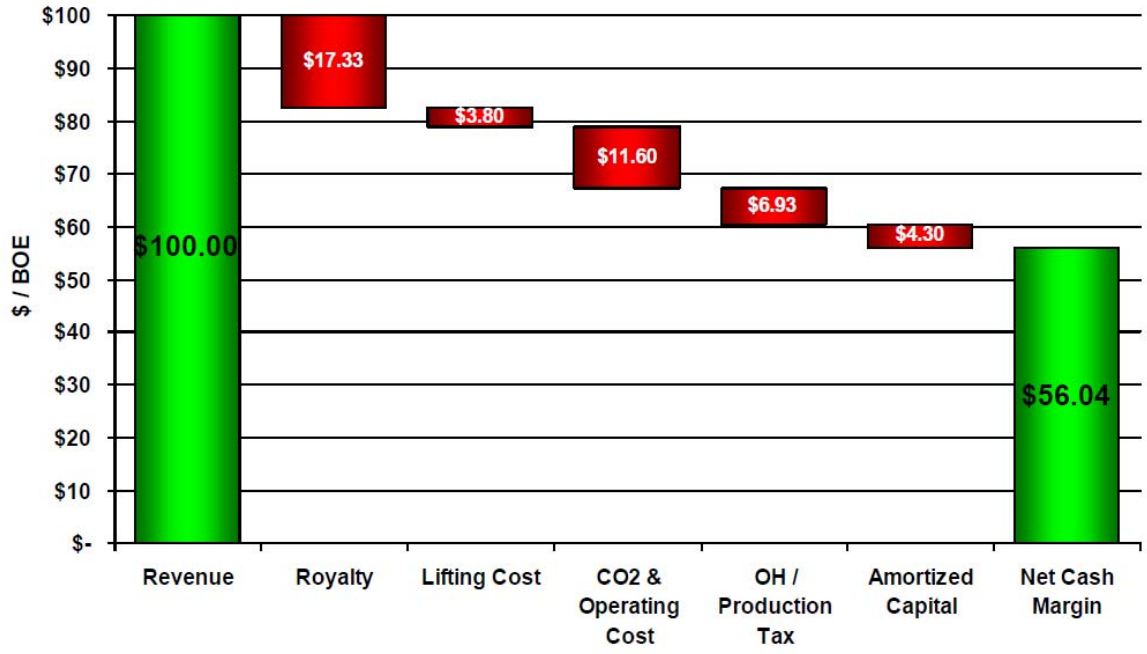
Permian Basin CO_2-EOR Project Economics



**$100/Bbl Marker Price*
Source: Occidental Petroleum Corporation, May 2011

"In the U.S., our Permian CO_2 operators continue to be our most profitable business, generating the highest free cash flow (after capital) among our entire portfolio of assets."

Stephen Chazen
President and CEO
Occidental Petroleum
October 25, 2012

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Opportunities for Improving CO_2-EOR Performance and Application

Even though CO_2-EOR already makes an important contribution, significant improvements are theoretically available in its performance and wider-scale application.

Some field projects, such as the CO_2-EOR floods at Denver Wasson and Weyburn, already practice selected aspects of “next generation” technology. However, with investments in research and field demonstrations, the contribution of CO_2-EOR - - to domestic energy security, to domestic CO_2 abatement, and to domestic revenues and economic well being - - could be much, much greater.

The following discussion of “next generation” CO_2 enhanced oil recovery summarizes both the opportunities and positive impacts of pursuing advances in CO_2-EOR technology.

"Next Generation" CO_2 Enhanced Oil Recovery

Use of more efficient CO_2-EOR technologies and extension of these technologies to new oil resources and settings constitutes "next generation" CO_2 enhanced oil recovery:

1. Scientifically-based advances in CO_2-EOR technology,
2. Integrating CO_2 capture with CO_2 utilization by CO_2-EOR,
3. Application of CO_2-EOR to residual oil zones (ROZs), and
4. Deployment of CO_2-EOR in offshore oil fields.

