



## ***An Updated Review of U.S. and Worldwide CO<sub>2</sub>-EOR Resources***

*Prepared For:*

**17<sup>th</sup> Annual Midland CO<sub>2</sub> Flooding Conference**

*Prepared By:*

**Tyler Van Leeuwen**

**ADVANCED RESOURCES INTERNATIONAL, INC.**

**Arlington, VA**

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Midland, TX

***Unconventional Resources • Enhanced Recovery • Carbon Sequestration***



**Advanced Resources  
International, Inc.**



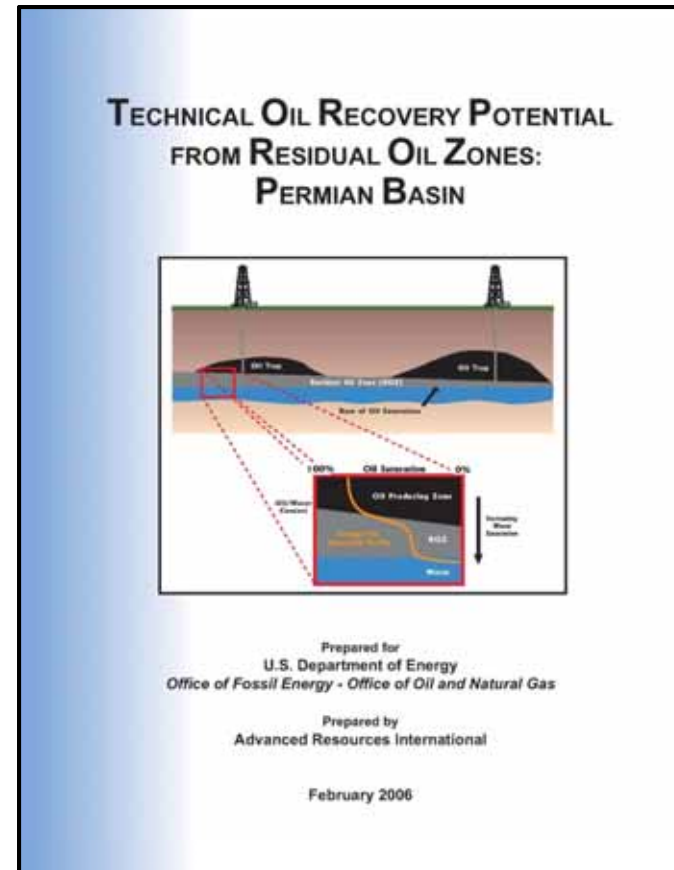
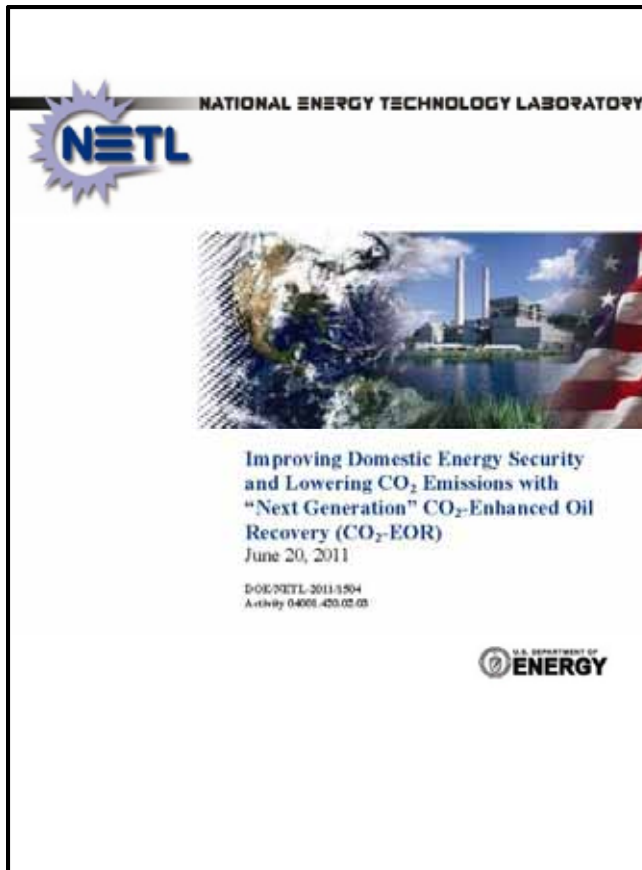
## Discussion Outline

1. How much domestic oil could be technically and economically recovered using CO<sub>2</sub>-EOR?
2. Where will we get enough CO<sub>2</sub>?
3. What is the potential for CO<sub>2</sub>-EOR internationally?

*We would like to acknowledge the valuable support provided by U.S. DOE/NETL for this presentation and its foundation reports.*

# CO<sub>2</sub>-EOR Resource Assessments

Two key reports prepared by Advanced Resources Int'l for U.S. DOE/NETL:



# Assessment Methodology

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To perform our nationwide assessments we use the following methodology:

- Assemble and maintain a proprietary “Big Oilfield Database,” containing reservoir characteristics, production and reserves data on 6,400 candidate oil reservoirs.
- Establish each reservoir’s suitability for miscible or immiscible CO<sub>2</sub>-EOR.
- Simulate CO<sub>2</sub> flood on representative type pattern using a modified version of CO2PROPHET.
- Run industry-standard costs and economics model to scale pattern results to the field level and determine if projects provide a sufficient rate of return (15-20%, BT) at given oil prices and CO<sub>2</sub> costs.

# CO<sub>2</sub>-EOR Technology

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We have performed our domestic resource assessments using two “technology cases”:

- “State of the Art” CO<sub>2</sub>-EOR
  - Broadly conforms to current industry best practices.
  - 1.0 HCPV CO<sub>2</sub> Injected.
  - Tapered WAG.
- “Next Generation” CO<sub>2</sub>-EOR
  - A set of technologies and flood design practices intended to improve flood sweep efficiency and improve displacement of mobile and immobile oil.
  - Addresses CO<sub>2</sub>-EOR potential in Alaska, the Offshore, and in Residual Oil Zones.

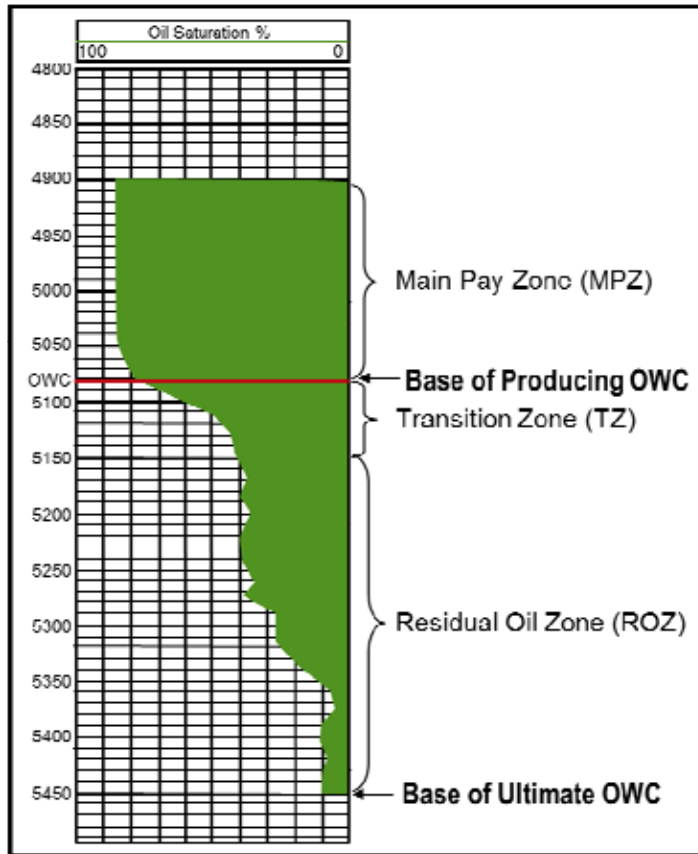
# “Next Generation” CO<sub>2</sub>-EOR Technology

