CCUS – Opportunities to Utilize Anthropogenic CO_2 for Enhanced Oil Recovery and CO_2 Storage*

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Search and Discovery Article #80269 (2012)**
Posted October 22, 2012

*Adapted from oral presentation given at AAPG Eastern Section meeting, Cleveland, Ohio, 22-26 September 2012
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Abstract

A study was completed to assess the global potential for geological storage of CO_2 in shale and coal formations and the impact of gas production from shales on CO_2 storage capacity in underlying deep saline aquifers due to potentially compromising cap rock integrity. The study evaluated the following major tasks:

- Global status of hydrocarbon production from shales and CBM and potential effects on CO_2 storage, both in the producing shales/coals themselves and underlying hydrocarbon reservoirs and/or deep saline formations.
- Current status of research into geological storage of CO_2 in shales and coals.
- Potential nature and rate of trapping processes; mechanisms of storing CO_2.
- CO_2 injectivity into shales and coals, with reference to industry fracturing practices.
- Containment issues arising from shale fracturing, both for shales as a storage medium, and in terms of cap rock integrity for underlying storage units, particularly deep saline aquifers.
- Methods for assessing storage capacities for CO_2 storage in shales and coals.
- High-level mapping and assessment of theoretical/effective capacities.

- Potential economic implications of CO_2 storage in shales and coals.

This article will present an overview of the study, its development, and significant findings.



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Eastern Section – AAPG

Session X - Carbon Capture & Sequestration II

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Unconventional Resources • Enhanced Recovery • Carbon Sequestration

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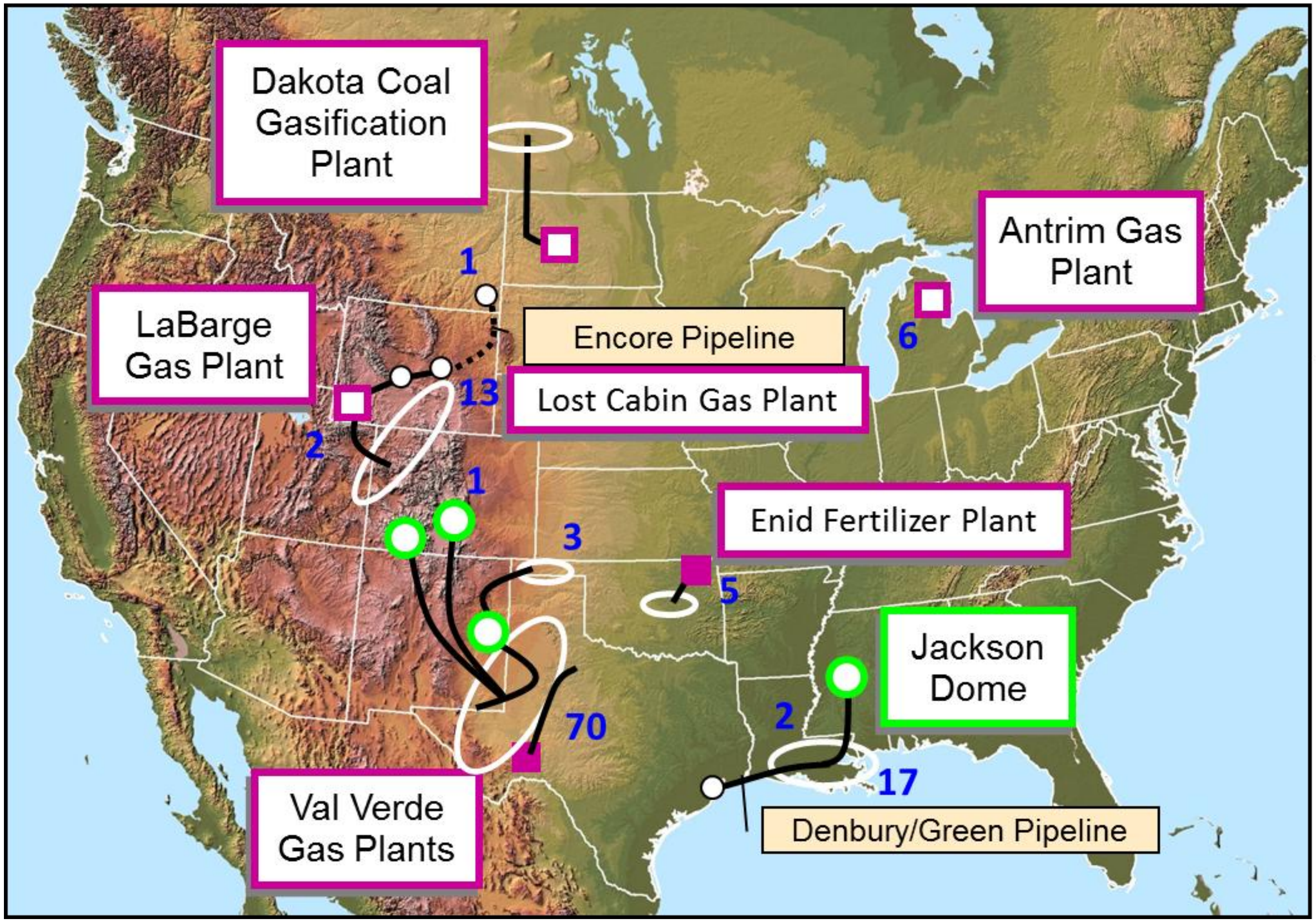
Presentation Topics

