

From CO_2-EOR to CCS: “Prospects and Challenges of Combining CO_2-EOR with Storage”

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Advanced Resources International

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Unconventional Resources • Enhanced Recovery • Carbon Sequestration

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Main Topics of Presentation

- **Objective: Addressing Common 'Myths'**
  - **EOR represents small fraction of the potential for storage**
  - **CO_2 is not stored during EOR**
- **Broad Benefits can be Realized**
  - **CO_2-EOR encourages CCS deployment**
  - **CCS helps realize the potential of CO_2-EOR**

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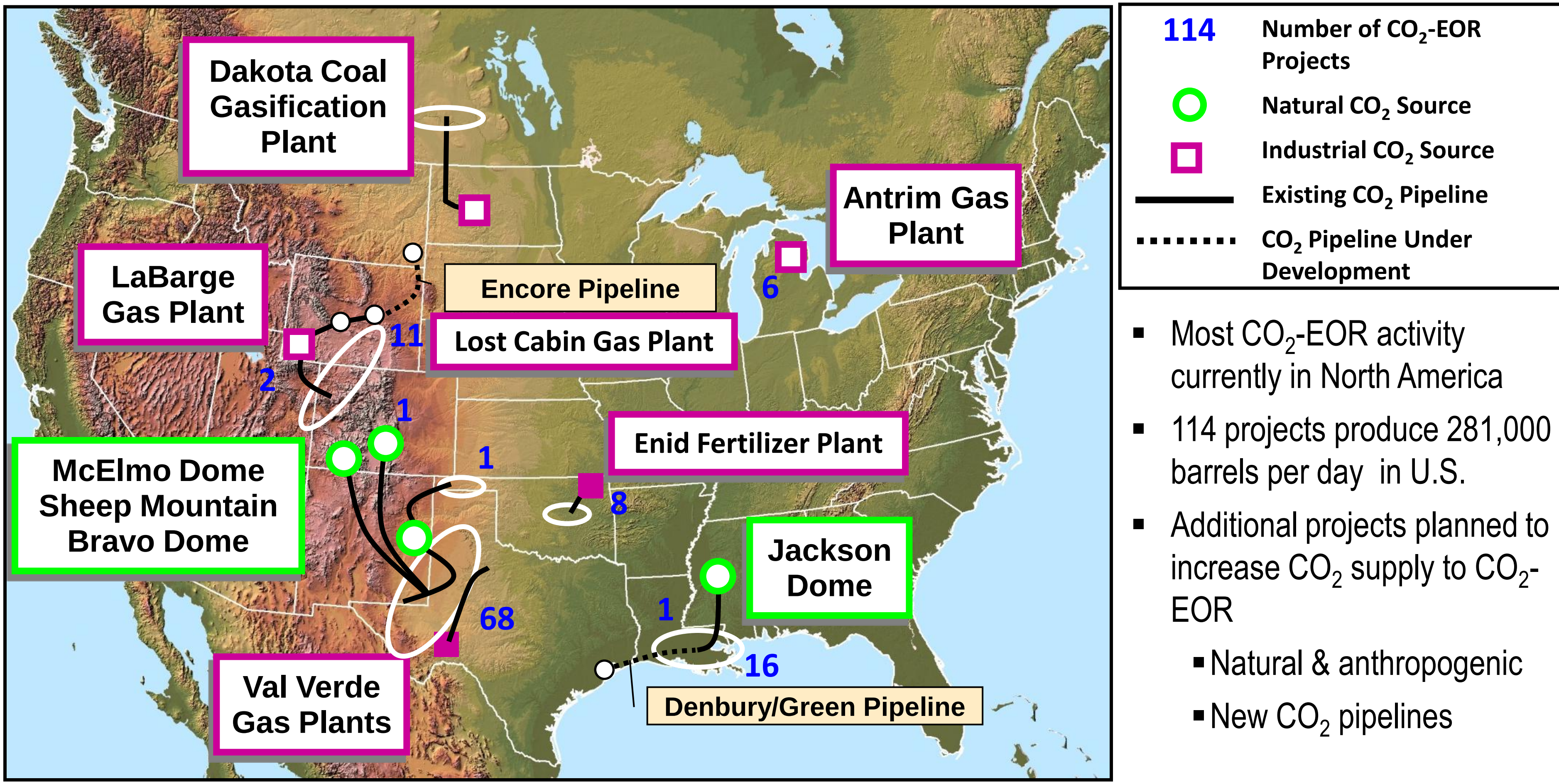
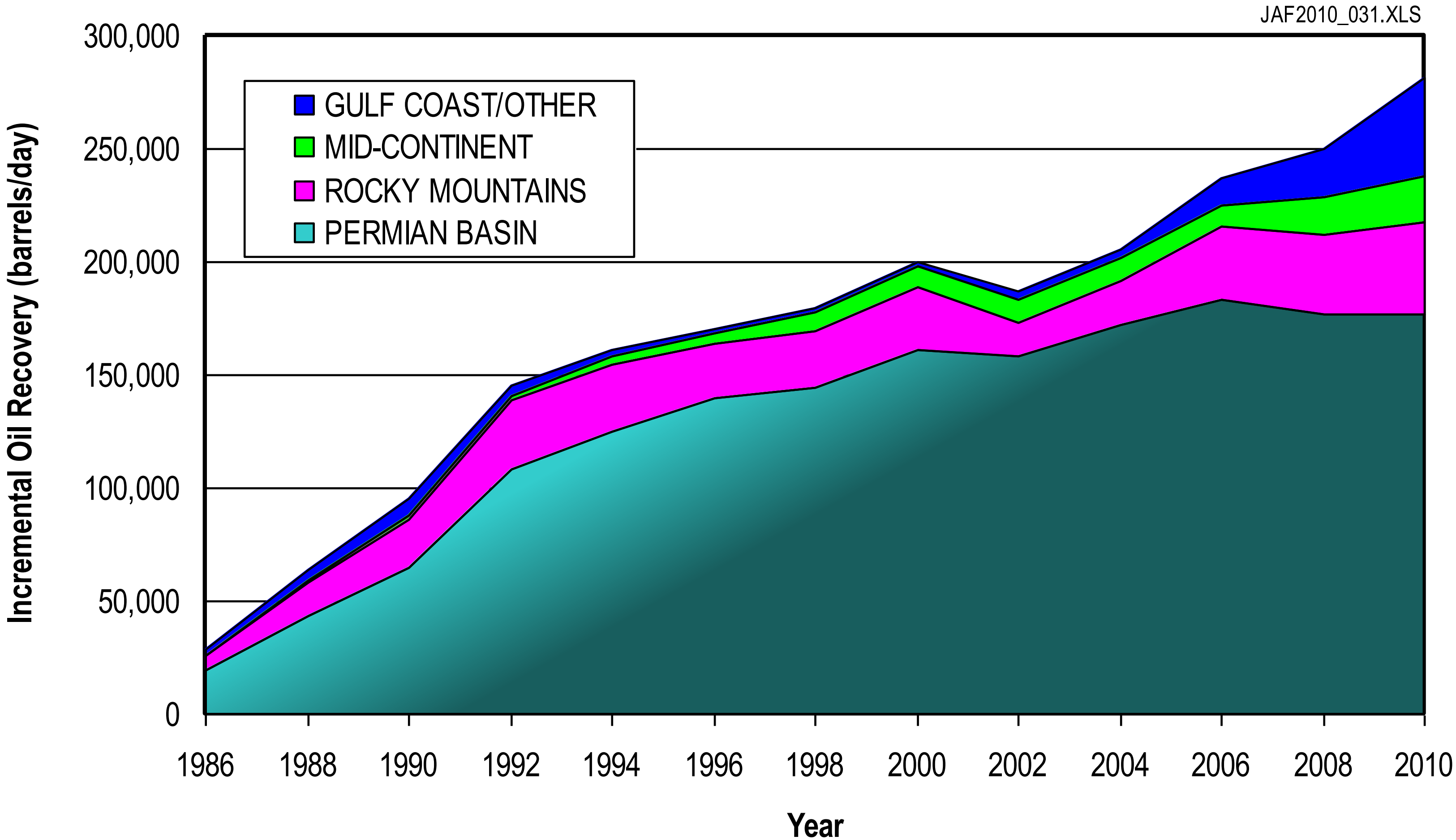
U.S. CO_2-EOR Activity – Oil Fields and CO_2 Sources