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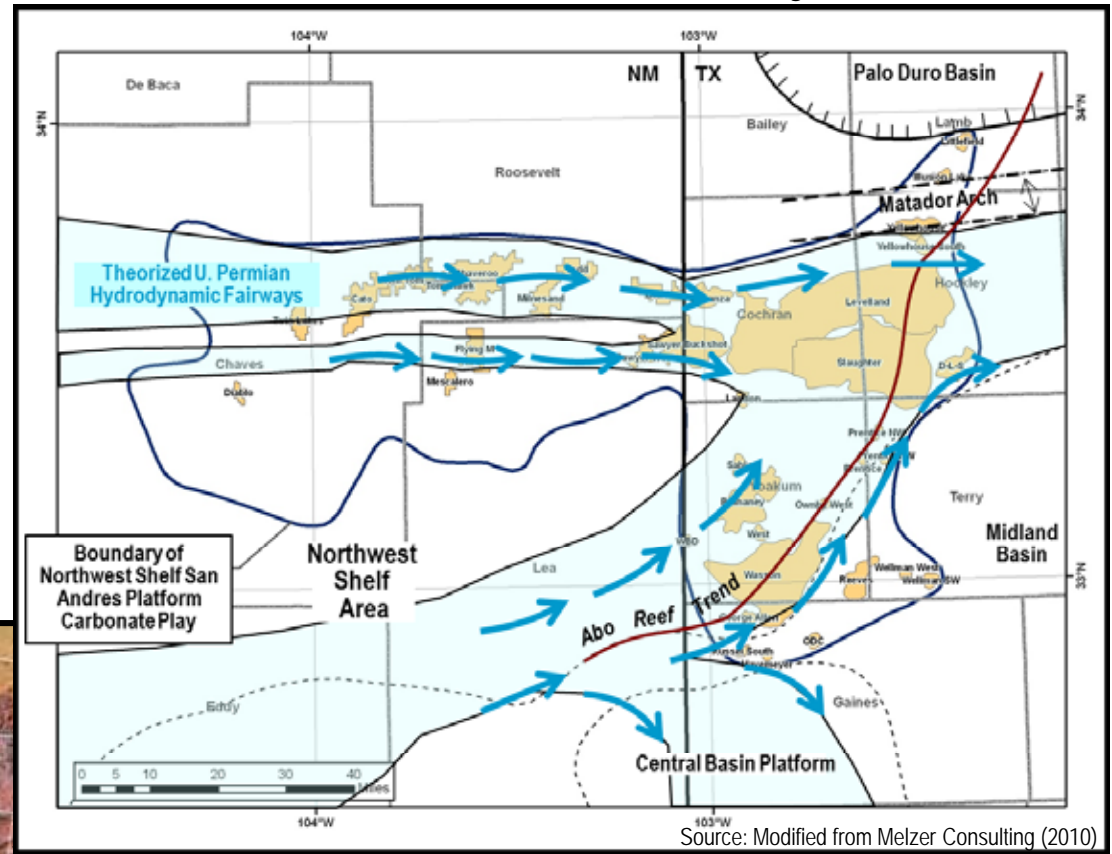
- **Innovative Flood Design and Well Placement.** Combining horizontal production and vertical CO<sub>2</sub> injection wells, enabling CO<sub>2</sub> to contact residual oil from poorly swept portions of the reservoir.
- **Viscosity and Miscibility Enhancement.** Developing mobility control with viscosity enhancers and lowering MMP with miscibility enhancers.
- **Increased Volume of CO<sub>2</sub> Injection.** Injecting up to 1.5 HCPV of CO<sub>2</sub>.
- **Flood Performance Diagnostics and Control.** Using instrumented observation wells and downhole sensors to monitor performance; using 4-D seismic and pressure plus zone-by-zone flow tests to “manage and control” the CO<sub>2</sub> flood.

# Application of CO<sub>2</sub>-EOR to the Residual Oil Zone (ROZ) Resource

Oil Saturation Profile in the TZ/ROZ

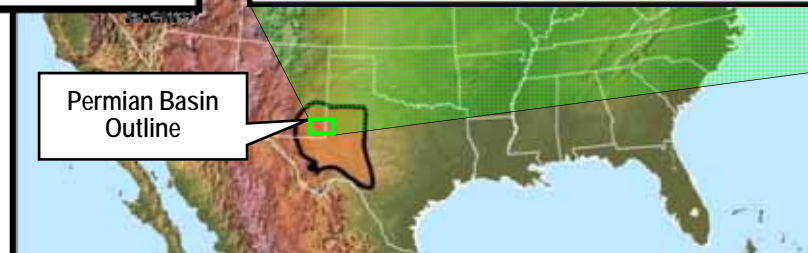


Permian Basin ROZ "Fairways"



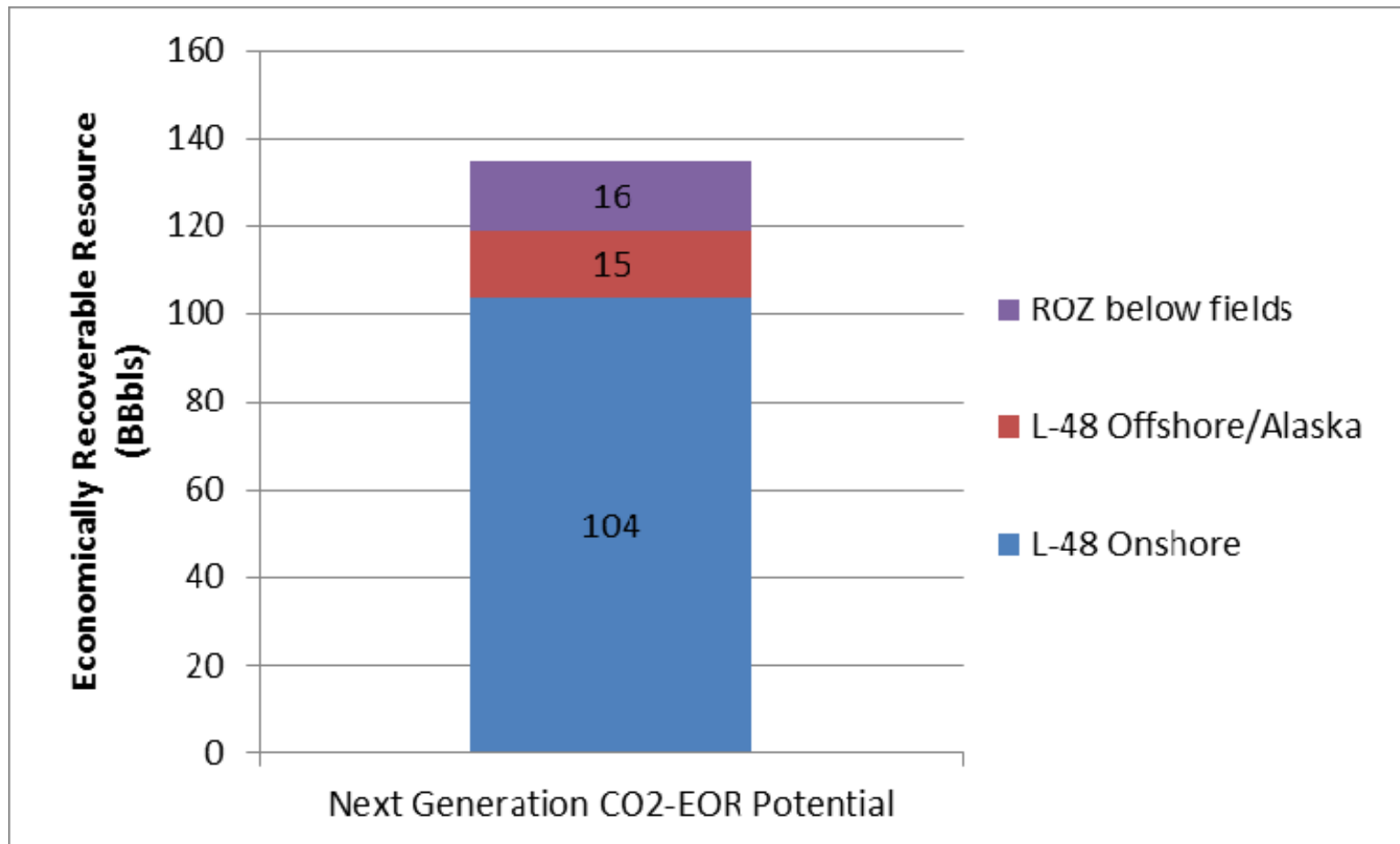
Source: Modified from Melzer Consulting (2010)

Source: Adapted from Pearson, Denver, USA, 1998



# Oil Recovery from "Next Generation" CO<sub>2</sub>-EOR Technology

## Technically Recoverable Resource



# Oil Recovery and CO<sub>2</sub> Demand From "Next Generation" CO<sub>2</sub>-EOR Technology\*

Reservoir Setting	Oil Recovery*** (Billion Barrels)		CO <sub>2</sub> Demand/Storage*** (Billion Metric Tons)	
	Technical	Economic**	Technical	Economic**
L-48 Onshore	104	60	32	17
L-48 Offshore/Alaska	15	7	6	3
Near-Miscible CO <sub>2</sub> -EOR	1	*	1	*
ROZ (below fields)****	16	13	7	5
<b>Sub-Total</b>	<b>136</b>	<b>80</b>	<b>46</b>	<b>25</b>
<b>Additional From ROZ "Fairways"</b>	<b>40</b>	<b>20</b>	<b>16</b>	<b>8</b>

\*The values for economically recoverable oil and economic CO<sub>2</sub> demand (storage) represent an update to the numbers in the NETL/ARI report "Improving Domestic Energy Security and Lowering CO<sub>2</sub> Emissions with "Next Generation" CO<sub>2</sub>-Enhanced Oil Recovery (CO<sub>2</sub>-EOR) (June 1, 2011).