- What is the potential for CO_2-EOR in the U.S. and globally?
- How much CO_2 storage could result from CO_2-EOR?
- Who will most benefit from pursuing CCUS with CO_2-EOR?
- What changes can help more rapid CCUS/CO_2-EOR deployment?
- What can slow it down?

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



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- 120 CO_2-EOR projects provide 352,000 bbl/day
- New CO_2 pipelines are expanding CO_2-EOR to new oil fields and basins.
  - 320 mile Green Pipeline
  - 226 mile Encore Pipeline

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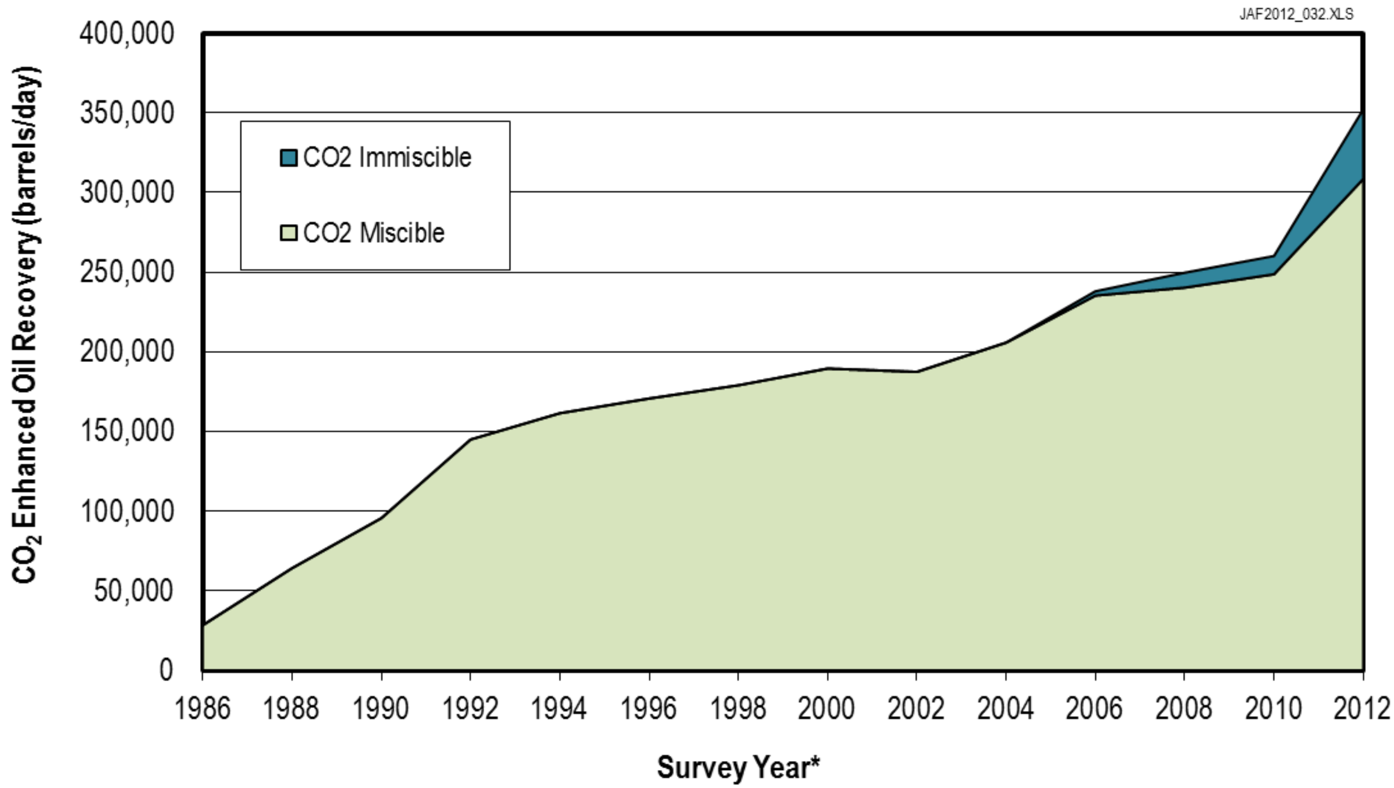
Crude Oil Production from CO_2-EOR