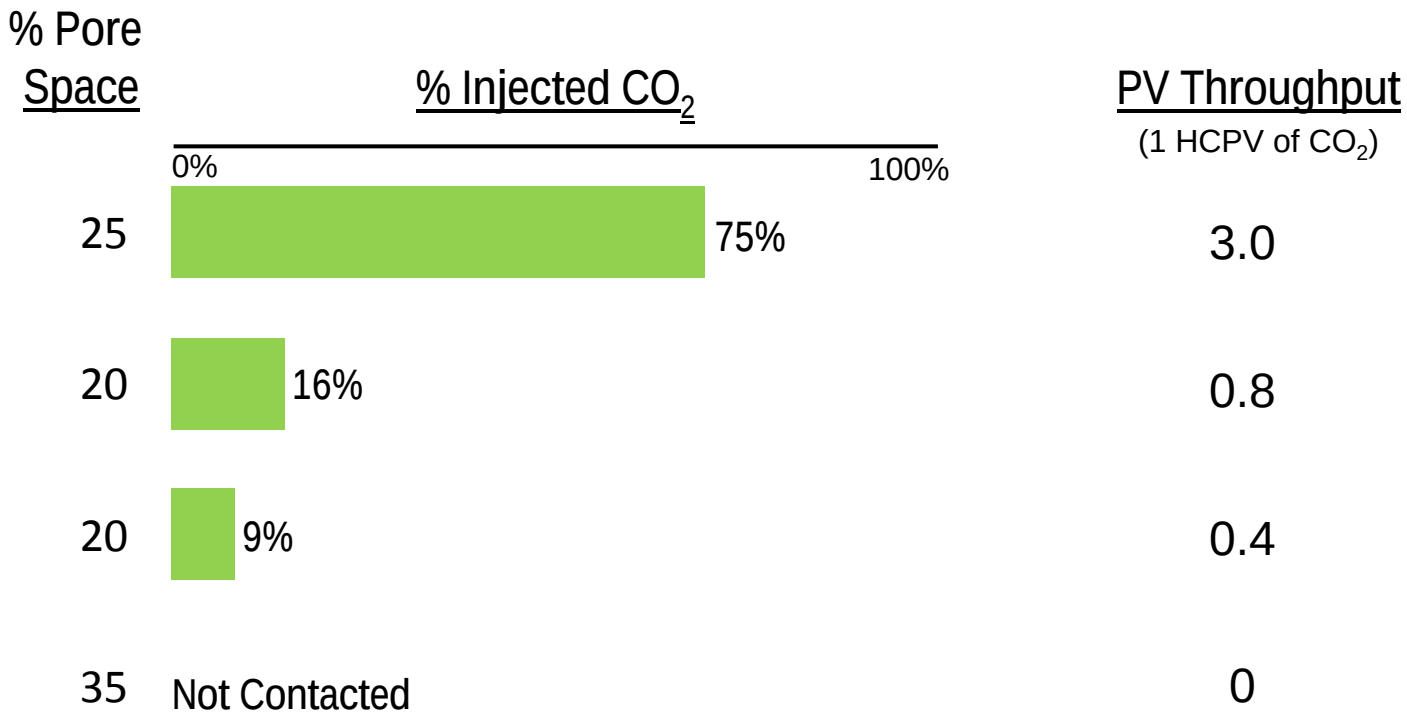
"Next Generation" CO_2 Enhanced Oil Recovery

Six scientifically-based advances in CO_2-EOR technology:

1. Advanced reservoir characterization (to map residual oil and reservoir heterogeneity);
2. Combination horizontal/vertical wells plus "smart" well technology (to better contact bypassed oil);
3. CO_2 mobility and flow path control agents (to improve reservoir conformance);
4. Increased volumes of efficiently targeted CO_2 (to improve oil recovery efficiency);
5. Near-miscible CO_2-EOR technology (to expand CO_2-EOR to additional oil reservoirs); and
6. Advanced reservoir surveillance and diagnostics technology (to "see and steer" the CO2 flood).

Performance of CO_2 Flood Without Advanced Mobility and Conformance Control

Without advanced mobility and conformance control, much of the injected CO_2 will channel through a modest portion of the reservoir's pore space.



Source: Modified by Advanced Resources, based on data from Wasson Denver Unit CO2 flood observation pilot (Goodyear and Jensen, 2011).

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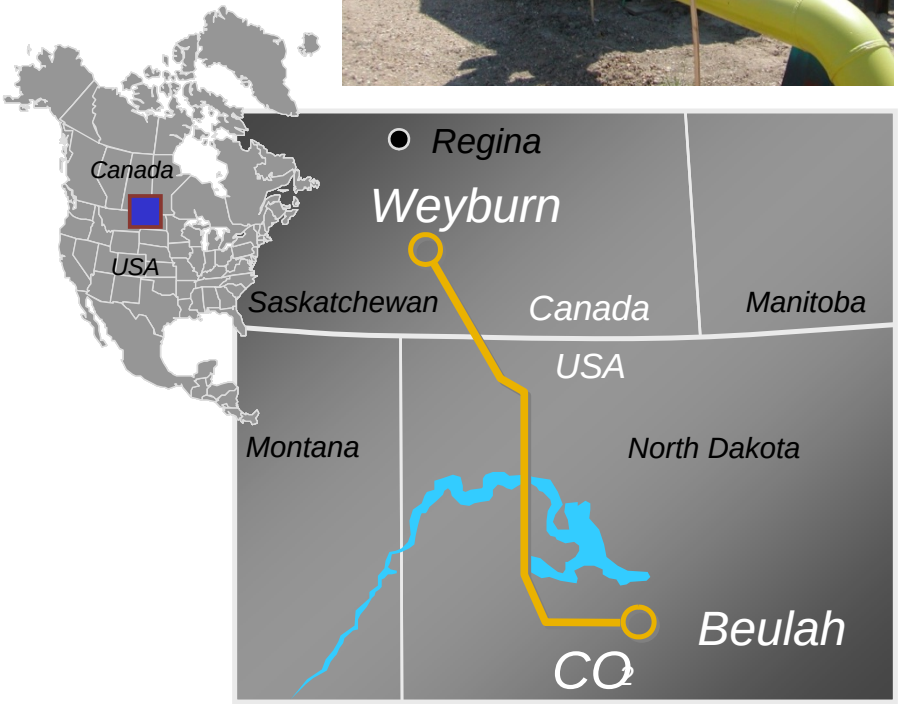
"Poster Child" for Integrating CO_2-EOR and CO_2 Storage