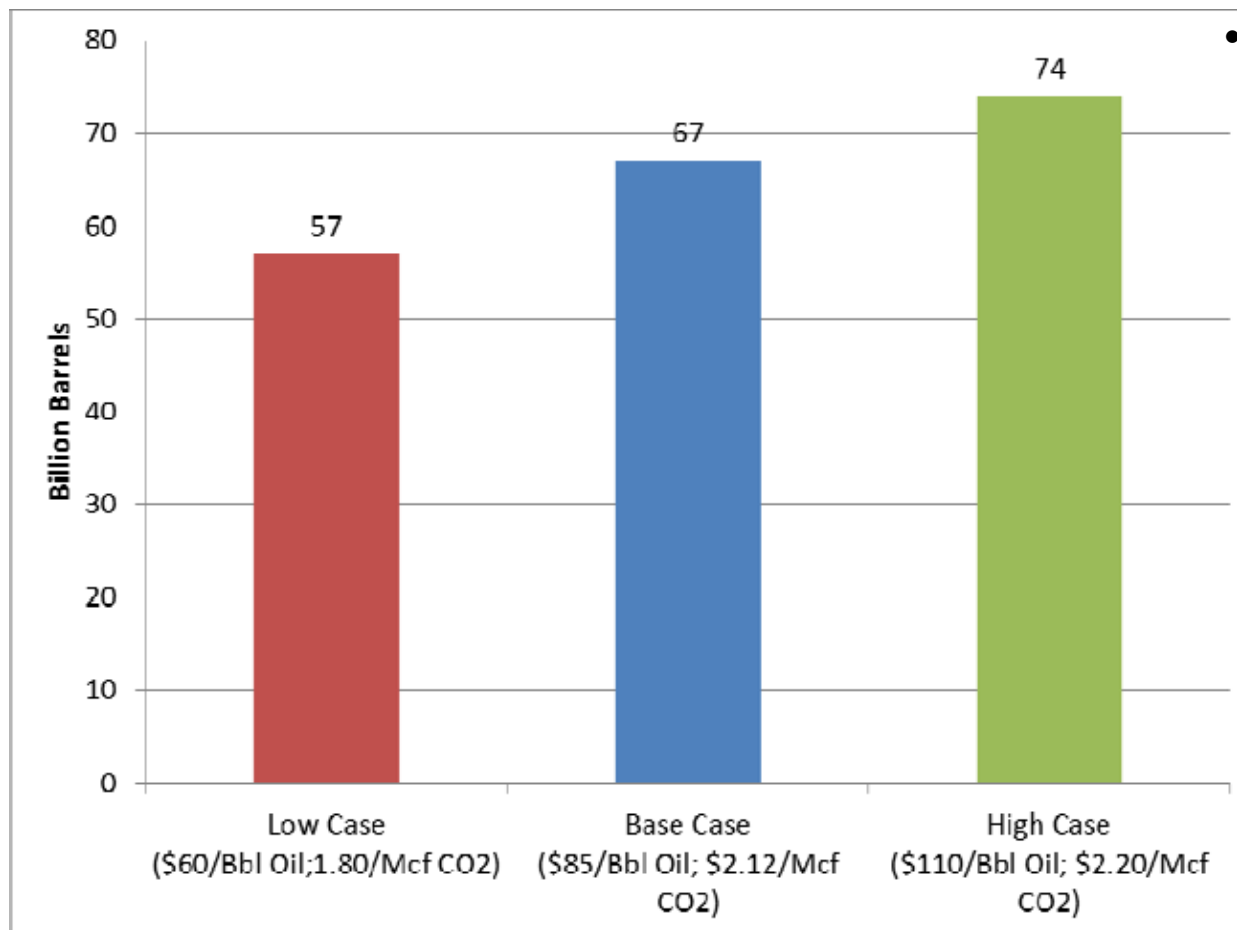
\*\*At \$85 per barrel oil price and \$40 per metric ton CO<sub>2</sub> market price with ROR of 20% (before tax).

\*\*\*Includes 2.6 billion barrels already being produced or being developed with miscible CO<sub>2</sub>-EOR and 2,300 million metric tons of CO<sub>2</sub> from natural sources and gas processing plants.

\*\*\*\* ROZ resources below existing oilfields in three basins; economics of ROZ resources are preliminary.

# Oil Recovery and CO<sub>2</sub> Storage From "Next Generation" CO<sub>2</sub>-EOR Technology\*

## Lower 48 (Onshore, Offshore & Alaska) Economically Recoverable Resource

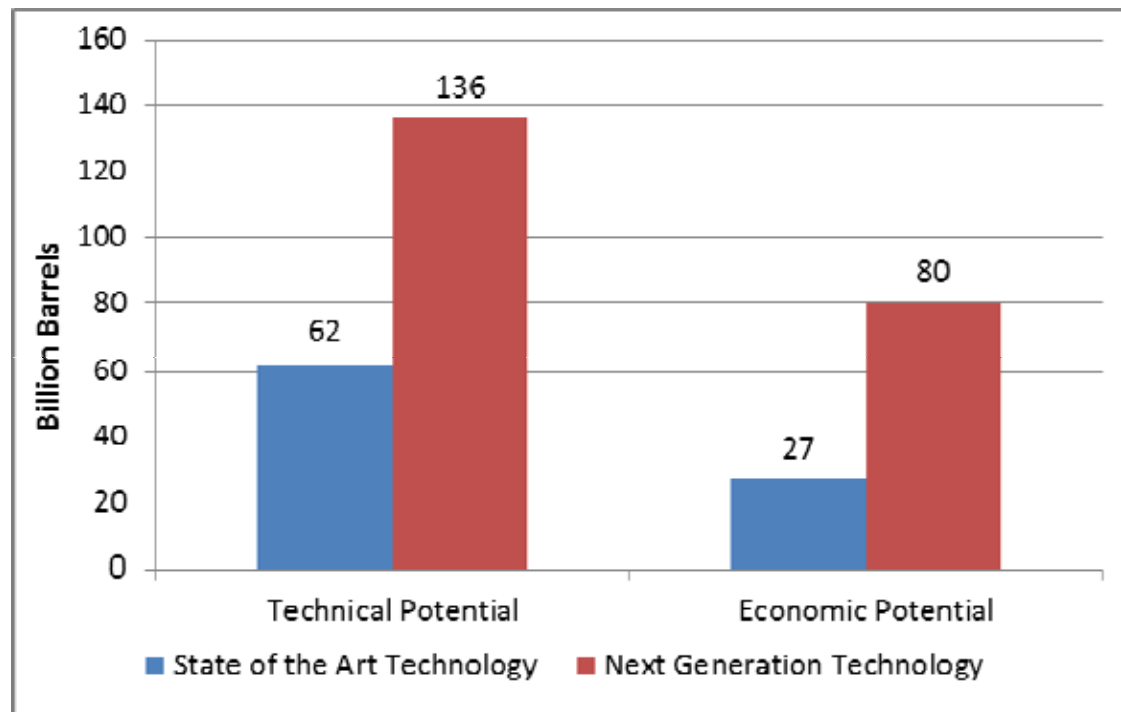


### Economics of many CO<sub>2</sub>-EOR favorable reservoirs are robust:

- At a pessimistic case of \$60/Bbl and \$1.80/mcf of CO<sub>2</sub> (3% of oil price), 57 Billion barrels are economically recoverable.
- At an optimistic case of \$110/Bbl and \$2.20/mcf of CO<sub>2</sub> (2% of oil price), 74 Billion barrels are economically recoverable.

