



# Global Opportunities for CO<sub>2</sub>-EOR with CCUS

Presented at:  
**2017 CO<sub>2</sub> for EOR as CCUS Conference**

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# Introduction

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- Utilizing and storing anthropogenic (industrial) CO<sub>2</sub>-EOR with EOR is gaining traction.
- CO<sub>2</sub>-EOR is overcoming the “niche opportunity” mindset.
- CO<sub>2</sub>-EOR represents large oil production potential.
- And leads to potential large demand for industrial CO<sub>2</sub> for CO<sub>2</sub>-EOR
- However, this potential cannot be realized without plentiful, affordable CO<sub>2</sub> (along with sufficient oil prices).



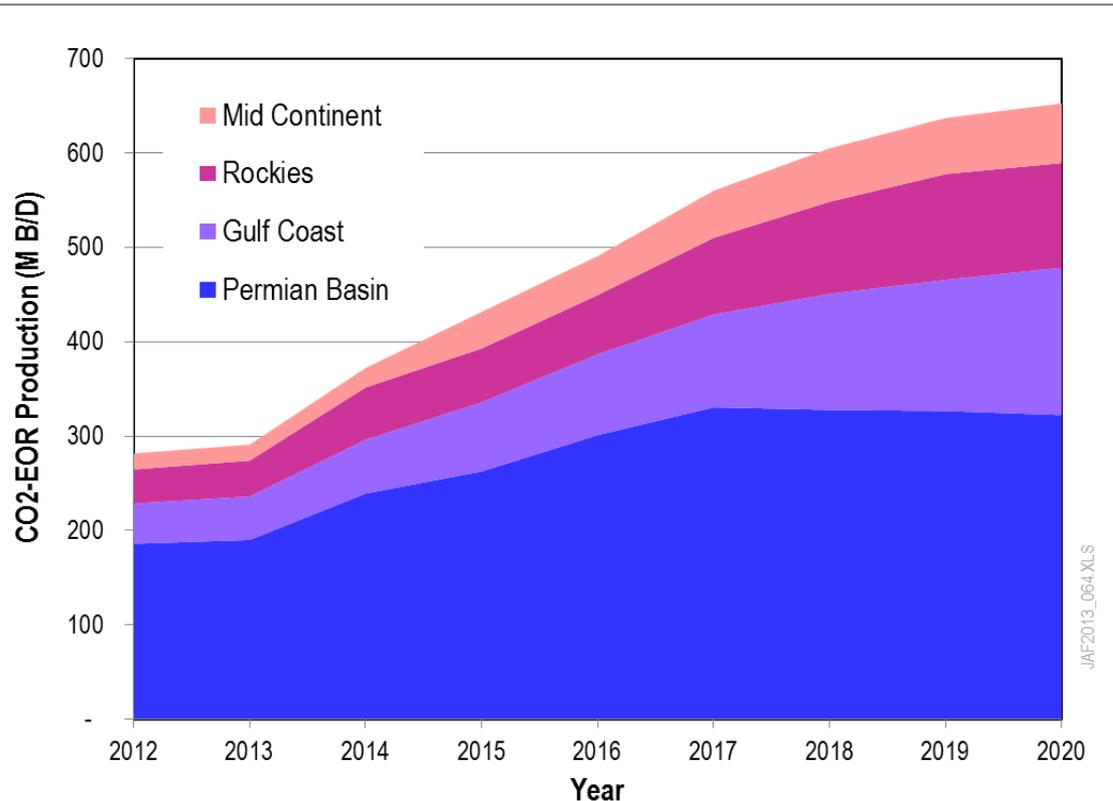
# Main Questions Addressed



- What is the potential for CO<sub>2</sub>-EOR?
  - U.S.
  - Global
- How much CO<sub>2</sub> storage could result from CO<sub>2</sub>-EOR?
- Is CO<sub>2</sub> effectively stored during CO<sub>2</sub>-EOR operations?
- Who will benefit from pursuing CCUS with CO<sub>2</sub>-EOR?
- What will it take to realize these benefits?