Source: EnCana, 2005

- **Largest CO_2 EOR project in Canada:**
  - OOIP 1.4 Bbbls
  - 200 MMB incremental oil from CO_2-EOR
- **World's largest geological CO_2 storage project:**
  - 2.4 MMt/year (current)
  - 24 MMt to date
- **A 200 mile CO_2 pipeline connects the Coal Gasification Plant at Beulah, ND with the Weyburn oil field in Canada.**

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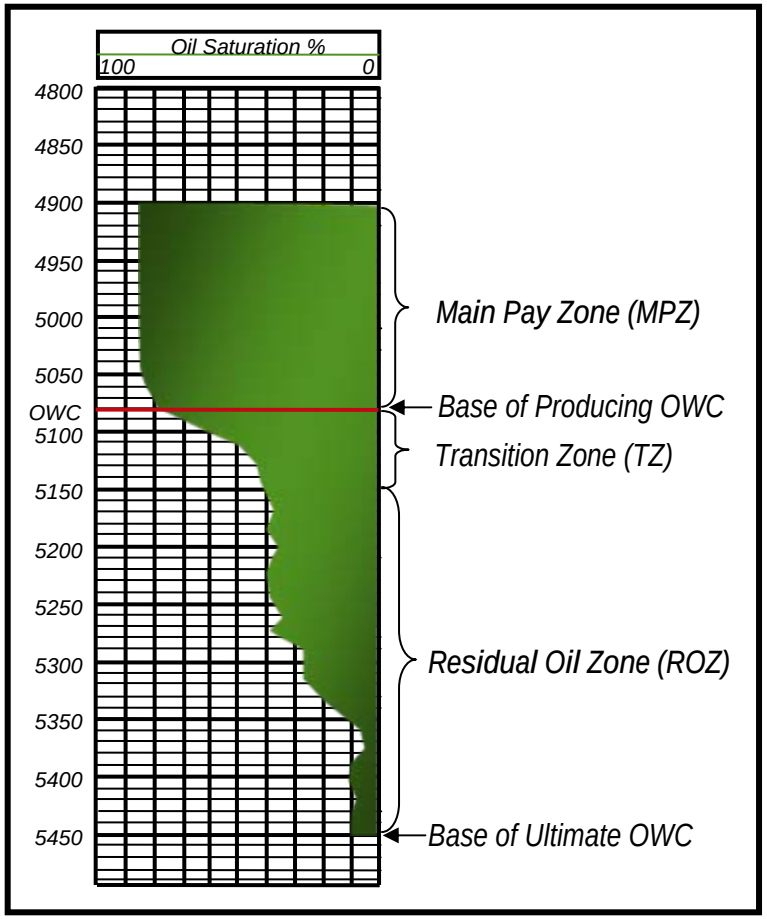
Permian Basin ROZ Below Existing Oil Fields

Oil Saturation Profile in the TZ/ROZ (Wasson Denver Unit Well Log)



Wasson Denver Unit Oil Resources (Billion Barrels)

	Main Pay Zone	TZ/ROZ
OOIP	2.4	3.0
P/S Recovery	1.1	1.5*
"Stranded"	1.3	1.5
EOR Potential	0.5**	0.5***

**Produced by nature. **Approximately 0.3 billion barrels already produced/proven to date. ***Numerous ROZ projects underway.*