- Most CO_2-EOR activity currently in North America
- 114 projects produce 281,000 barrels per day in U.S.
- Additional projects planned to increase CO_2 supply to CO_2-EOR
  - Natural & anthropogenic
  - New CO_2 pipelines

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2010 and other sources.

Growth Of CO_2-EOR Production in the U.S.



Source: Advanced Resources Int'l., based on Oil and Gas Journal, 2010.

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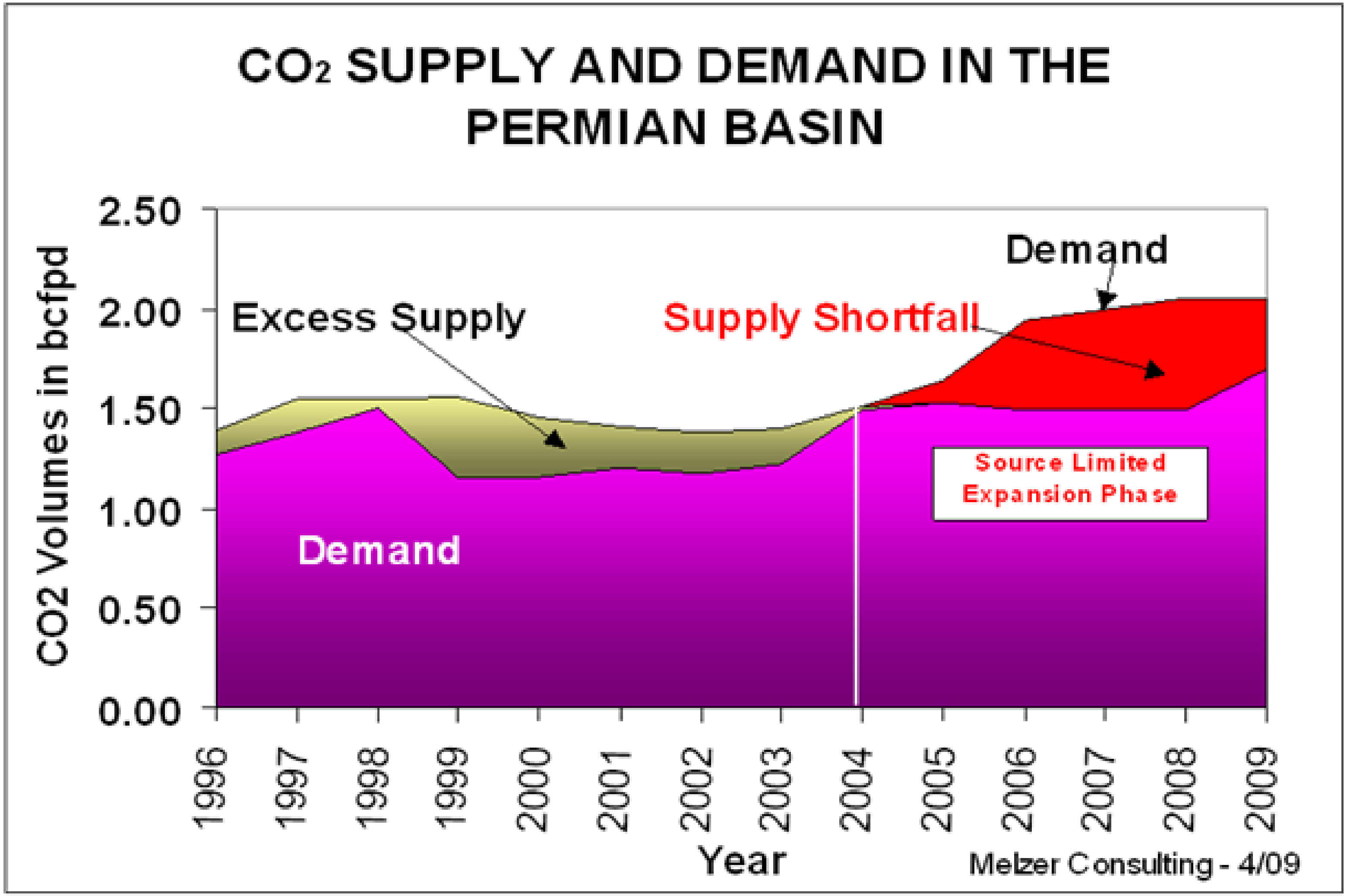
Significant Volumes of CO_2 Are Already Being Injected for EOR in the U.S.