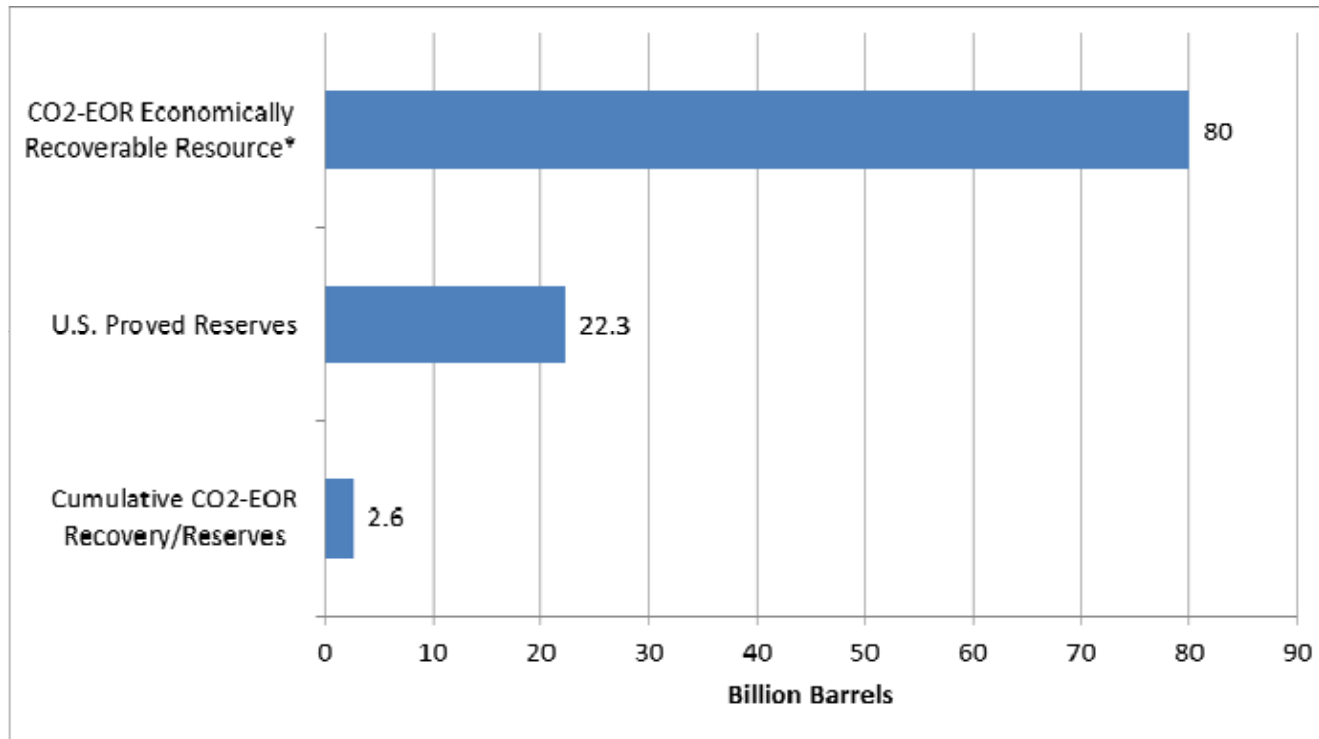
# Comparison of “Next Generation” and “State of Art” CO<sub>2</sub>-EOR

“Next Generation” CO<sub>2</sub>-EOR would provide significantly higher volumes of economic oil recovery and CO<sub>2</sub> demand than current technology.



\*At \$85/B oil price, \$40/mt CO<sub>2</sub> price and 20% ROR, before tax.

# CO<sub>2</sub>-EOR: Domestic Energy Supply Solution?



- Nationwide application of “Next Generation” CO<sub>2</sub>-EOR technology could significantly increase the domestic resource base.
- Work performed by ARI for NRDC shows that production from CO<sub>2</sub>-EOR could reach over 4MMBbls/d in 2030.

\*At \$85/B oil price, \$40/mt CO<sub>2</sub> price and 20% ROR, before tax.

# CO<sub>2</sub>-EOR: Stimulus Package?

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The production of 80 billion barrels of oil with “Next Generation” CO<sub>2</sub> would help revitalize the U.S. economy and create large new sources of revenues:

- Overall revenues and economic activity equal to \$6.8 trillion.
- New Federal and state revenues, from royalties, severance taxes and income taxes of \$1.6 trillion.
- Markets for domestic services and sales of materials of \$2.1 trillion.

Importantly, the CO<sub>2</sub>-EOR industry would create a market for captured CO<sub>2</sub> emissions from the electric power and other industries, equal to over \$1 trillion\* (at a sales price of \$40 per metric ton).

\*Assumes 90% of total CO<sub>2</sub> demand is met by anthropogenic CO<sub>2</sub>.

## Distribution of Revenues from “Next Generation” CO<sub>2</sub>-EOR

Revenue Recipient	Value Chain Function	Revenues	
		Per Barrel	TOTAL
		(\$)	(\$ billion)
1. Federal/State Treasuries	Royalties/Severance/Income Taxes	\$20.50	\$1,640
2. Power/Industrial Companies	Sale of Captured CO <sub>2</sub> Emissions	\$12.60	\$1,010
3. Other	Private Royalties	\$7.70	\$620
4. Oil Industry	Return of/on Capital	\$18.20	\$1,450
5. U.S. Economy	Services, Materials and Sales	\$26.00	\$2,080
	<b>Total</b>	<b>\$85.00</b>	<b>\$6,800</b>

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## Distribution of Economic Value of Incremental Oil Production from CO<sub>2</sub>-EOR

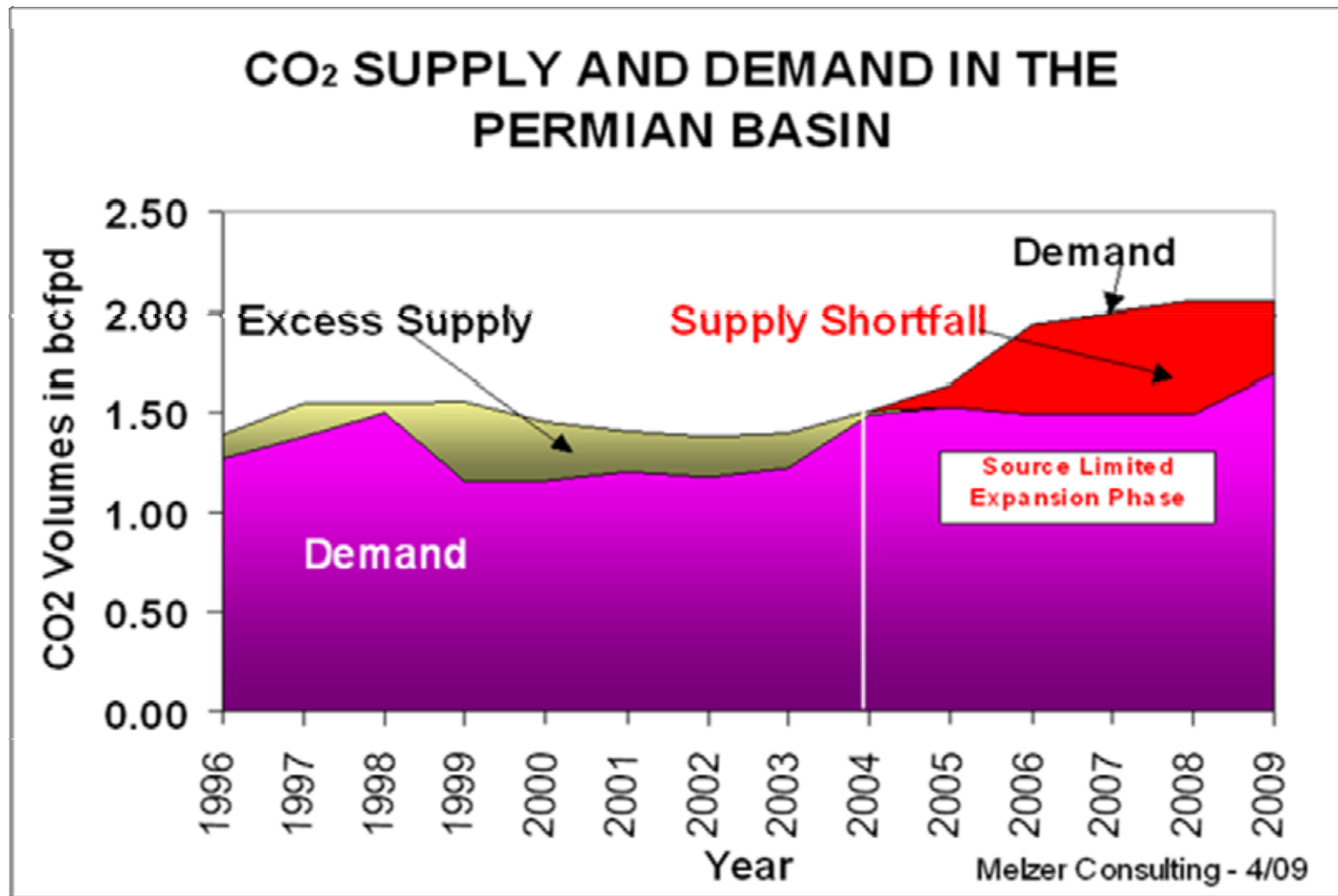
Notes		Oil Industry	Federal/ State	Power Plant/Other	Private Royalties	U.S. Economy
1	Domestic Oil Price (\$/B)	\$85.00				
2	Less: Royalties	(\$14.90)	\$2.50		\$12.40	
3	Production Taxes	(\$3.50)	\$4.10		(\$0.60)	
4	CO <sub>2</sub> Purchase Costs	(\$14.00)		\$12.60		\$1.40
5	CO <sub>2</sub> Recycle Costs	(\$9.60)				\$9.60
6	O&M/G&A Costs	(\$9.00)				\$9.00
7	CAPEX	(\$6.00)				\$6.00
	<b>Total Costs</b>	<b>(\$57.00)</b>		-		
	<b>Net Cash Margin</b>	<b>\$28.00</b>	<b>\$6.60</b>	<b>\$12.60</b>	<b>\$11.80</b>	<b>\$26.00</b>
8	Income Taxes	(\$9.80)	\$13.90	-	(\$4.10)	-
	<b>Net Income (\$/B)</b>	<b>\$18.20</b>	<b>\$20.50</b>	-	<b>\$7.70</b>	