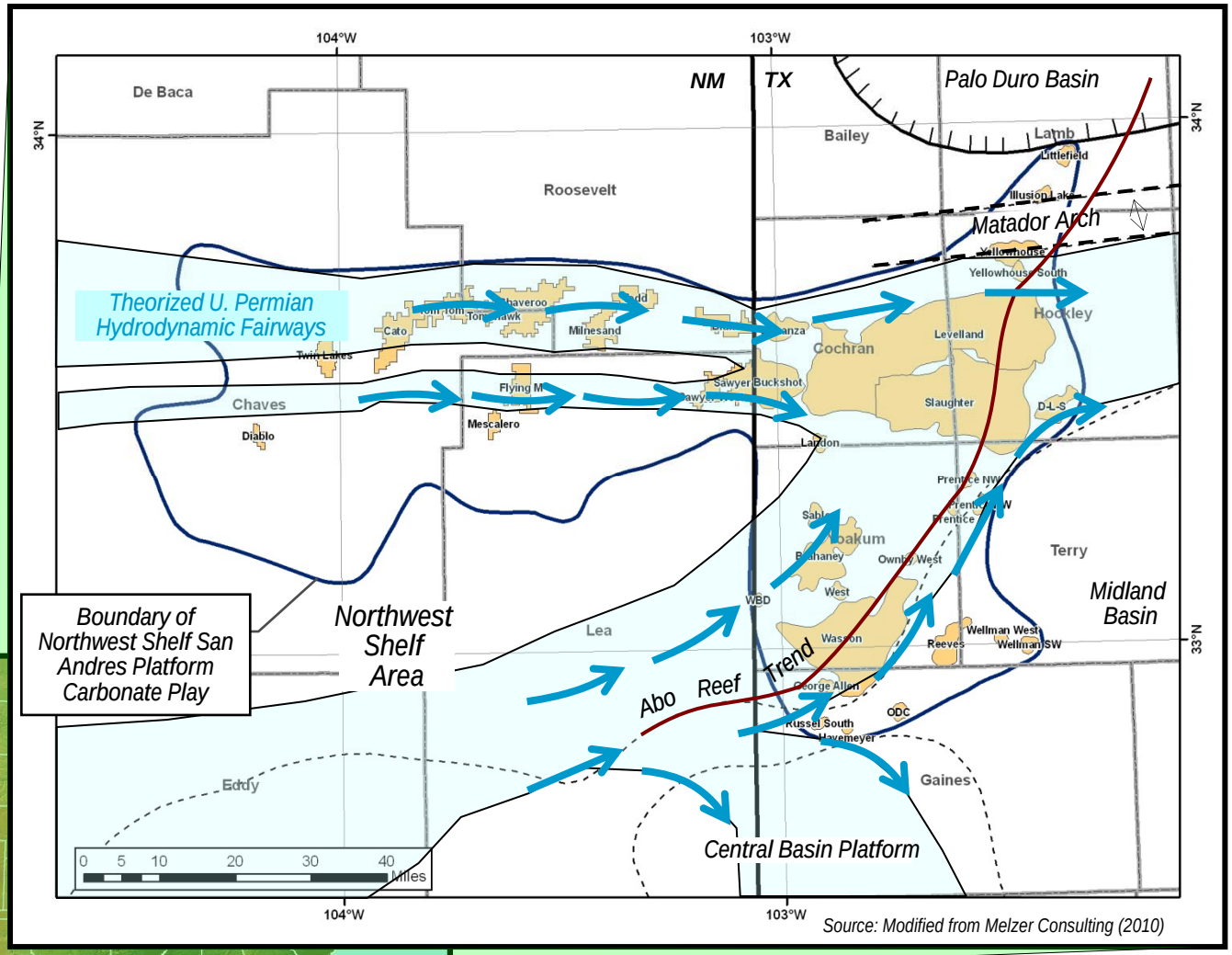
Seminole Unit (San Andres) ROZ Project

(Three Hess Oil operated miscible CO_2 floods in the ROZ interval show successful oil response.)

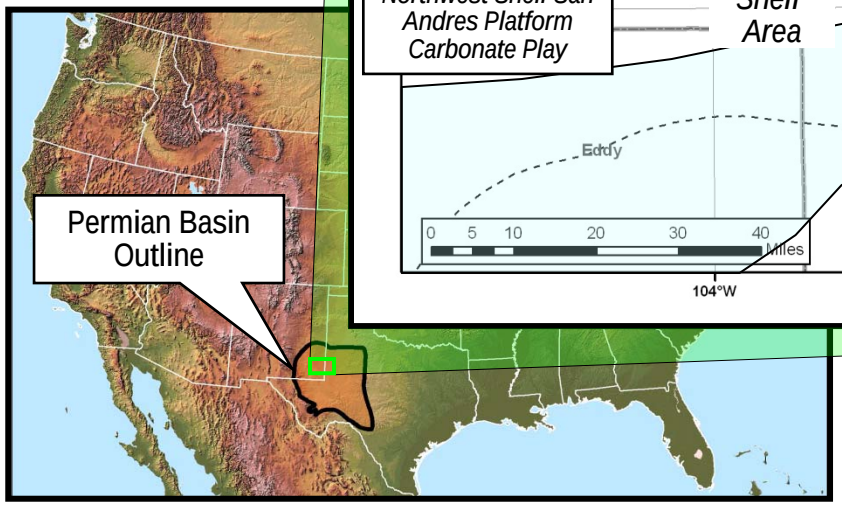
Project	Acres	CO_2 Injection Patterns	Oil Production (B/D)	
			2010	2012
Phase 1	500	10	1,200	1,200
Phase 2	480	9	1,700	1,800
Stage 1	2,320	29	1,000	3,500

Permian Basin ROZ "Fairways"

ARI and Melzer estimate that up to 100 million barrels of OIP exist in the ROZ "Fairways" of the Permian Basin.