State / Province for EOR / Storage	CO_2 Source Type and Location	CO_2 Supply (MMcfd)	
		Geologic	**Anthropogenic**
Texas-Utah- New Mexico-Oklahoma	Geologic (Colorado-New Mexico) Gas Processing (Texas)	1,540	180
Colorado-Wyoming	Gas Processing (Wyoming)	-	320
Mississippi	Geologic (Mississippi)	900	-
Michigan	Ammonia Plant (Michigan)	-	15
Oklahoma	Fertilizer Plant (Oklahoma)	-	30
Saskatchewan	Coal Gasification (North Dakota)	-	150
TOTAL (MMcfd)		**2,440**	**695**
TOTAL (million tonnes per year)		**47**	**13**

** Source: Advanced Resources International, 2009*

***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)*

Since 2004, CO_2-EOR Demand for CO_2 has Exceeded CO_2 Supply in the Permian Basin



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Oil Recovery and CO_2 Storage in the U.S. From "Next Generation" CO_2-EOR Technology*

Reservoir Setting	Oil Recovery*** (Billion Barrels)		CO_2 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_2-EOR	1	*	1	*
ROZ (below fields)****	16	13	7	5
Sub-Total	**136**	**80**	**46**	**25**
Additional From ROZ “Fairways”	**40**	**20**	**16**	**8**

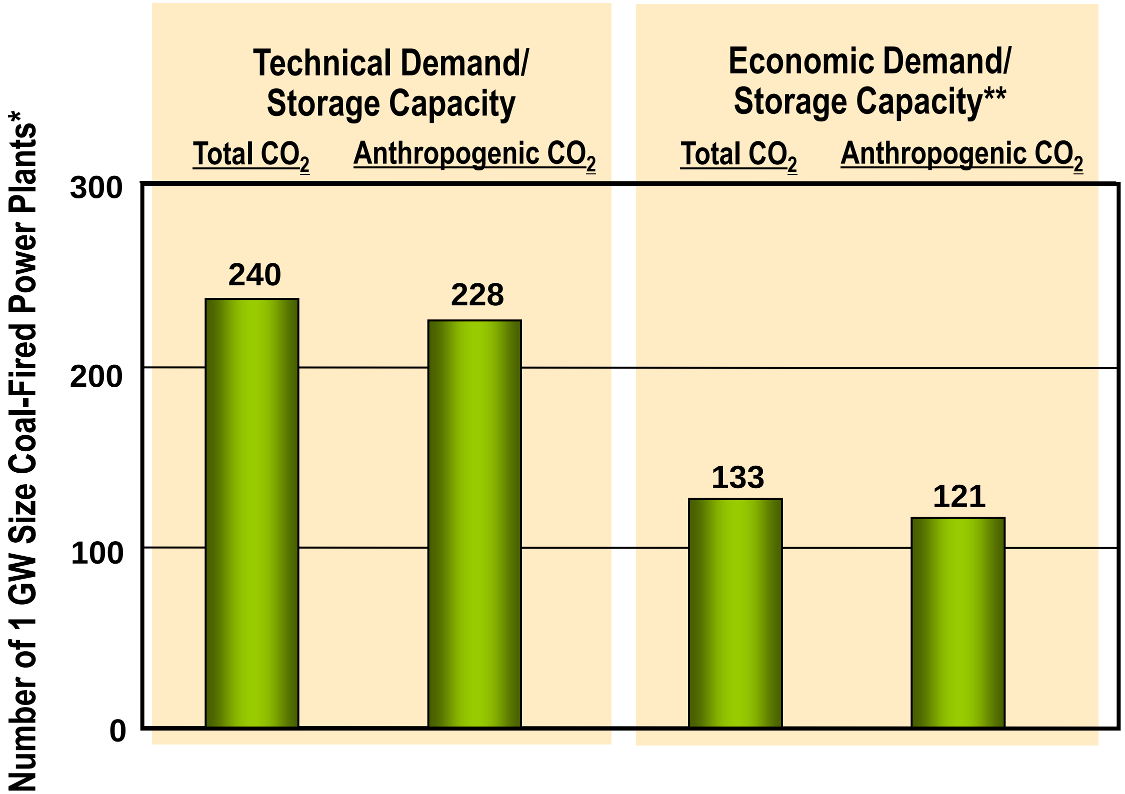
*The values for economically recoverable oil and economic CO_2 demand (storage) represent an update to the numbers in the NETL/ARI report “Improving Domestic Energy Security and Lowering CO_2 Emissions with “Next Generation” CO_2-Enhanced Oil Recovery (CO_2-EOR) (June 1, 2011).