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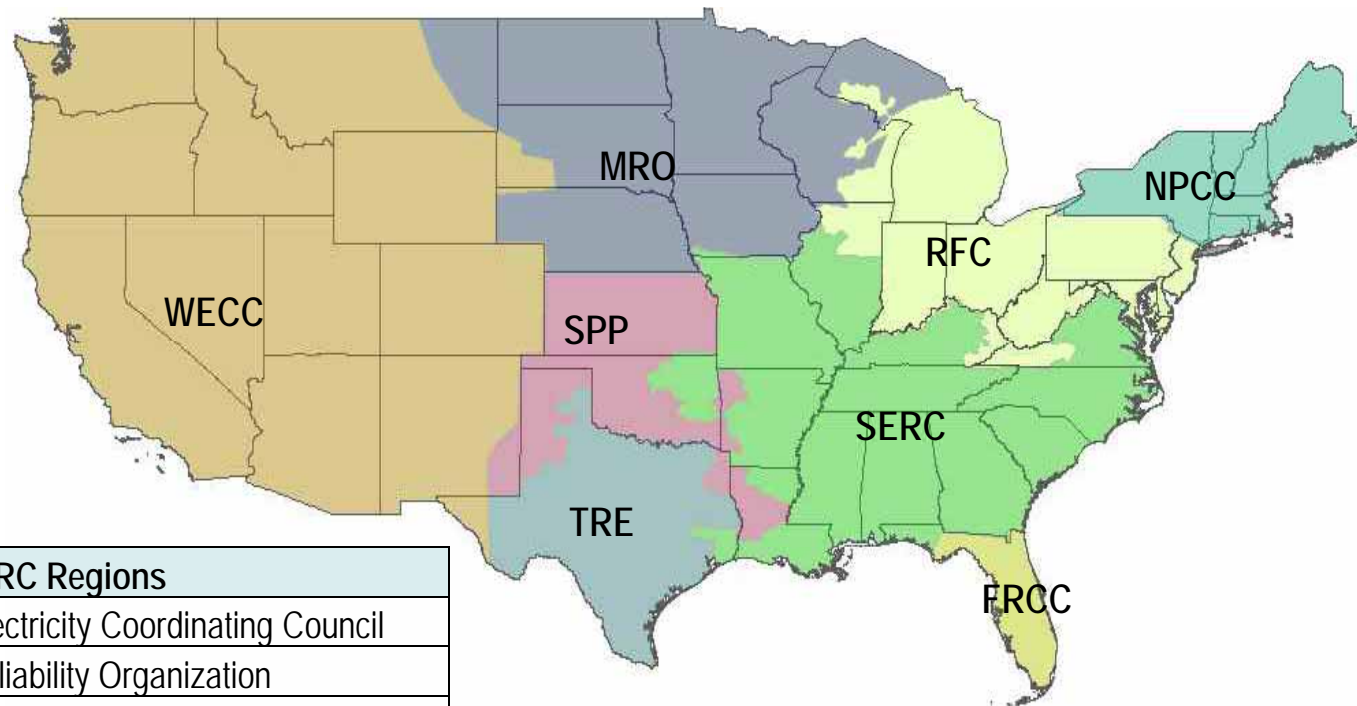
Notes: (1.) Assumes \$85 per barrel of oil; (2.) Royalties are 17.5%; 1 of 6 barrels produced are from federal and state lands; (3.) Production and ad valorem taxes of 5%, from FRS data; (4.) CO<sub>2</sub> market price of \$40/tonne, including transport; 0.35 tonne of purchased CO<sub>2</sub> per barrel of oil; CCS would meet about 90% of CO<sub>2</sub> demand; (5.) CO<sub>2</sub> recycle cost of \$16/tonne; 0.6 tonnes of recycled CO<sub>2</sub> per barrel of oil; (6.) O&M/G&A costs from ARI CO<sub>2</sub>-EOR cost models; (7.) CAPEX from ARI CO<sub>2</sub>-EOR cost models; (8.) Combined Federal and state income taxes of 35%, from FRS data.

# Putting the CO<sub>2</sub> in CO<sub>2</sub>-EOR

Realizing the nationwide resource potential of CO<sub>2</sub>-EOR will require a large expansion of available CO<sub>2</sub> supplies.