# Near-Term Potential for Oil Production from U.S. CO<sub>2</sub>-EOR

## CO<sub>2</sub>-EOR Production by Region (MB/D)



Source: Advanced Resources International (2013)

Increased CO<sub>2</sub> supplies are enabling new CO<sub>2</sub>-EOR projects and expansion of existing CO<sub>2</sub> floods:

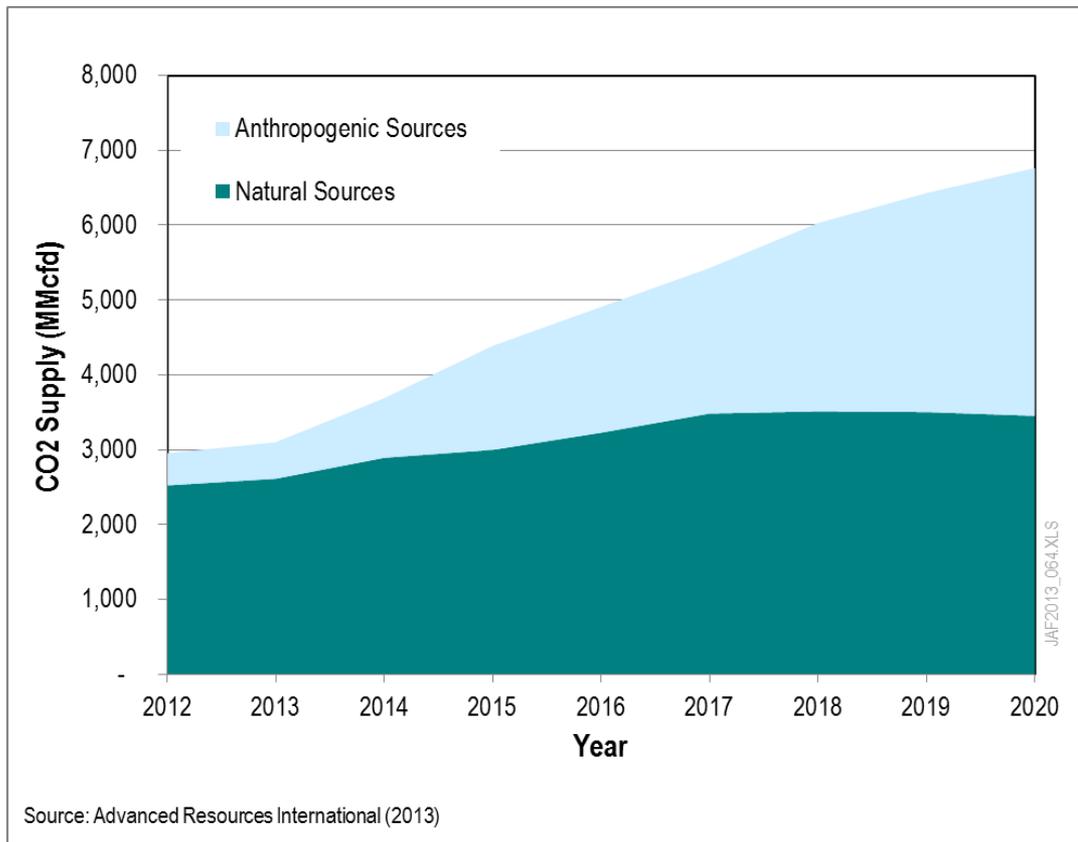
- Bell Creek, Montana
- Burbank and NE Hardesty, Oklahoma
- Seminole ROZ Stages 1-3, Goldsmith, West TX
- Webster, Conroe, Thompson, East TX

These and other announced new/expanded CO<sub>2</sub> floods could drive significant growth in near-term CO<sub>2</sub>-EOR-based oil production:

- 430,000 B/D by 2015
- 650,000 B/D by 2020

# Rapidly Increasing Utilization and Storage of Anthropogenic CO<sub>2</sub> with EOR

## CO<sub>2</sub> Supply by Source Type (MMcfd)

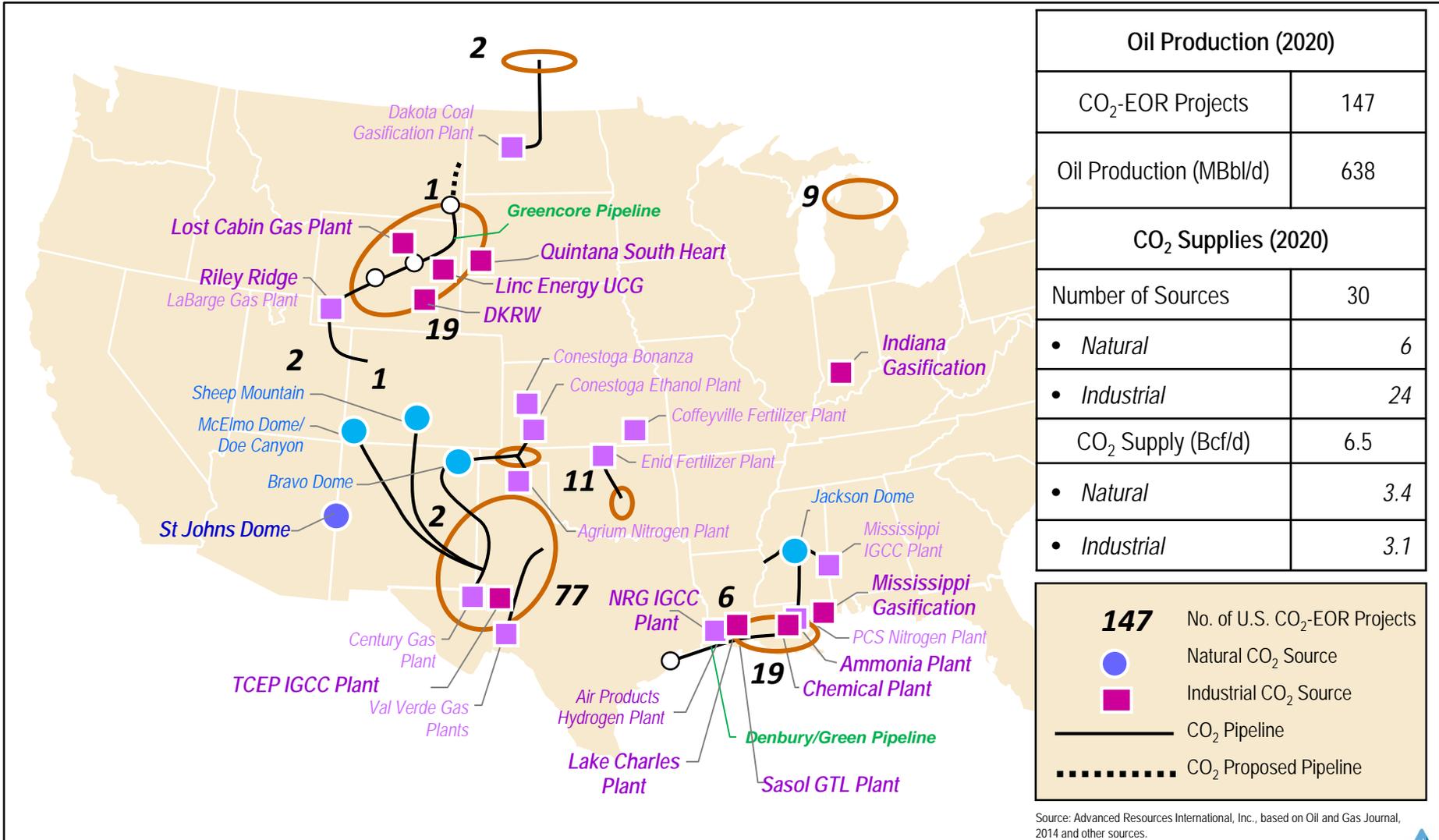


In a study for U.S. DOE/NETL, Advanced Resources tabulated the announced new sources of CO<sub>2</sub> supply scheduled to come on-line by 2020.

These could result in significant growth in CO<sub>2</sub> supplies for EOR (most of it from anthropogenic sources):

- 4.4 Bcfd (~ 85 million metric tons per year) by 2015
- 6.8 Bcfd (>130 million metric tons per year) by 2020

# Announced CO<sub>2</sub>-EOR Operations and CO<sub>2</sub> Sources (2020)



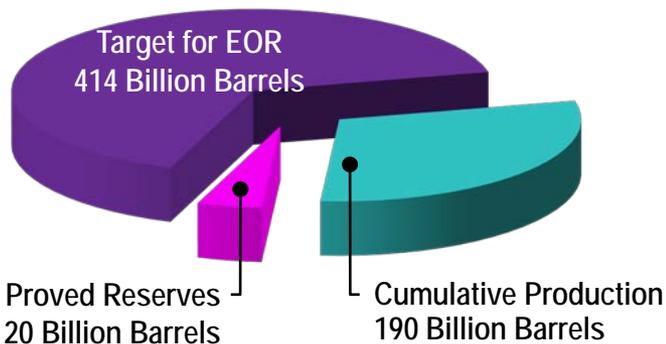
Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2014 and other sources.