**At $85 per barrel oil price and $40 per metric ton CO_2 market price with ROR of 20% (before tax).

***Includes 2.6 billion barrels already being produced or being developed with miscible CO_2-EOR and 2,300 million metric tons of CO_2 from natural sources and gas processing plants.

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

U.S. Demand for CO_2: Number of 1 GW Size Coal-Fired Power Plants



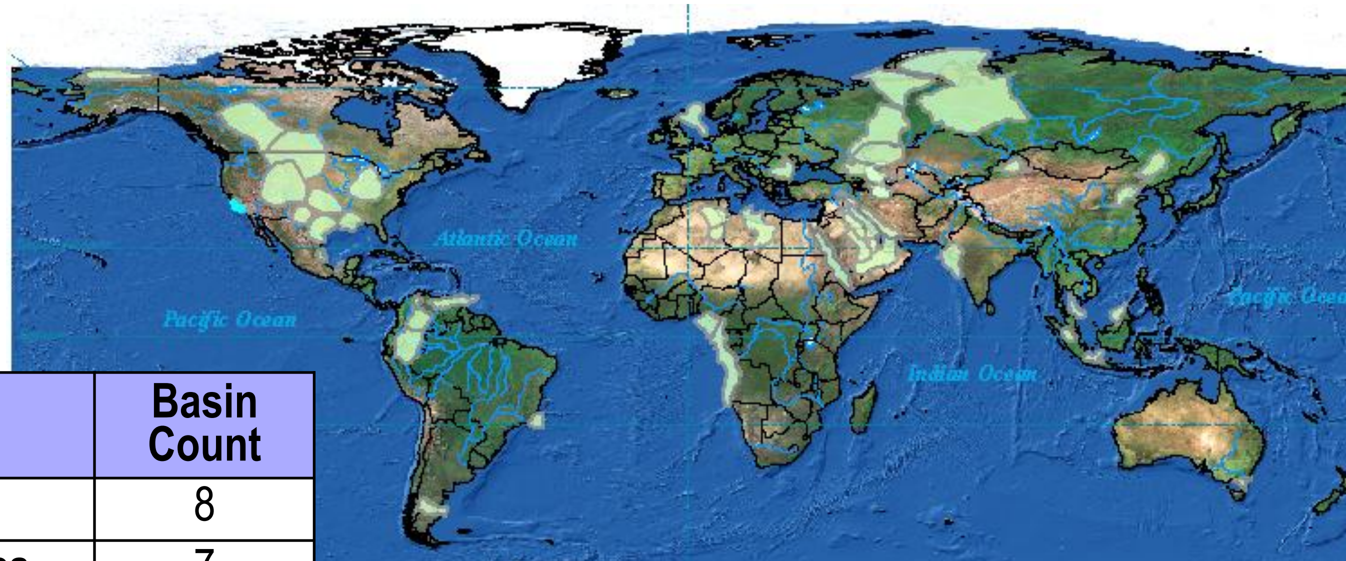
*Assuming 7 MMmt/yr of CO_2 emissions, 90% capture and 30 years of operations per 1 GW of generating capacity.
**At an oil price of $85/B, a CO_2 market price of $40/mt and a 20% ROR, before.

Reservoir Setting	Number of 1GW Size Coal-Fired Power Plants***	
	Technical	Economic*
L-48 Onshore	170	90
L-48 Offshore/Alaska	31	14
Near-Miscible CO2-EOR	5	1
ROZ**	34	28
Sub-Total	**240**	**133**
Additional From ROZ "Fairways"	**86**	**43**

*At $85 per barrel oil price and $40 per metric ton CO_2 market price with ROR of 20% (before tax).
** ROZ resources below existing oilfields in three basins; economics of ROZ resources are preliminary.
***Assuming 7 MMmt/yr of CO_2 emissions, 90% capture and 30 years of operation per 1 GW of generating capacity; the U.S. currently has approximately 309 GW of coal-fired power plant capacity.

Source: Advanced Resources Int'l (2011).

Assessment of Global CO_2-EOR Potential



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
North America/United States	14
South Asia	1
S. Africa/Antarctica	2
Total	**54**