Nearly doubled during the past 5 years
In 2012, 6% of total U.S. crude oil production.



**Data is for EOR production rate at end of prior year; U.S. crude oil production of 6.02 MMB/D in 2012.*
Source: Advanced Resources Int'l. and the Oil and Gas Journal, 2012.

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

Location of EOR / Storage	CO_2 Source Type and Location	CO_2 Supply (MMcfd)	
		Geologic	Anthropogenic
Texas, New Mexico, Oklahoma, Utah	Geologic (Colorado, New Mexico) Gas Processing, Fertilizer Plant (Texas)	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 (MMcfd)		**2,530**	**685**
TOTAL (MMt per 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)*

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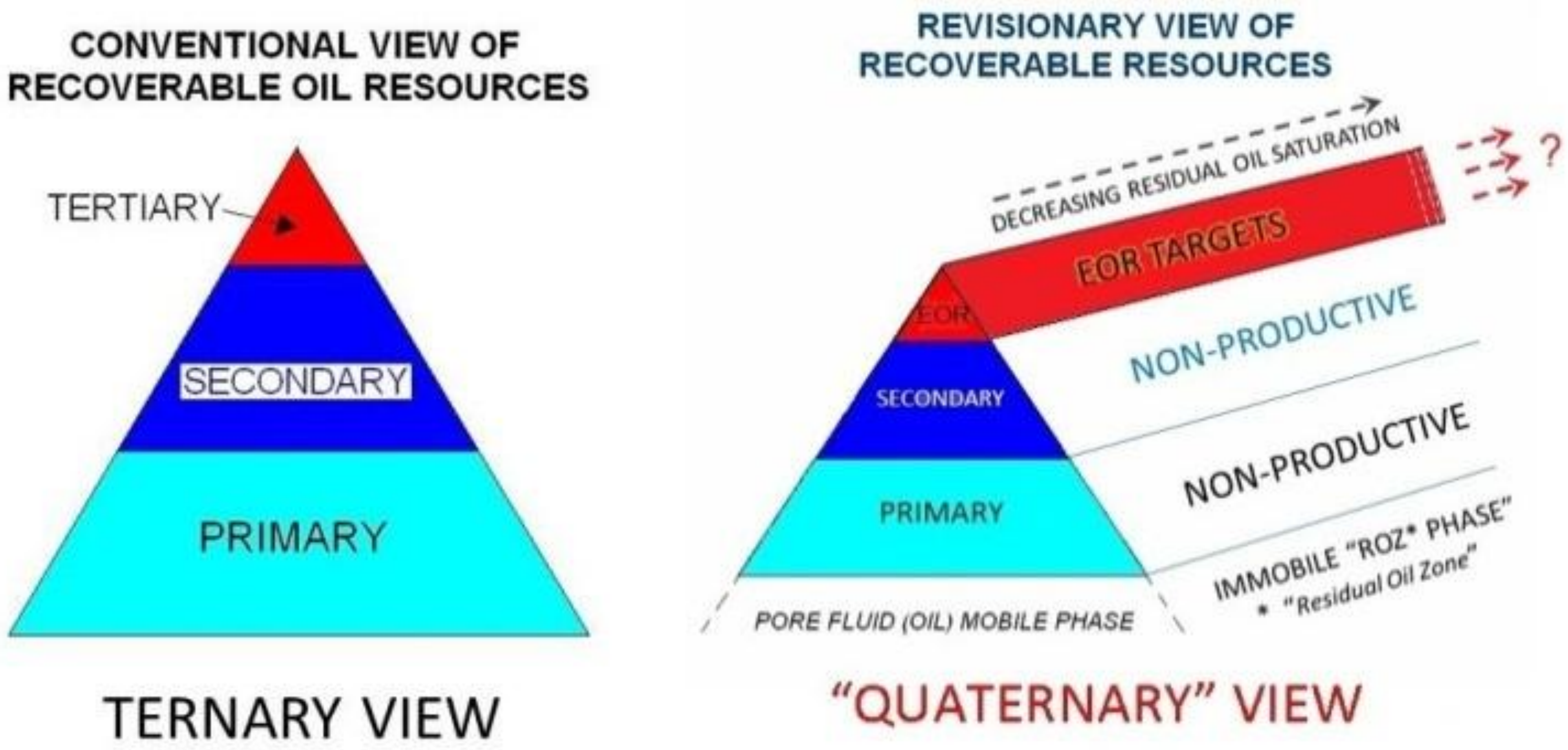
Just How Big are the EOR Targets?



Melzer CO2nsulting

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Oil Recovery and CO_2 Storage 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.*

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Oil Recovery and CO_2 Storage Potential in World's Oil Basins*

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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*