# Matching CO<sub>2</sub> Demand from EOR and CO<sub>2</sub> Capture from Coal-Fired Power Plants

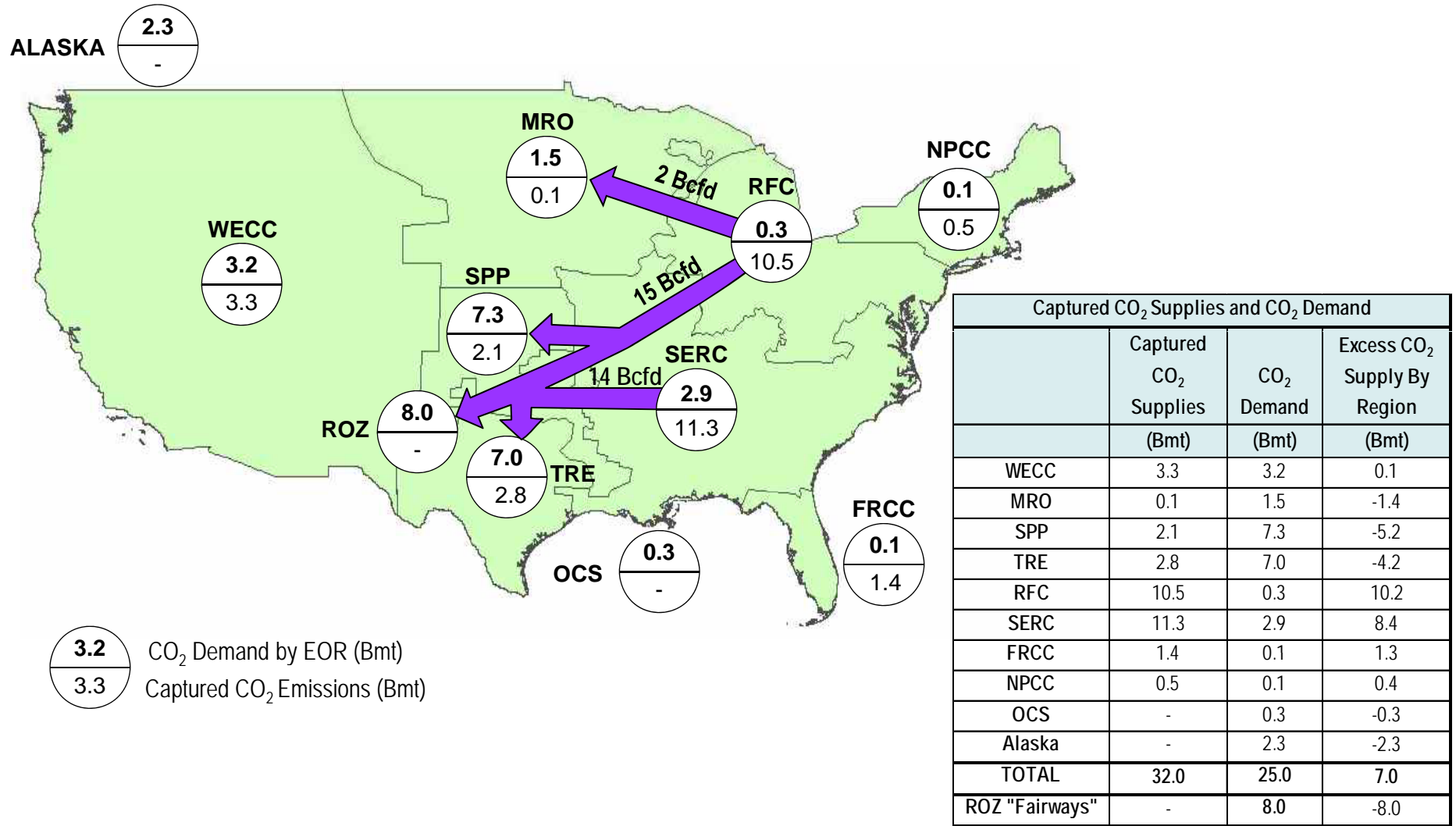


NERC Regions	
WECC	Western Electricity Coordinating Council
MRO	Midwest Reliability Organization
SPP	Southwest Power Pool, RE
TRE	Texas Reliability Entity
RFC	Reliability First Corporation
SERC	SERC Reliability Corporation
FRCC	Florida Reliability Coordinating Council
NPCC	Northeast Power Coordinating Council

The matching of CO<sub>2</sub> demand and CO<sub>2</sub> capture is examined on a NERC regional basis.

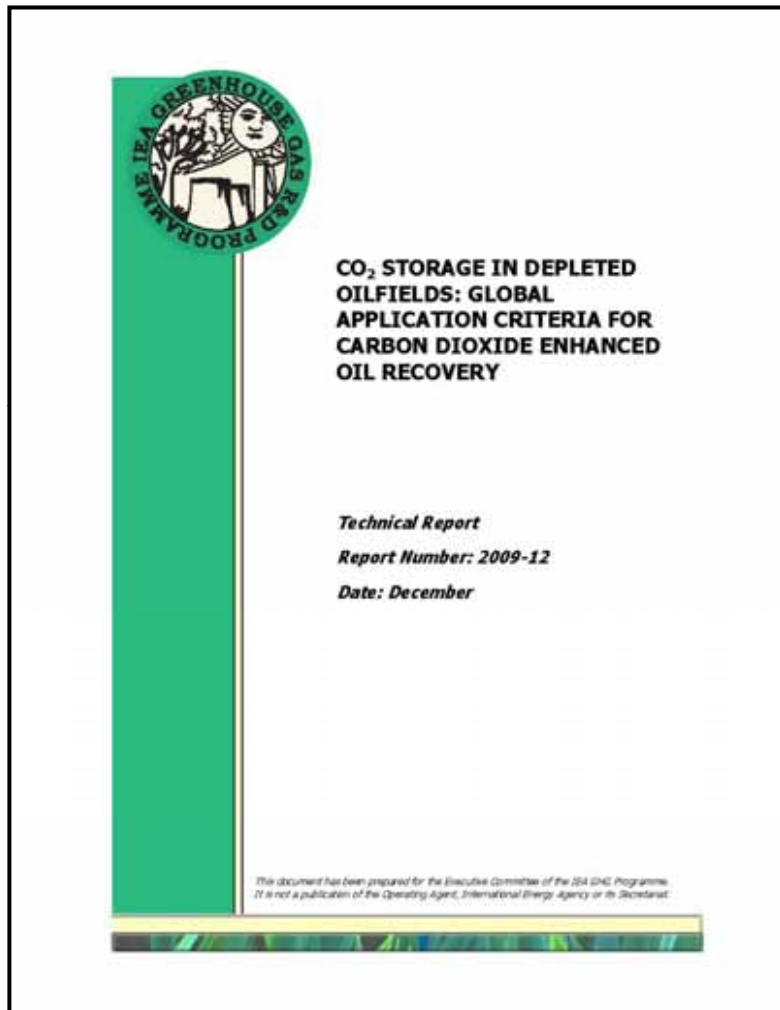
Source: North American Electric Reliability Corporation

# Linking CO<sub>2</sub> Supplies from Power Plants with CO<sub>2</sub>-EOR Demand



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Source: EIA Annual Energy Outlook 2011

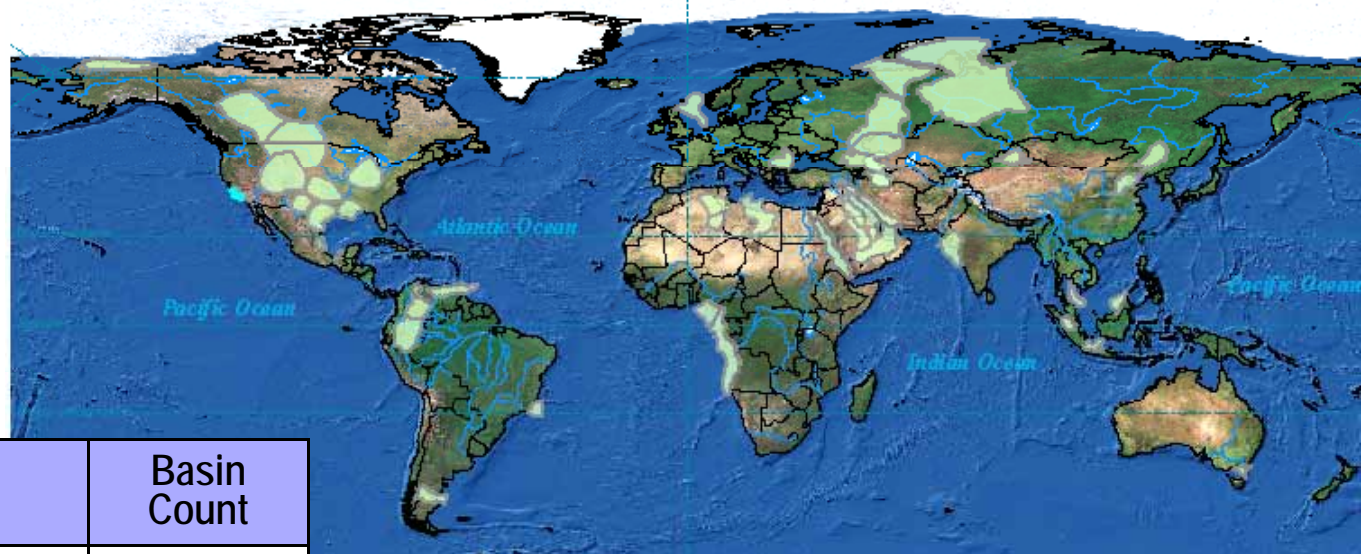


## Worldwide Potential for Using CO<sub>2</sub>-EOR to Store CO<sub>2</sub> and Recover Additional Oil

Advanced Resources prepared for the International Energy Agency Greenhouse Gas Programme (IEA GHG) an assessment of CO<sub>2</sub> storage and oil recovery potential offered by CO<sub>2</sub>-EOR.

CO<sub>2</sub> supplies are primarily from new CO<sub>2</sub> emissions capture facilities with pipeline transportation from power plants, cement plants and refineries to geologically favorable oil fields.