Assessed 54 large world oil basins for CO_2-based Enhanced Oil Recovery

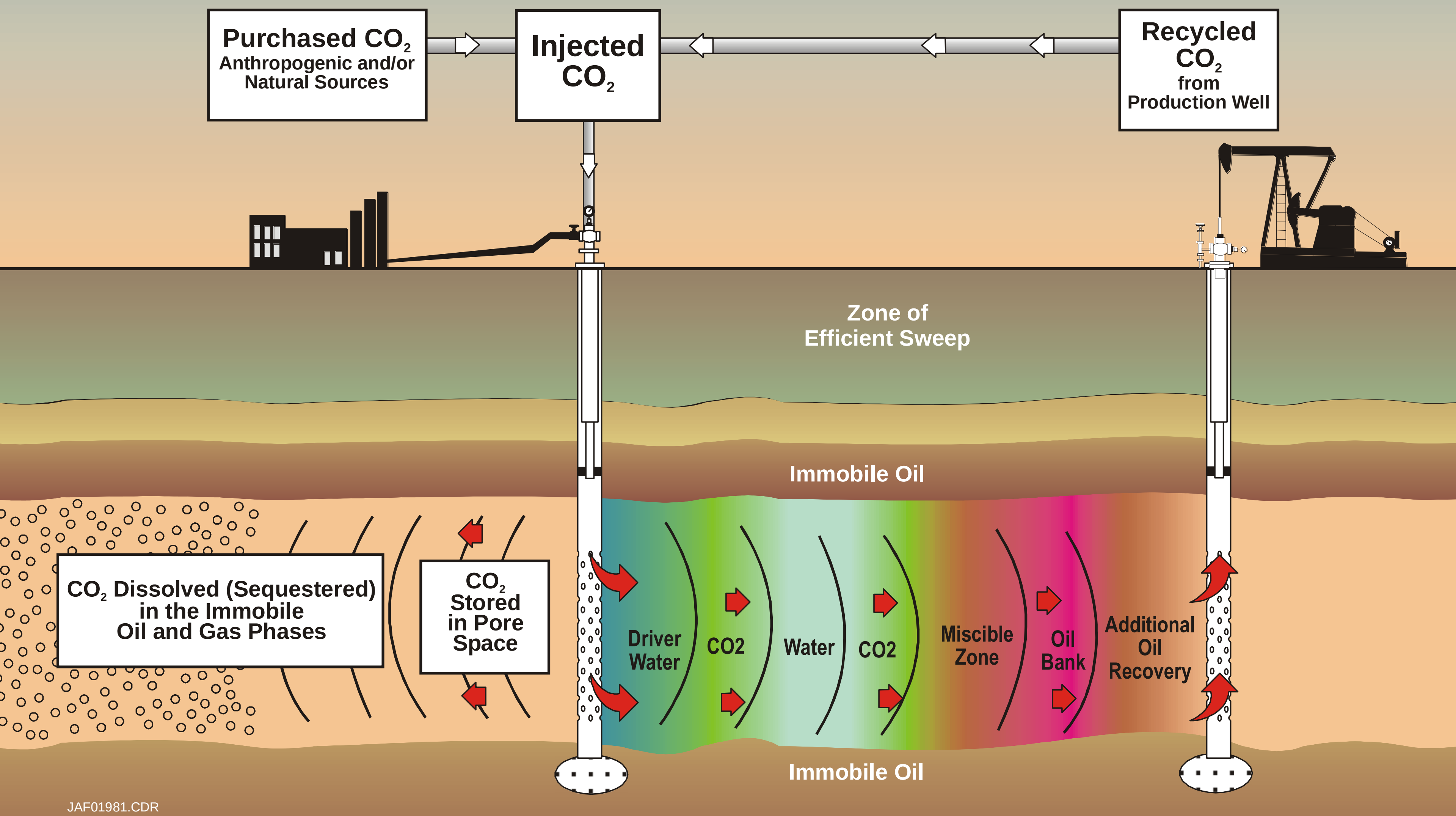
- High level, 1st order assessment of CO_2-EOR and associated storage potential, using U.S. experience as analogue.
- Tested basin-level estimates with detailed modeling of 47 large oil fields in 6 basins.

Technical Oil Recovery and CO_2 Storage Potential in World's Oil Basins* From "Next Generation" CO_2-EOR Technology

Region	CO_2-EOR Oil Recovery ("Next Generation" CO_2-EOR)	CO_2 Storage Capacity ("Next Generation" CO_2-EOR)
	(Billion Barrels)	(Billion Metric Tons)
1. Asia Pacific	47	10
2. C. & S. America	93	21
3. Europe	41	10
4. FSU	232	50
5. M. East/N. Africa	595	142
6. NA/Other	38	11
7. NA/U.S.**	177	41
8. South Asia	-	-
9. S. Africa/Antarctica	74	16
TOTAL	**1,296**	**301**

* Includes potential from discovered and undiscovered fields, but not estimated future growth in discovered fields
** Not including offshore & Alaska

Overview of CO_2-EOR Process



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CO_2 RETENTION

Industry's Historical Definition

CO_2 Retention: amount of CO_2 injected in a reservoir that remains:

$$\frac{(CO_2 \text{ Injected* } - CO_2 \text{ Produced})}{(CO_2 \text{ Injected*})}$$

Question: Should the denominator more appropriately be CO_2 purchased or acquired?

In general, the CO_2 volume stored for EOR is approximately the volume initially purchased

** Note that it is 'Total Injected Volumes' which Includes Recycled Volumes*

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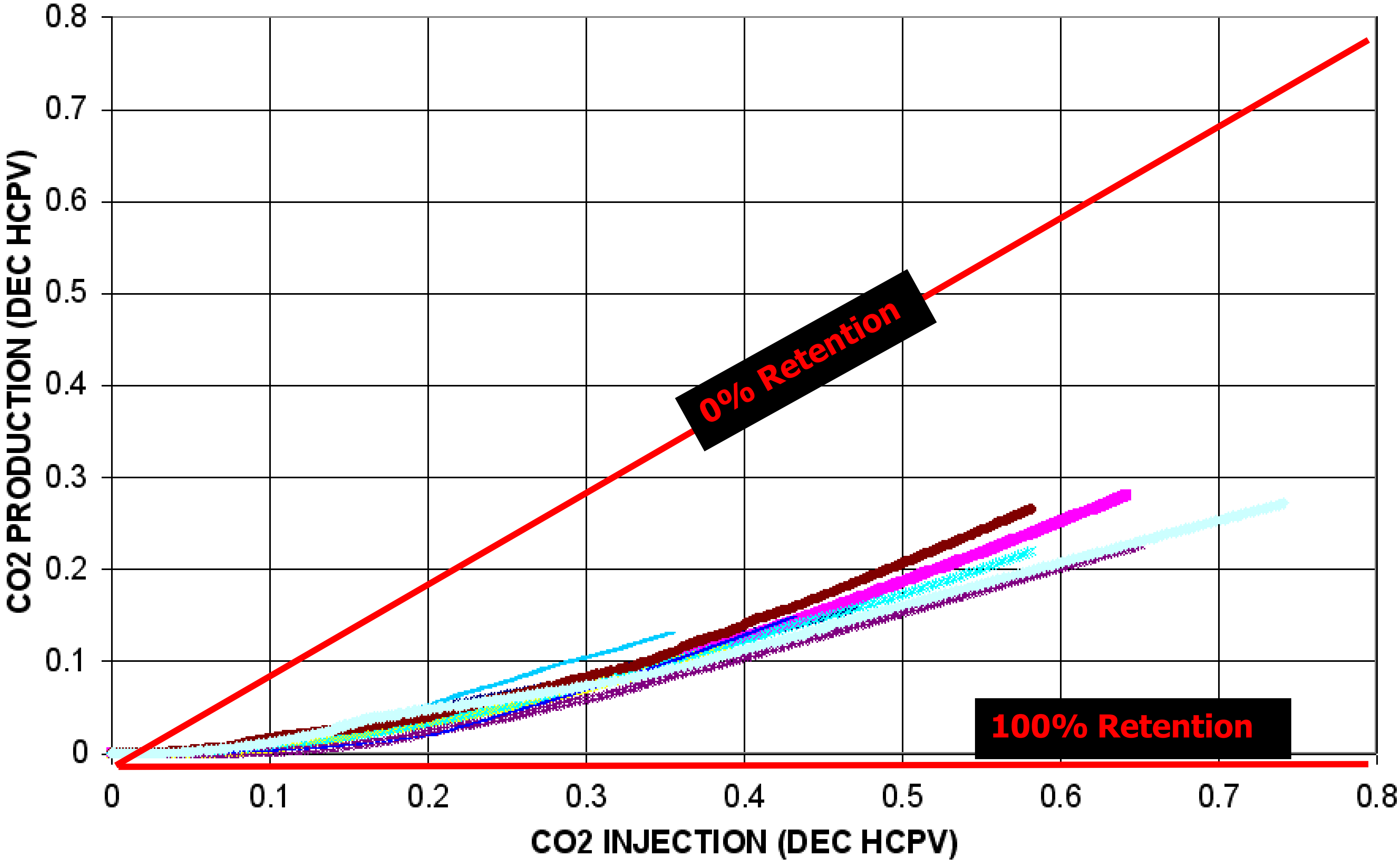
Carbonate Comparison