Source: Modified from Melzer Consulting (2010)



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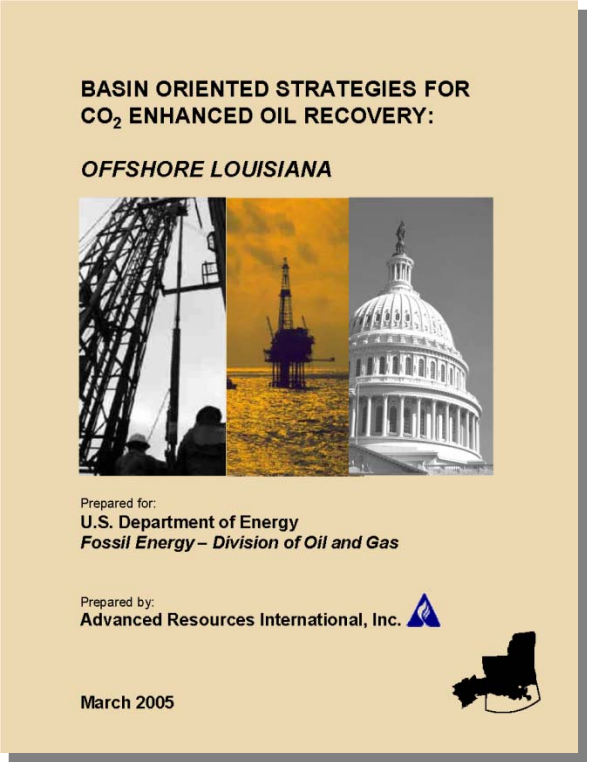
Deployment of CO_2-EOR in Offshore Oil Fields



In 2005, Advanced Resources took a "first look" at the CO_2-EOR potential of oil fields located in the shallow-water shelf of offshore Louisiana. Since then, a number of efforts have been undertaken to bring offshore CO_2-EOR closer to reality:

- In mid-2012, Scotland established CENSOR-CO_2 - - Center for North Sea Enhanced Oil Recovery with CO_2 - - to "unlock 3 billion barrels of oil from the North Sea."
- In a recent SPE paper, Shell discusses efforts "to implement new generation CO_2 projects, including offshore application."

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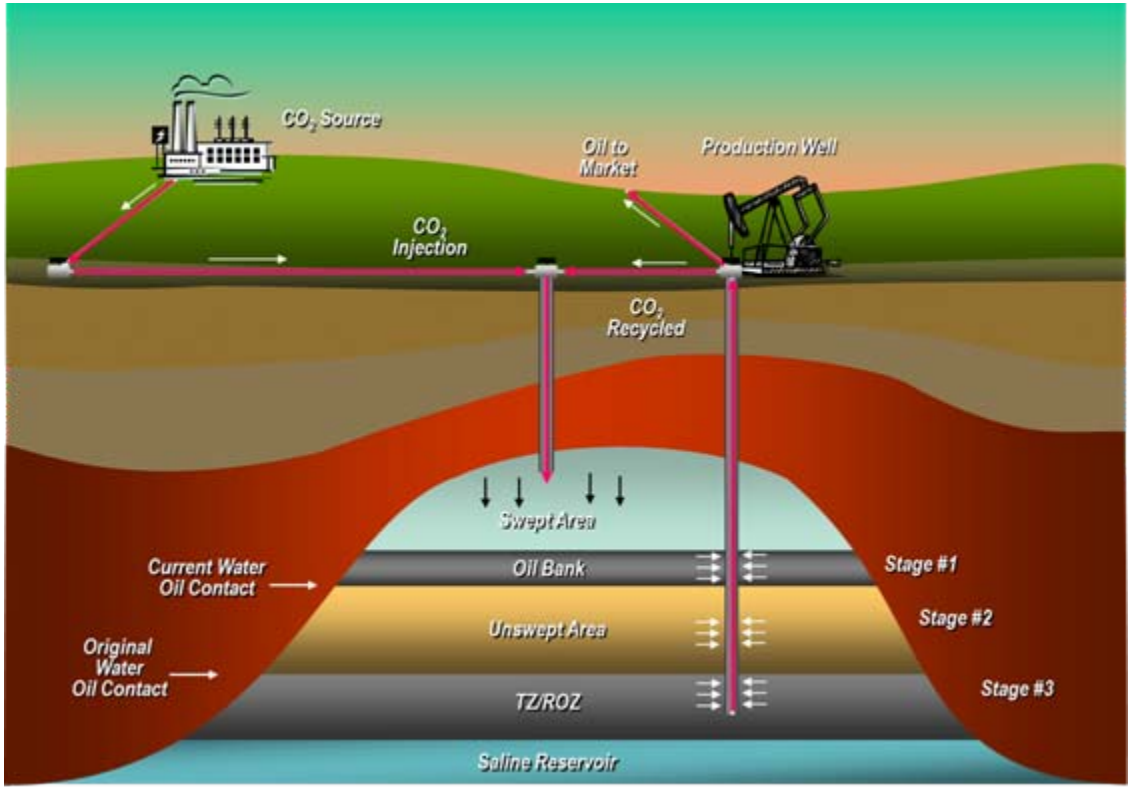
2. To What Extent Can CO_2-EOR Provide Carbon Neutral Energy?