# World Potential from CO<sub>2</sub> Enhanced Oil Recovery



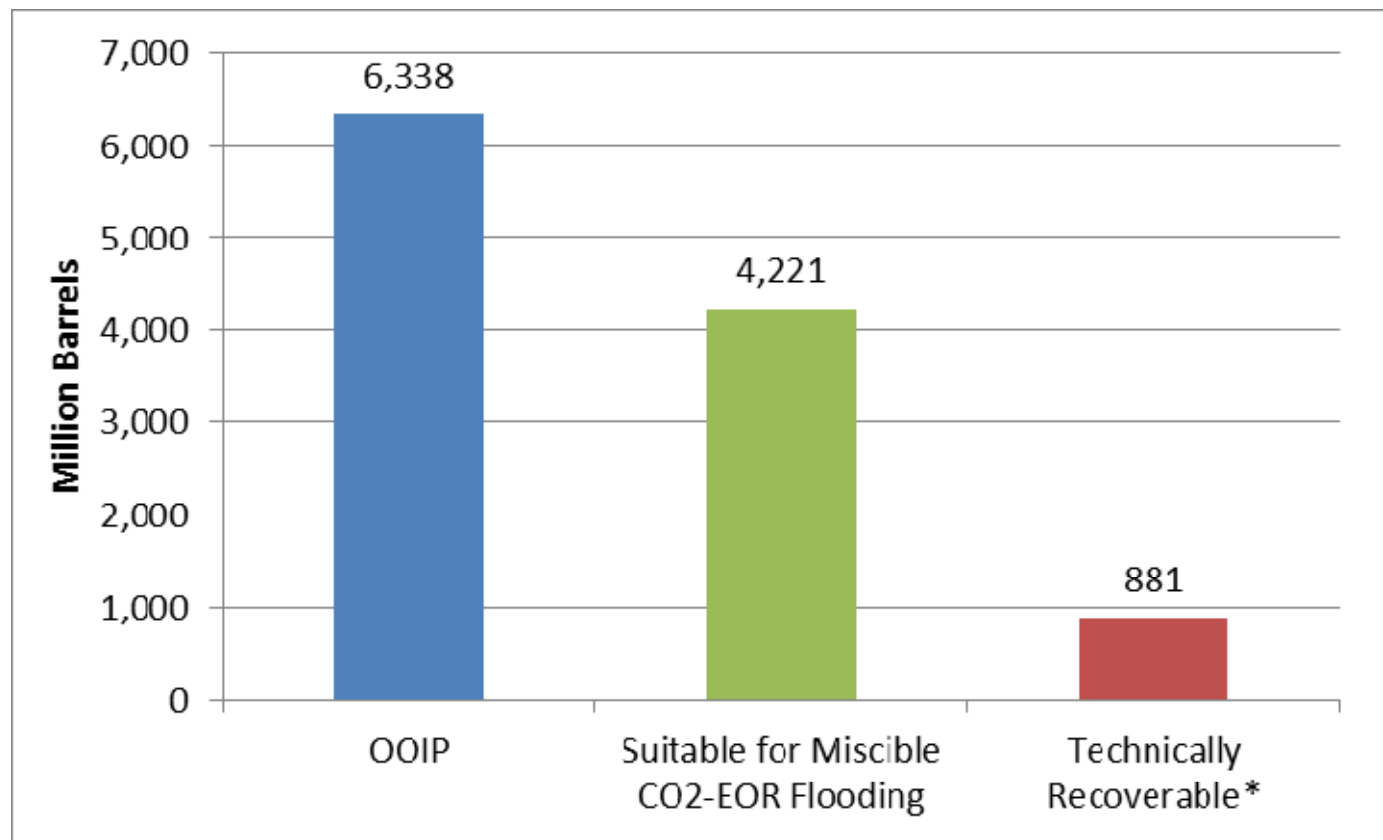
Region Name	Basin Count
Asia Pacific	8
Central and South America	7
Europe	2
Former Soviet Union	6
Middle East and North Africa	11
North America/Other	3
South Asia	1
S. Africa/Antarctica	2
<b>Total</b>	<b>40</b>

Assessed 40 large world oil basins for CO<sub>2</sub>-based Enhanced Oil Recovery.

- High level, 1<sup>st</sup> order assessment of CO<sub>2</sub>-EOR and associated storage potential, using U.S. experience as analog.
- Tested basin-level estimates with detailed modeling of 47 large oil fields in 6 basins.

# Results of World CO<sub>2</sub>-EOR Study

Over 880 billion barrels of oil are technically recoverable with “State of the Art” CO<sub>2</sub>-EOR. Producing this resource would require 261 billion metric tons of CO<sub>2</sub>.

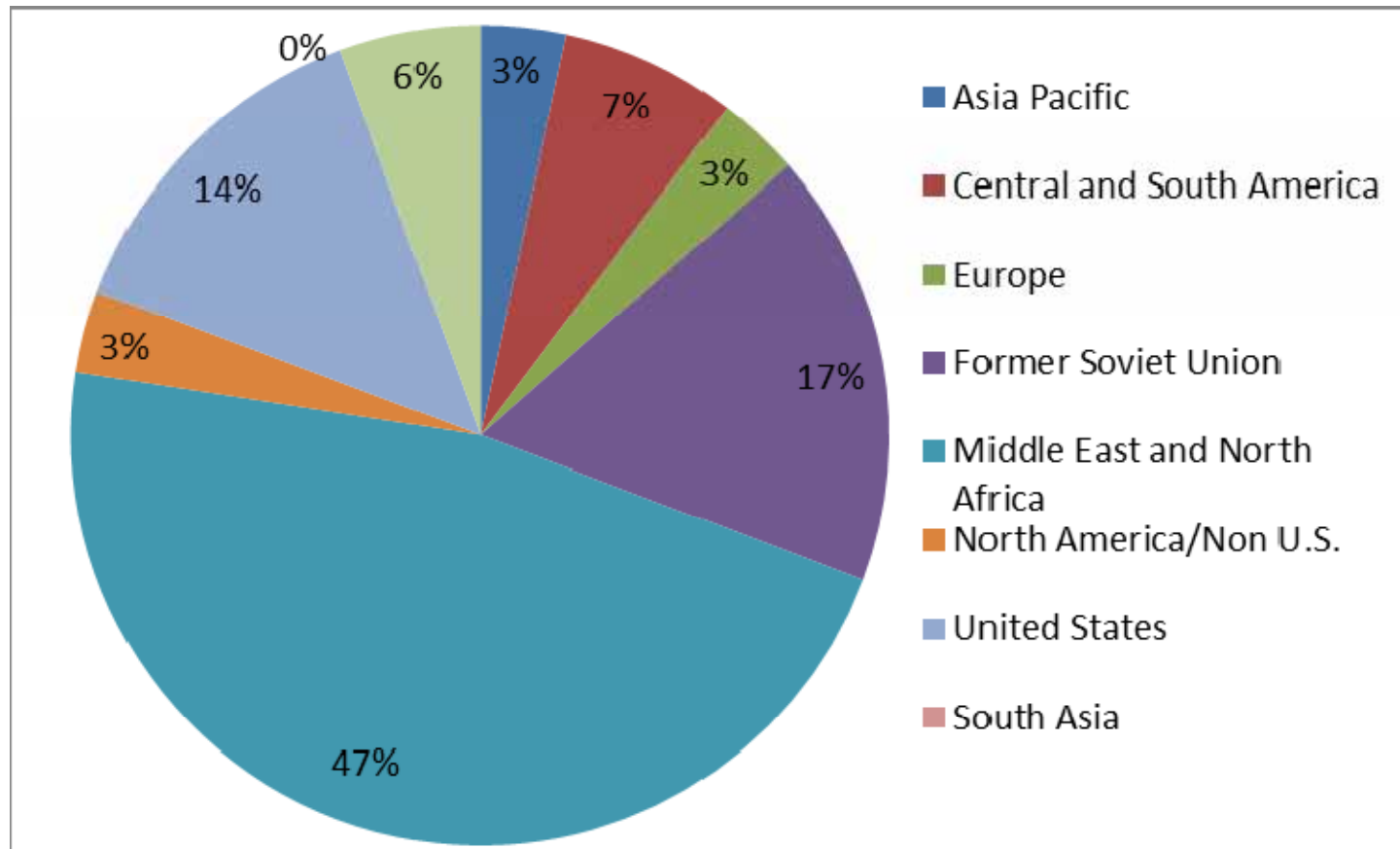


\* Reserve additions could add an additional 49 billion barrels to this total.