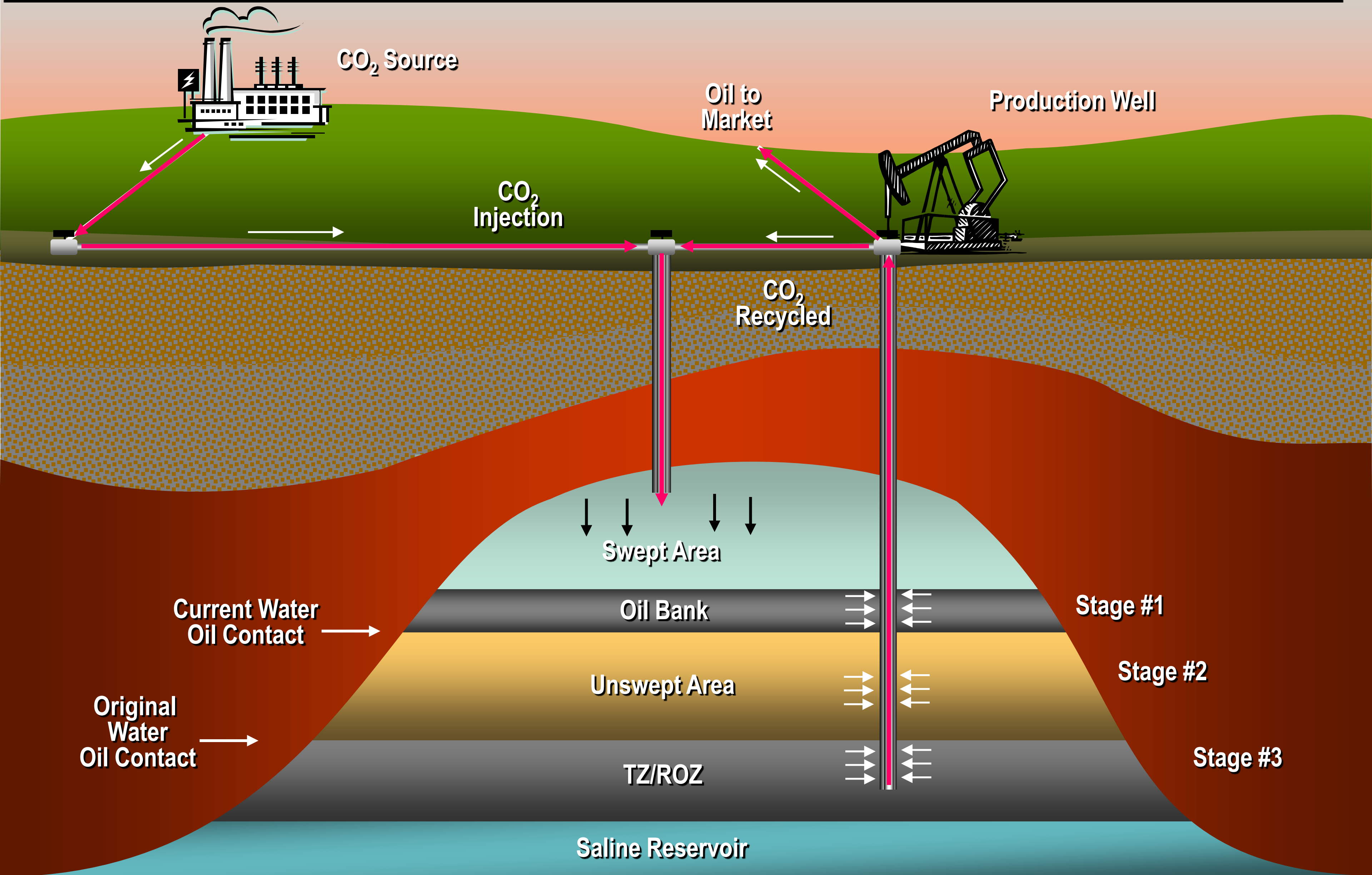
West Texas San Andres Formation



Alternative Approaches to Increase CO_2 Storage with CO_2-EOR

- Inject CO_2 earlier in project life
- Inject CO_2 longer
- Continuously inject CO_2 instead of alternating with water via WAG
- Inject and CO_2 into the residual oil/transition zone
- Inject CO_2 into other geologic horizons accessible from same surface infrastructure used for CO_2-EOR
- Produce residual water to “make more room” for CO_2.