At 1 metric ton of CO_2 injected per 2.5 barrels of oil recovered, the carbon balance of CO_2-EOR is close to neutral, when using otherwise vented CO_2.

With a gravity stable process, CO_2-EOR can store more CO_2 than the carbon content of the oil ("green oil").

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Opposition to Storing CO_2 with EOR Seems Misplaced

A number of activities besides CO_2-EOR bring additional oil to the surface, including exploration and drilling for conventional oil.

Except in environmentally fragile areas, no public official concerned with energy security and economic well-being has called for a stop to conventional oil exploration or production.

Norway's Statoil announced a goal of 60% recovery from its offshore oilfields. This announcement was meet with praise not protest.

CO_2-EOR is much more carbon-neutral than conventional oil exploration or Norway's actions on conservation of its oil resources.

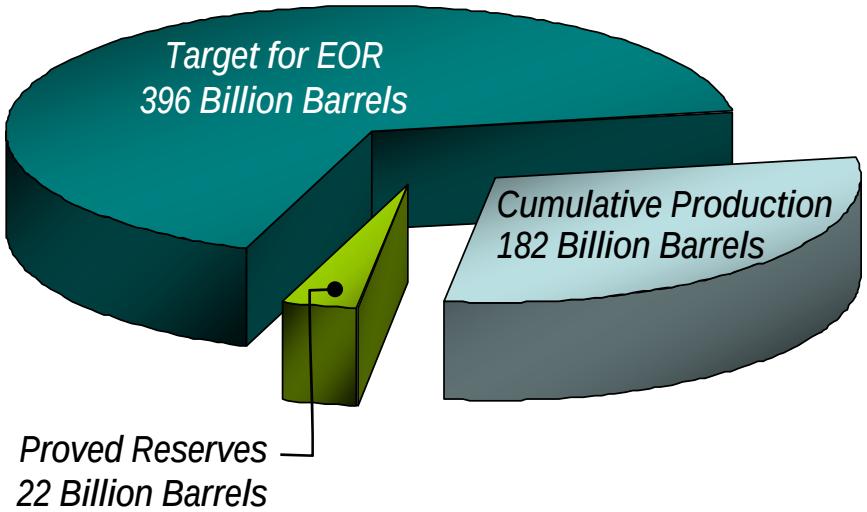
3. What is the "Size of the Prize?"

Large volumes of oil remain "stranded" in U.S. reservoirs after traditional recovery.

400 BILLION BARRELS OF OIL
IN MAIN PAY ZONES.

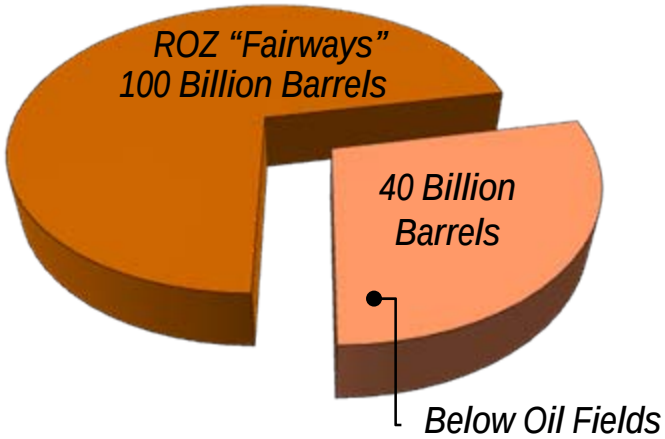
Original Oil In-Place: 600 B Barrels

"Stranded" Oil In-Place: 396 B Barrels



140 BILLION BARRELS OF OIL IN
RESIDUAL OIL ZONES (ROZs).

*Oil In-Place: 140 B Barrels**



Source: Advanced Resources Int'l. (2011); Melzer Consulting (2012)

*Within ROZ "Fairways" of the Permian Basin and below oil fields in 3 U.S. basins