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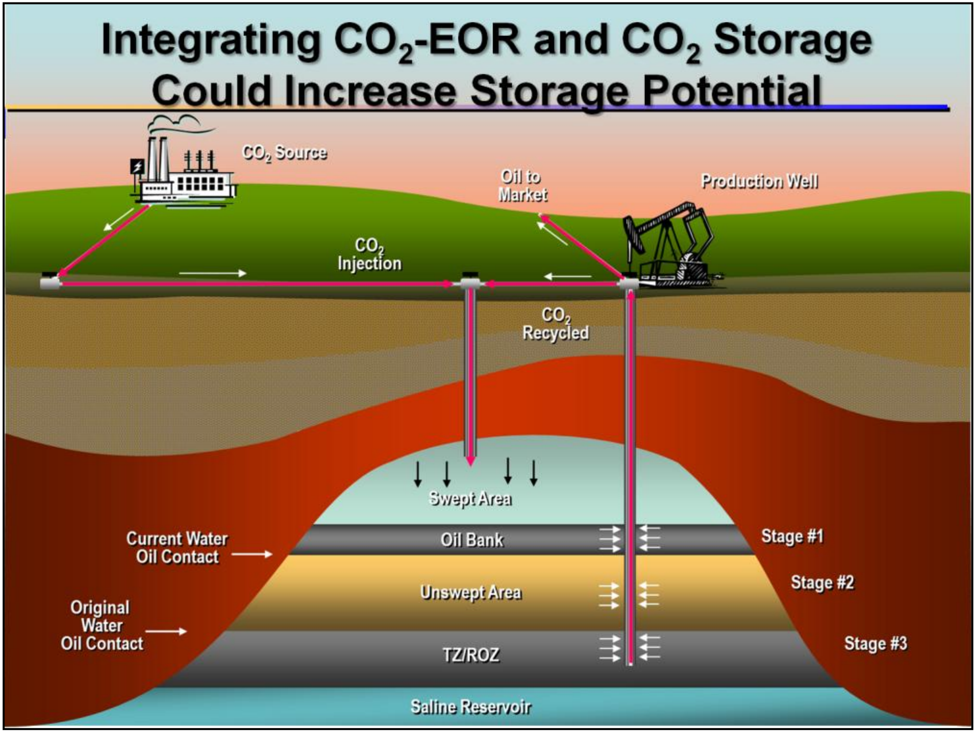
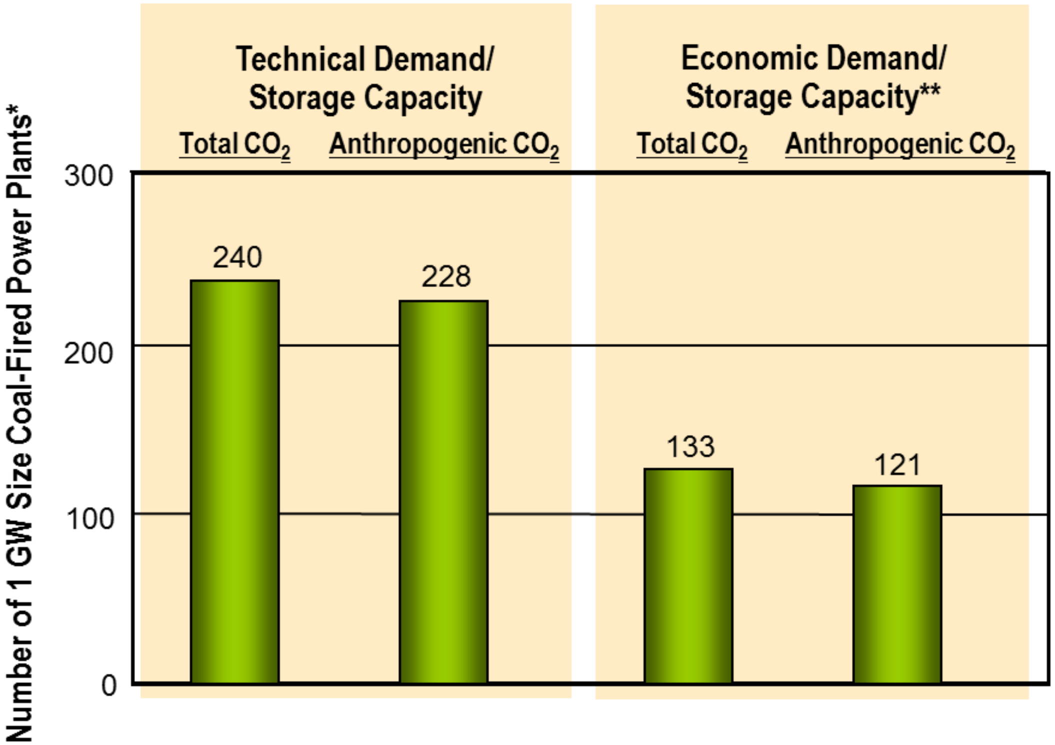
Presenter's notes: After screening 54 world basins for CO_2-EOR potential and deleting the basins and oil fields that are not technically favorable for miscible CO_2-EOR
we estimate that 470 to 880 billion barrels could be recovered from fields favorable for miscible CO_2-EOR,
and depending on the extent to which CO_2-EOR is expanded and applied to both smaller fields and in fields that remain to be discovered.



Presenter's notes: Alternative Approaches to CO_2 Storage with CO_2-EOR can increase storage potential

- 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.

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.
Source: Advanced Resources Int'l (2011).

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.