Integrating CO_2-EOR and CO_2 Storage Could Increase Storage Potential



CCS Needs CO_2-EOR

Benefits of Using CO_2-EOR to Accelerate CCS Deployment

- ***Additional Revenues Offset the Costs of CCS***. Sale of captured CO_2 for EOR provides revenue that can offset the costs of CCS. The value of this offset is highly project dependent.
- ***Variety of Entities can Benefit from these Revenues***. Can include oil producers, land owners, the sources of CO_2 emissions, the government, and the economy.
- ***CO_2-EOR Helps Overcome Other Barriers to CCS***. Enables CCS projects to be implemented while "difficult issues" (e.g., pore space rights, public acceptance) are resolved.
- ***Increasing Energy Production***. Productive use of captured CO_2 emissions industrial facilities could increase oil production.
- ***Oil Production with Lower CO_2 "Footprint.*** " Production from CO_2-EOR has half the emissions of traditional production; optimizing for CO_2 storage results in an even smaller, and perhaps negative, "footprint"

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CO_2-EOR Needs CCS

Achieving the Benefits of Increased Production from CO_2-EOR Requires CO_2

- Growth in production from CO_2-EOR is now limited by the availability of reliable, affordable CO_2.
  - There are more prospective CO_2-EOR projects than there is CO_2 to supply them
- If increased volumes of CO_2 do not result from CCS, then the benefits cited from CO_2-EOR may not be realized.
- Thus, not only does CCS need CO_2-EOR to ensure viability of CCS, but CO_2-EOR needs CCS to ensure adequate CO_2 to facilitate CO_2-EOR growth.
- This will become even more apparent as potential new targets for CO_2-EOR become recognized.

Current CCS Activities and Project Plans are Dominated by CCS Applications

- Of the 9 planned DOE CCS Demonstration Projects, 7 propose to utilize CO_2-EOR
- Worldwide, the Global CCS Institute reports 77 large-scale integrated projects (LSIPs) at various stages of the asset life cycle
  - 34 (44%) are targeted for EOR.
- 8 of these projects are operating, and 4 are in the execution phase of the project life cycle
  - 5 of the 8 operating projects and 3 of 4 in execution are injecting CO_2 for EOR

EOR has Attractive Features for CO_2 Storage Relative to Saline Formations

- Much reduced footprint (perhaps an order of magnitude in area) for the underground CO_2 plume
- Oil production can lower storage technical risk because of lower reservoir pressure requirements for CO_2 storage
- Historical production operations provide:
  - Baseline of reservoir data and production history
  - Known trap and seal integrity tested over geologic time
  - Existing infrastructure at the site
  - Generally, local public acceptance for similar operations to CO_2 storage

Significant Challenges Still Remain

- Value proposition not always apparent
  - More challenging without a price on carbon
  - Including in the Clean Development Mechanism <u>may</u> help
- Old fields require major infrastructure; cost of system recapitalization is significant
  - US Permian basin projects support ~$10-$25/tonne delivered at injection pressure because they leverage infrastructure.
  - Offshore projects challenged even with “free CO_2,” storage credits and high oil prices.
- The number of companies with CO_2-EOR experience is limited; BUT GROWING

Significant Challenges Still Remain (cont.)

- Balancing EOR field CO_2 requirements with CO_2 supply source
  - Requires new collaborations between entities that have not commonly collaborated before
  - Understanding full project life-cycle energy and carbon balance
- Regulatory frameworks are evolving regarding the transition of EOR to storage, but are not there yet
  - Issues include long term monitoring requirements, pipeline siting and access, long-term liability, and pore space rights
- EVERY STORAGE RESERVOIR IS UNIQUE!
  - No “one size fits all” solutions

Concluding Thoughts and Observations

1. ***CO_2-EOR Offers Large CO_2 Storage Capacity Potential.*** CO_2-EOR in oil fields can accommodate a major portion of the CO_2 captured from industrial facilities for the next 30 years.
2. ***CO_2 is Stored with CO_2-EOR.*** The amount stored depends on the priority placed on maximizing/optimizing storage.
3. ***CCS Benefits from CO_2-EOR***. The revenues (or cost reduction) from sale of CO_2 to EOR helps CCS economics, overcomes some barriers, while producing oil with a lower CO_2 emissions "footprint."
4. ***CO_2-EOR Needs CCS.*** Large-scale implementation of CO_2-EOR is dependent on CO_2 supplies from industrial sources.
5. ***Both CCS and CO_2-EOR Still Need Supportive Policies and Actions.*** Supportive policies and pre-built CO_2 pipelines would greatly accelerate the integrated use of CO_2-EOR and CCS.

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Distribution of Economic Value of Incremental Oil Production from CO_2-EOR

(Given Fiscal Regime in the U.S.)

Notes		Oil Industry	Private Minerals	Federal/ State	Power Plant/ Transportation	U.S. Economy
1	**Domestic Oil Price ($/B)**	**$100.00**				
2	Less: Royalties	($17.50)	$14.60	$2.90		
3	• Production Taxes	($4.10)	($0.70)	$4.80		
4	• CO2 Purchase Costs	($17.50)			$17.50	
5	• CO2 Recycle Costs	($12.00)				$12.00
6	• Other O&M Costs	($8.00)				$8.00
7	• Amortized CAPEX	($4.00)				$4.00
	Total Costs	**($63.10)**			-	
	Net Cash Margin	**$36.90**	**$13.90**	**$7.70**	**$17.50**	**$24.00**
8	**Income Taxes**	**($12.90)**	**($4.90)**	**$17.80**	**?**	**?**
	Net Income ($/B)	**$24.00**	**$9.00**	**$25.50**		

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1. Assumes $100 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 cost of $50/metric ton, including transport; 0.35 tonne of purchased CO_2 per barrel of oil.
5. CO_2 recycle cost of $20/ metric ton; 0.6 tonne of recycled CO_2 per barrel of oil.
6. Other O&M/G&A expenses 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.