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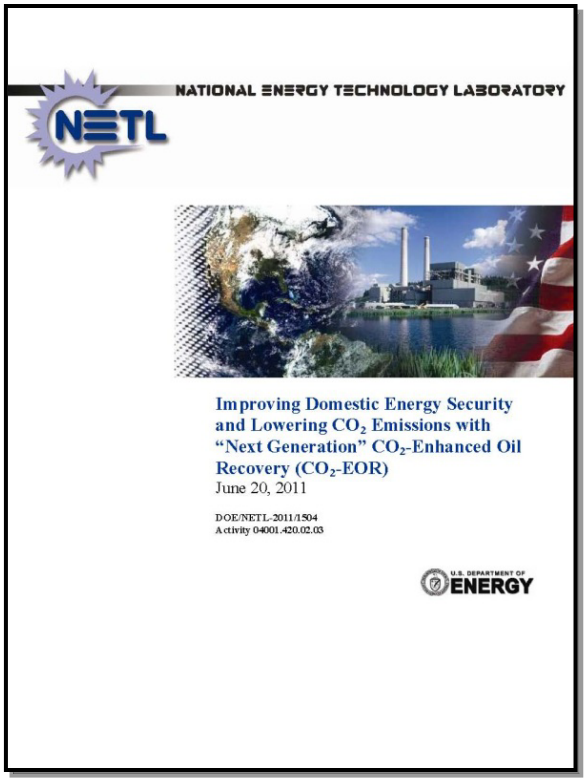
Oil Recovery and CO_2 Demand/Storage: "Next Generation" CO_2-EOR Technology

Two publically available reports, prepared by Advanced Resources Int'l and Melzer Consulting for U.S. DOE/NETL, provide the analytical foundation for the estimates of oil production and CO_2 demand by the CO_2-EOR industry.


NATIONAL ENERGY TECHNOLOGY LABORATORY

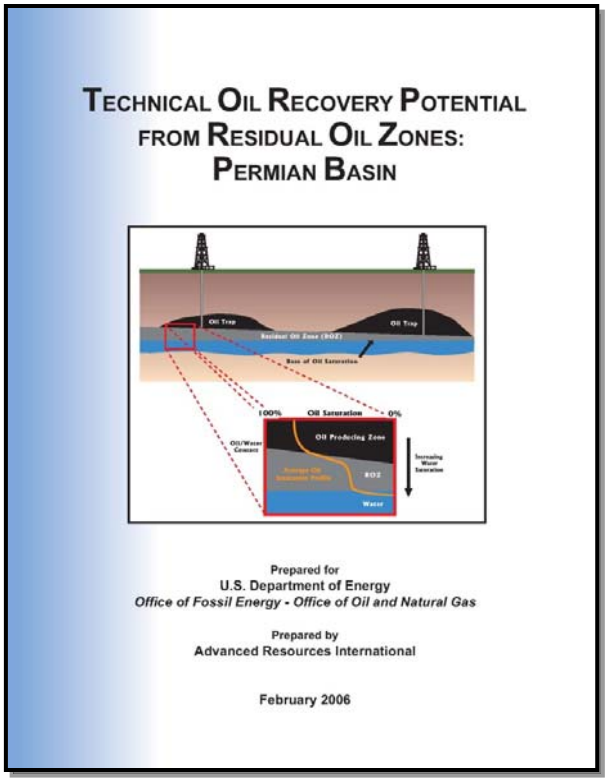
NETL

Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (CO_2-EOR)

June 20, 2011

DOE/NETL-2011/1504
Activity 04001.420.02.03

U.S. DEPARTMENT OF ENERGY


TECHNICAL OIL RECOVERY POTENTIAL FROM RESIDUAL OIL ZONES: PERMIAN BASIN

Prepared for
U.S. Department of Energy
Office of Fossil Energy - Office of Oil and Natural Gas

Prepared by
Advanced Resources International

February 2006

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The Size of the Prize

- In the U.S., the "size of the oil prize" for "next generation" CO_2-EOR technology is 100 billion barrels of economically recoverable oil,* nearly four times larger than from today's "state of the art" CO_2-EOR technology and practices.
- The economic demand for CO_2 from "next generation" CO_2-EOR is 33 billion metric tons. Subtracting 3 billion metric tons of natural CO_2, the "size of the CO_2 utilization and storage prize" in the U.S. is 30 billion metric tons.
- This is equal to 35 years of CO_2 emissions captured from 140 GWs of coal-fired power.

Using an oil price of $85 per barrel, a CO_2 price of $40 per metric ton, and a return on investment hurdle of 20%. All economic value numbers are expressed in U.S. dollars.