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Demand for CO_2 by the EOR Industry

- **The economic demand from CO_2-EOR – 25 to 32 Gt of CO_2**
- **Current/planned CO_2 supplies can only provide 4 to 7 Gt**
  - Natural sources – 2.1 to 2.6 Gt
  - Gas processing – 0.7 to 3.0 Gt (high end includes LaBarge reserves)
  - Other industrial – 1.1 Gt
- **CO_2-EOR can accelerate capture & storage of anthropogenic CO_2**
  - The Weyburn integrated CO_2-EOR and CO_2 storage project is the existing "poster child".
  - Summit's Texas Clean Energy IPCC Project, with 2.5 million metric tons per year of captured CO_2 serves as the new "model" for CCUS.
- **A large-scale national pipeline network is needed to link the Ohio Valley & Southeast U.S. captured CO_2 emissions with Mid-Continent, Rockies and West Texas oil fields**

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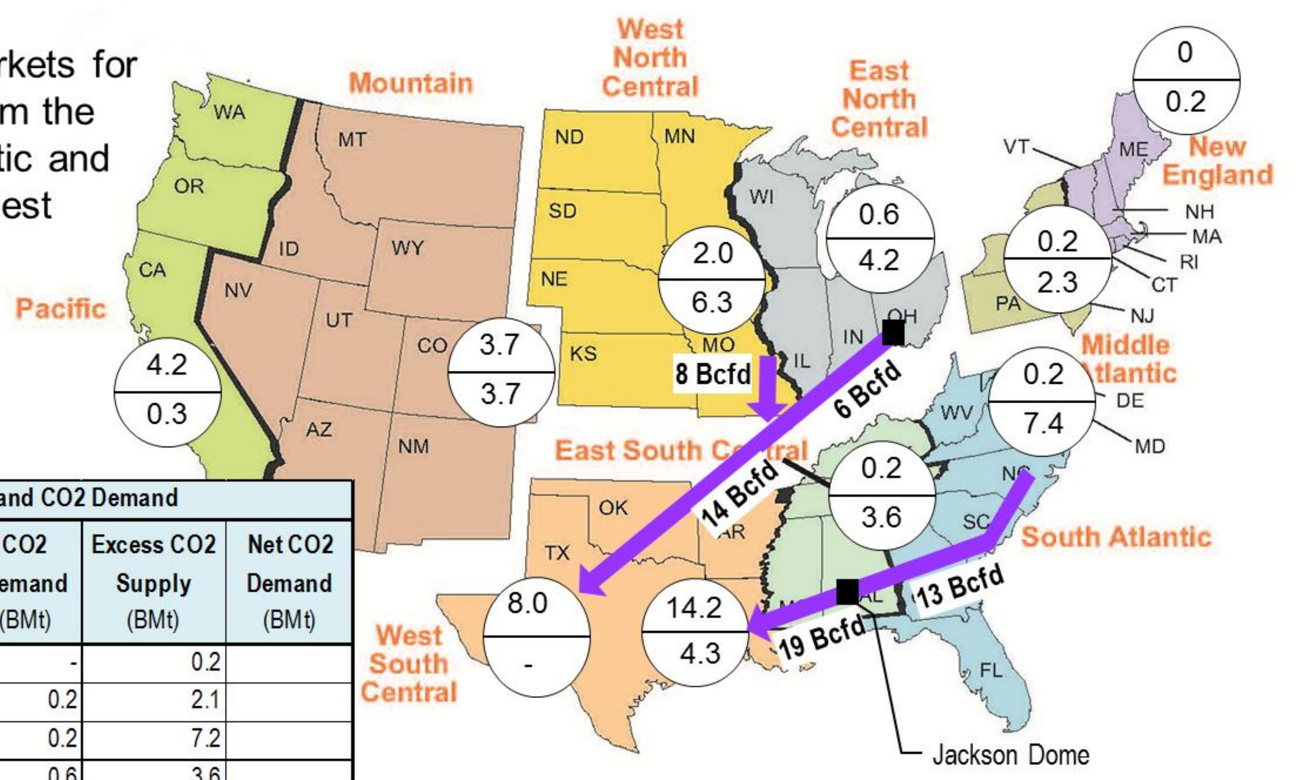
Linking CO_2 Supplies with CO_2-EOR Demand

The primary EOR markets for excess CO_2 supplies from the Ohio Valley, South Atlantic and Mid-Continent is East/West Texas and Oklahoma.