Distribution of Economic Value of Incremental Oil Production from CO_2-EOR
(Given Fiscal Regime in the U.S.)

	Recipients of Revenues from CO_2-EOR	Oil Price $75/B	Oil Price $100/B
1	Oil Industry	$15.50	$24.00
2	Private Mineral Owner	$6.80	$9.00
3	Power Plant/CO_2 Transporter	$14.00	$17.50
4	Federal/State Governments	$17.70	$25.50
5	U.S. Economy	$21.00	$24.00
	TOTAL	$75.00	$100.00

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*Range reflects: (1) 30 billion barrels of oil and 8.8 Gt of CO_2 demand using State-Of-The-Art CO_2-EOR at $75/B oil price/$40 mt CO_2 sales price and (2) 58 billion barrels of oil and 20 Gt of CO_2 demand using Next Generation CO_2-EOR at $100/B oil price and $50/mt CO_2 sales price.

**Total demand reduced by 2.1 Gt from natural sources and gas processing plants.

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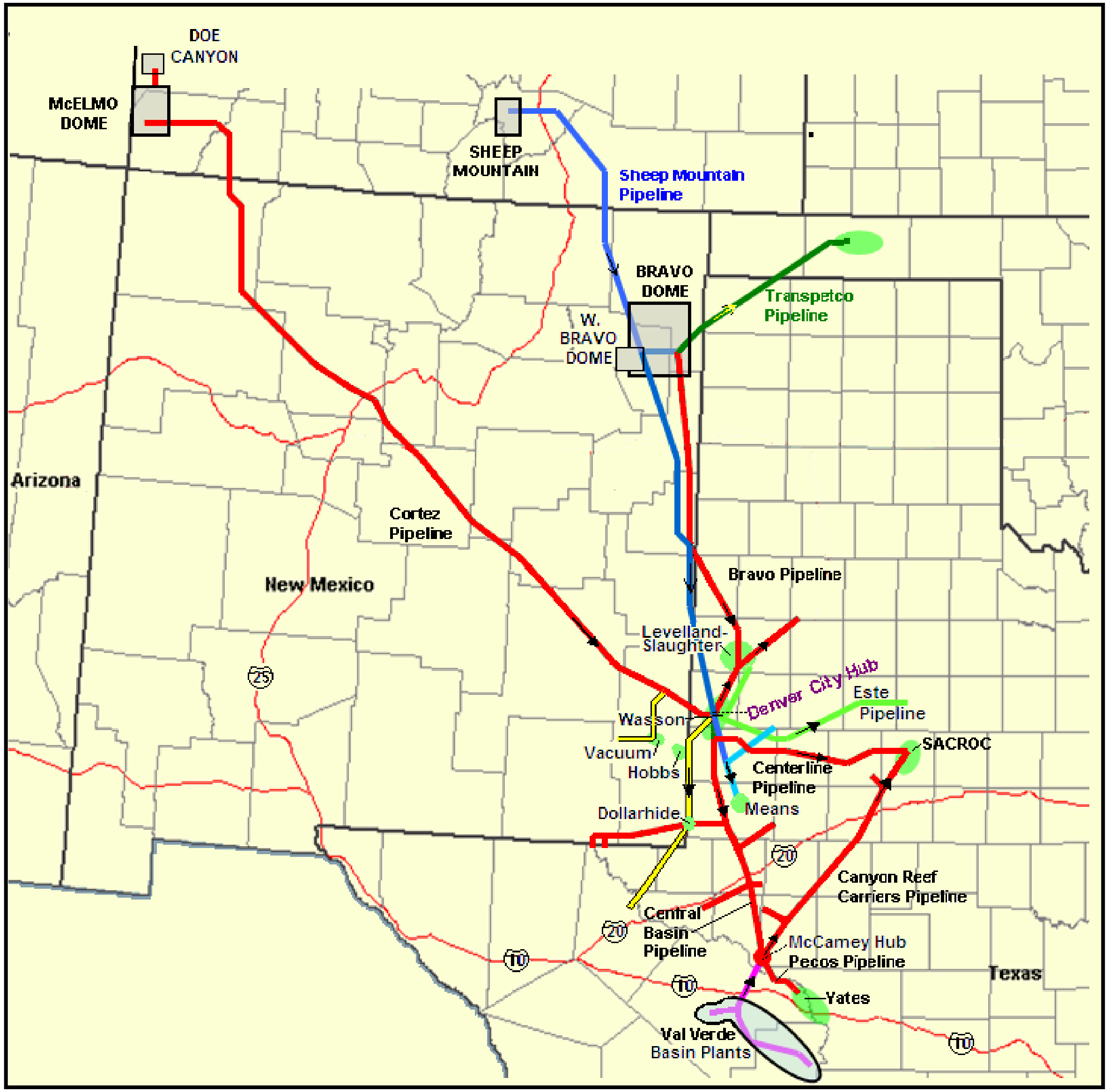
Existing CO_2 Pipelines (U.S. Permian Basin)



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Life Cycle Analyses of the Integration of "Next Generation" CO_2 Storage with EOR

	"Next Generation"	"Second Generation" CO_2-EOR & Storage		
	CO_2-EOR	CO_2-EOR	Storage	Total
CO_2 Storage (million metric tons)	32	76	33	109
Storage Capacity Utilization	22%	53%	23%	76%
Oil Recovery (million barrels)	92	180	-	180
% Carbon Neutral*	74%	90%	-	129%

* Includes the entire life-cycle CO_2 emissions, including those associated with CO_2-EOR operations, crude transport, refining, and the combustion of the incremental oil produced