# World CO<sub>2</sub>-EOR Potential (Including Reserves Growth)

CO <sub>2</sub> -EOR Potential in Discovered and Undiscovered Fields					
Region Name	Total OOIP (MMBO)	Total OOIP Available for Miscible Flooding (MMBO)	Estimated EOR Recovery Efficiency	CO <sub>2</sub> -EOR Oil Technically Recoverable (MMBO)	CO <sub>2</sub> Demand (GT)
Asia Pacific	274,647	148,404	20%	29,633	8
Central and South America	501,421	331,400	18%	61,071	20
Europe	187,086	126,818	23%	28,660	8
Former Soviet Union	1,054,617	714,881	21%	151,578	42
Middle East and North Africa	2,870,061	1,945,494	21%	411,523	125
North America/Non U.S.	180,503	122,356	23%	28,696	9
United States	871,670	580,503	21%	121,126	34
South Asia	28,278	0	N/A		
Sub-Saharan Africa and Antarctica	370,000	250,807	19%	48,881	15
<b>Sub Total</b>	<b>6,338,283</b>	<b>4,220,662</b>	<b>21%</b>	<b>881,167</b>	<b>261</b>
World Reserve Growth	1,175,040	782,446	21%	163,370	49
<b>Grand Total</b>	<b>7,513,323</b>	<b>5,003,108</b>	<b>42%</b>	<b>1,044,537</b>	<b>310</b>

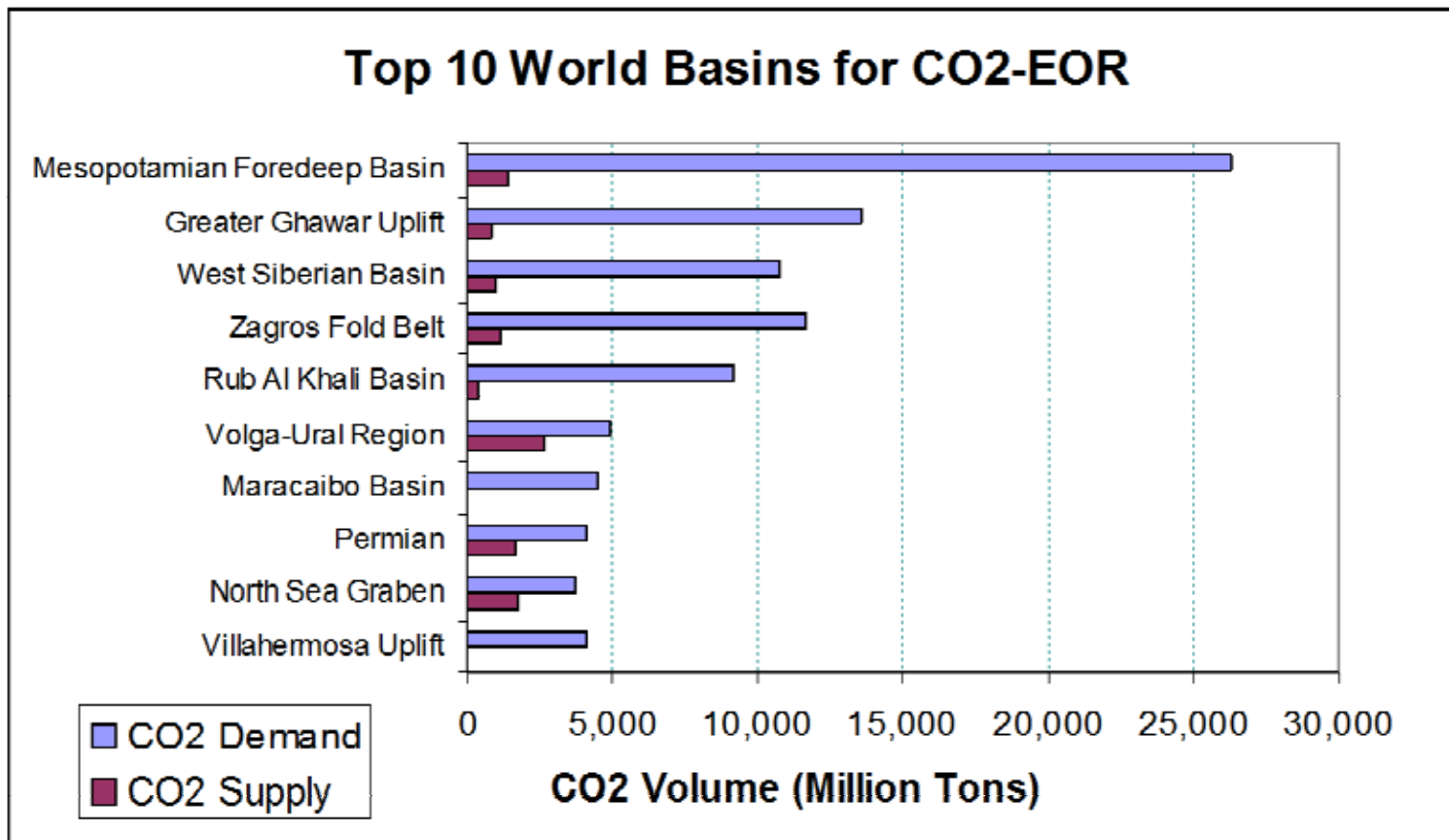
# World CO<sub>2</sub>-EOR Potential



The majority of international CO<sub>2</sub>-EOR potential is in the MENA region (47%; 412 BBbls), followed by the FSU (17%; 152 BBbls)

# World CO<sub>2</sub>-EOR CO<sub>2</sub> Demand

However, some of the world basins with the largest potential are very CO<sub>2</sub> constrained.



# Summary

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1. CO<sub>2</sub>-EOR has potential to technically recover up to 136 billion barrels of oil and purchase up to 46 billion metric tons of CO<sub>2</sub>
  - Equal to the emissions from 240 one-GW size coal-fired power plants\*
2. The ROZ “fairway” resource would add 40 billion barrels of technically recoverable oil and 16 billion metric tons of CO<sub>2</sub> demand (and storage capacity).
3. The economic oil recovery and CO<sub>2</sub> storage potential is about one-half of the technical potential, it depends on oil prices, CO<sub>2</sub> capture costs, availability of “Next Generation” CO<sub>2</sub>-EOR technology, and the viability of the ROZ resource.
  - Under “Base Case” assumptions of \$85/Bbl oil and \$2.12/Mcf CO<sub>2</sub>, 80 billion barrels of oil could be recovered at a 20% IRR.
4. Significant economic benefits would follow the development of this potential, with total revenues and economic activity of \$6.8 Trillion.

\*Assuming 7 MMmt/yr of CO<sub>2</sub> emissions, 90% capture and 30 years of operation per 1 GW of generating capacity.

## Summary (cont.)

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4. Realizing the massive potential of CO<sub>2</sub>-EOR technology will require CO<sub>2</sub> supplies orders of magnitude greater than those currently available.
  - Over 25 Billion tons of additional CO<sub>2</sub> supplies are needed to produce the oil resource identified by our work.
5. The needed CO<sub>2</sub> for nationwide EOR development could come from carbon capture technology applied to the nation's coal-fired power plant fleet.
  - Bringing the CO<sub>2</sub> from emissions-heavy hubs like the Ohio River Valley and Southwest to the Permian and Mid-Continent would require regional, high volume CO<sub>2</sub> pipelines.
6. The U.S. is not unique in its possession of significant CO<sub>2</sub>-EOR oil resources.
  - Almost 900 Billion barrels could be technically recoverable in worldwide basins, concentrated in the Middle East and Former Soviet Union.
  - The U.S. does appear to be unique in possessing adequate CO<sub>2</sub> supplies. The majority of high potential EOR basins do not have sufficient sources of CO<sub>2</sub> within reasonable distances.



**Office Locations:**

**Washington, DC**

4501 Fairfax Drive, Suite 910  
Arlington, VA 22203  
Phone: (703) 528-8420  
Fax: (703) 528-0439

**Houston, TX**

11490 Westheimer, Suite 520  
Houston, TX 77077  
Phone: (281) 558-9200  
Fax: (281) 558-9202

**Knoxville, TN**

603 W. Main Street, Suite 906  
Knoxville, TN 37902  
Phone: (865) 541-4690  
Fax: (865) 541-4688

**Cincinnati, OH**

1282 Secretariat Court  
Batavia, OH 45103  
Phone: (513) 460-0360  
Email: [scarpenter@adv-res.com](mailto:scarpenter@adv-res.com)

**Advanced  
Resources  
International**  
[www.adv-res.com](http://www.adv-res.com)