Captured CO2 Supplies and CO2 Demand				
Region	Captured CO2 Supplies* (BMt)	CO2 Demand (BMt)	Excess CO2 Supply (BMt)	Net CO2 Demand (BMt)
New England	0.2	-	0.2	
Middle Atlantic	2.3	0.2	2.1	
South Atlantic	7.4	0.2	7.2	
East North Central	4.2	0.6	3.6	
West North Central	6.3	2.0	4.3	
East South Central	3.6	0.2	3.3	
West South Central	4.3	14.2		**9.9**
Mountain	3.7	3.7		
Pacific	0.3	4.2		**3.8**
Total	**32.2**	**25.3**	**20.8**	**13.7**
ROZ "Fairways"		**8.0**		**8.0**

* Capture from 200 GW of coal-fired power plants, 90% capture rate.

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Pacific

4.2	CO_2 Demand by EOR (Bmt)
0.3	Captured CO_2 Emissions (Bmt)

Sources: EIA Annual Energy Outlook 2011 for CO2 emissions; NETL/Advanced Resources Int'l (2011) CO2 demand.

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Distribution of Economic Value of Incremental Oil Production from CO_2-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	CO2 Purchase Costs	($14.00)		$12.60		$1.40
5	CO2 Recycle Costs	($9.60)				$9.60
6	O&M/G&A Costs	($9.00)				$9.00
7	CAPEX	($6.00)				$6.00
	Total Costs	**($57.00)**		-		
	Net Cash Margin	**$28.00**	**$6.60**	**$12.60**	**$11.80**	**$26.00**
8	**Income Taxes**	**($9.80)**	**$13.90**	**-**	**($4.10)**	**-**
	Net Income ($/B)	**$18.20**	**$20.50**	-	**$7.70**	

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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; 0.35 tonne of purchased CO_2 per barrel of oil; CCS would meet about 90% of CO_2 demand; (5.) CO_2 recycle cost of $16/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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Distribution of Benefits from "Next Generation" CO_2-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_2 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
	Total	**$85.00**	**$6,800**

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While CCS Needs the U to make CCUS, CO_2-EOR Also Needs the CO_2 from CCS

- **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 CCUS, then these benefits from CO_2-EOR will not be realized.**
- **Thus, not only does CCUS need CO_2-EOR to ensure viability of CCUS, but CO_2-EOR needs CCUS to ensure adequate CO_2 to facilitate CO_2-EOR growth.**
- **This will become even more apparent as potential even more new targets for CO_2-EOR become recognized.**

Current CCS Activities and Project Plans are Dominated by CCUS Applications

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- **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**
  - Of which 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

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Presenter's notes: To overcome these barriers, in addition to > 120 CO_2-EOR projects being pursued around the world, the Global CCS Institute reports 77 large-scale integrated research and demonstration projects (LSIPs) at various stages of the asset life cycle

Include 8 operating projects and 4 projects in the execution phase of the project life cycle

Vast majority in developed countries

Of the 77 LSIPs, 34 (44%) are targeted for EOR applications. 5 of the 8 LSIPs and 3 of the 4 in execution are injecting CO_2 for EOR

Outside of North America, the CCSI identified projects underway in China, Netherlands, UAE

Significant Challenges Still Remain

- **Value proposition not always apparent**
  - More challenging without a price on carbon
  - Including in Clean Development Mechanism may 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**

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Significant Challenges Still Remain (cont.)

- **Balancing EOR field CO_2 requirements with CO_2 supplies creates challenges, at least initially**
  - Requires new collaborations between entities that have not commonly collaborated before
  - Understanding project life-cycle energy/carbon balance
- **Regulatory frameworks evolving regarding the transition of EOR to storage, but 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

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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 CCUS.*** Large-scale implementation of CO_2-EOR is dependent on CO_2 supplies from industrial sources.
5. ***Both CCUS and CO_2-EOR Still Need Supportive Policies and Actions.*** Focused R&D investment, supportive policies and pre-built CO_2 pipelines can greatly accelerate the integrated use of CO_2-EOR and CCUS.

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Thank you!

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