Impact of Applying "Next Generation" vs. SOA CO_2-EOR Technology to U.S. Oil Fields and ROZ

Resource Area	Economic Oil Recovery (BBbls)*		Demand for CO_2 (Billion Metric Tons)	
	SOA	Next Gen.	SOA	Next Gen.
More efficient recovery, "Lower 48" oil fields	24	60	7	17
Alaska/Offshore	3	7	1	3
Residual Oil Zone (below oil fields)	-	13	-	5
Residual Oil Zone "Fairways" (preliminary)	-	20	-	8
Total	27	100	8	33

*At $85 per barrel and $40 per metric ton, CO_2 market price with 20 % rate of return (before tax).
Source: Advanced Resources International, Inc. (2011)

4. To What Extent Could CO_2-EOR Provide A Market-Driven Option for CO_2 Capture?

"Next generation" CO_2-EOR technology would generate gross domestic production (GDP) of $8.5 trillion, over the next thirty to forty years.

As part of this, the U.S. CO_2-EOR industry could provide:

- Revenues of $1.3 trillion for CO_2, with 90% for CO_2 capture.
- About $2.1 trillion of severance and income taxes.
- About $2.3 trillion of demand for services and materials.

Over 30 billion metric tons of anthropogenic CO_2, otherwise vented to atmosphere, would be permanently stored.

The "Value Chain" of "Next Generation" CO_2-EOR

Revenue Recipient	Value Chain Function	Revenues Per Barrel ($)	TOTAL* ($ billion)
Power/Industrial Companies	Sale of CO_2	$13.20	$1,320**
Federal/State Treasuries	Severance/Income Taxes	$21.30	$2,130
U.S. Economy	Services, Materials and Sales	$23.00	$2,300
Other	Private Mineral Rights	$7.70	$770
Oil Industry	Return of/on Capital	$19.80	$1,980
	Total	$85.00	$8,500

*Assuming 100 billion barrels of economically feasible oil recovery; oil prices of $85 per barrel and CO_2 sales price of $40/metric tons.
**Of the 33 billion metric ton, $1,320 billion overall market for CO_2, anthropogenic CO_2 captured from power and other industrial plants would be 30 billion metric tons and $1,200 billion.
Source: Advanced Resources International, Inc. (2011)

Distribution of Economic Value of Oil Production from CO_2-EOR

Notes		EOR Industry	Federal/ State	Power Plant/Other	Private Royalties	U.S. Economy
1	Domestic Oil Price ($/B)	$85.00				
2	Less: Royalties	($14.90)	$2.50		$12.40	
3	Production Taxes	($3.50)	$4.10		($0.60)	
4	CO2 Purchase Costs	($13.20)		$13.20		
5	CO2 Recycle Costs	($6.00)				$6.00
6	O&M/G&A Costs	($10.00)				$10.00
7	CAPEX	($7.00)				$7.00
	Total Costs	($54.60)		-		
	Net Cash Margin	$30.40	$6.60	$13.20	$11.80	$23.00
8	Income Taxes	($10.60)	$14.70	-	($4.10)	-
	Net Income ($/B)	$19.80	$21.30	$13.20	$7.70	$23.00

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Notes: (1.) Assumes $85 per barrel of oil; (2.) Royalties are 17.5%; 1 of 6 barrels produced are from federal and state lands; (3.) Production and ad valorem taxes of 5%, from FRS data; (4.) CO_2 market price of $40/tonne, including transport; 0.33 tonnes of purchased CO_2 per barrel of oil; CCS meets 90% of CO_2 demand; (5.) CO_2 recycle cost of $10/tonne; 0.6 tonnes of recycled CO_2 per barrel of oil; (6.) O&M/G&A costs from ARI CO_2-EOR cost models; (7.) CAPEX from ARI CO_2-EOR cost models; (8.) Combined Federal and state income taxes of 35%, from FRS data.

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Advanced Power Plants Plan to Use EOR for CO_2 Storage

Southern Company's Kemper County IGCC Plant

- 582 MW fueled by Mississippi Lignite
- Will Capture 65% of CO_2
- Negotiating agreement to sell 1.1 to 1.5 million tons of CO_2 per year for EOR (170-225 MMcfd)
- Project expected to cost $2.4 B and be operational by 2014.

*Source: Mississippi Power, Denbury Resources

Summit's Texas Clean Energy IGCC Project

- 400 MW IGCC with 90% capture
- Located near Odessa in Permian Basin
- Sell 2.5 million tons of CO_2 per year to EOR market
- Expected cost $1.75 B; $350 MM award under CCPI Round 3.

Source: Siemens Energy

Summary Observations

"Next generation" CO_2 enhanced oil recovery deserves to be a major part of a worldwide carbon management strategy:

- CO_2 enhanced oil recovery is a viable, growing enterprise,
- The oil produced is low carbon energy,
- The "size of the prize" is large, and
- CO_2-EOR can provide a market-driven option for accelerating CO_2 capture.

Acknowledgements. This study was sponsored by the U.S. Department of Energy, National Energy Technology Laboratory, under Contract No. DE-FE0004001.

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