# CO<sub>2</sub>-EOR: A Niche or Robust Carbon Management Strategy?

**U.S. Conventional Oil Endowment.** The U.S. conventional oil in-place endowment is 624 billion barrels. Primary recovery and water flooding will recover about a third of this oil endowment, leaving behind 414 billion barrels.

Much of this “left behind oil” (284 billion barrels) is technically favorable for CO<sub>2</sub>-EOR and is widely distributed across the U.S.

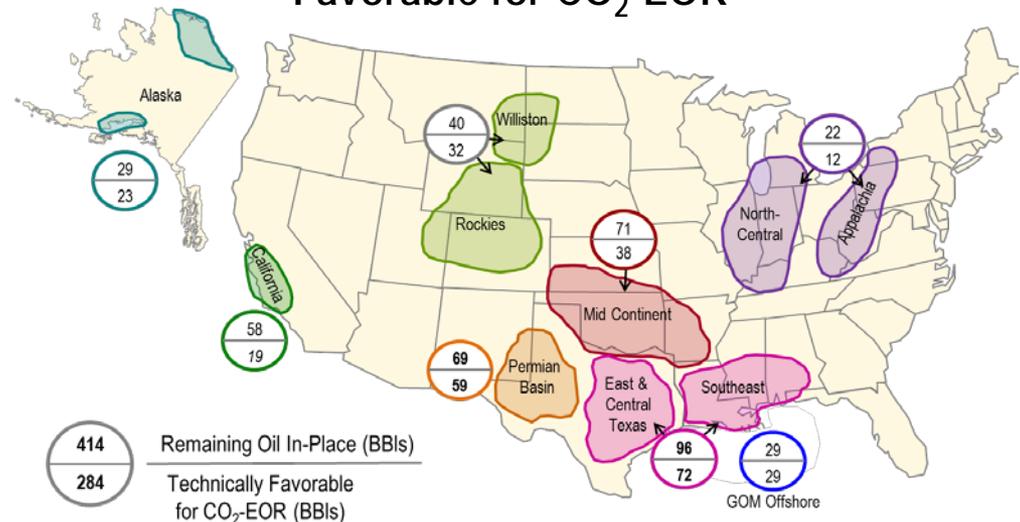
Original Oil In-Place: 624 B Barrels  
Remaining Oil In-Place: 414 B Barrels



\*Does not include “tight” oil production or reserves.

Source: Advanced Resources International, 2015.

## Conventional Domestic Oil Resources Favorable for CO<sub>2</sub>-EOR



Source: Advanced Resources International internal analysis, 2016

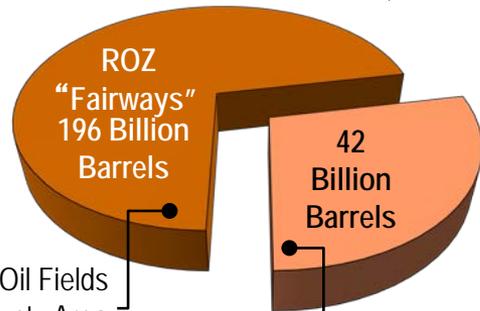
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# “Next Generation” CO<sub>2</sub>-EOR Technologies and New Resource Targets can Further Expand this Potential

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1. Scientifically-based advances in CO<sub>2</sub>-EOR technology
2. Integrating CO<sub>2</sub> capture with CO<sub>2</sub> utilization by CO<sub>2</sub>-EOR
- 3. Application of CO<sub>2</sub>-EOR to residual oil zones (ROZs)**
4. Deployment of CO<sub>2</sub>-EOR in offshore oil fields.
5. Deployment of CO<sub>2</sub>-EOR in tight (shale) oil formations.

## Over 238 Billion Barrels of Oil “Left Behind” in Residual Oil Zones (ROZs)



Beyond Oil Fields  
(Twelve County Area  
of Permian Basin)

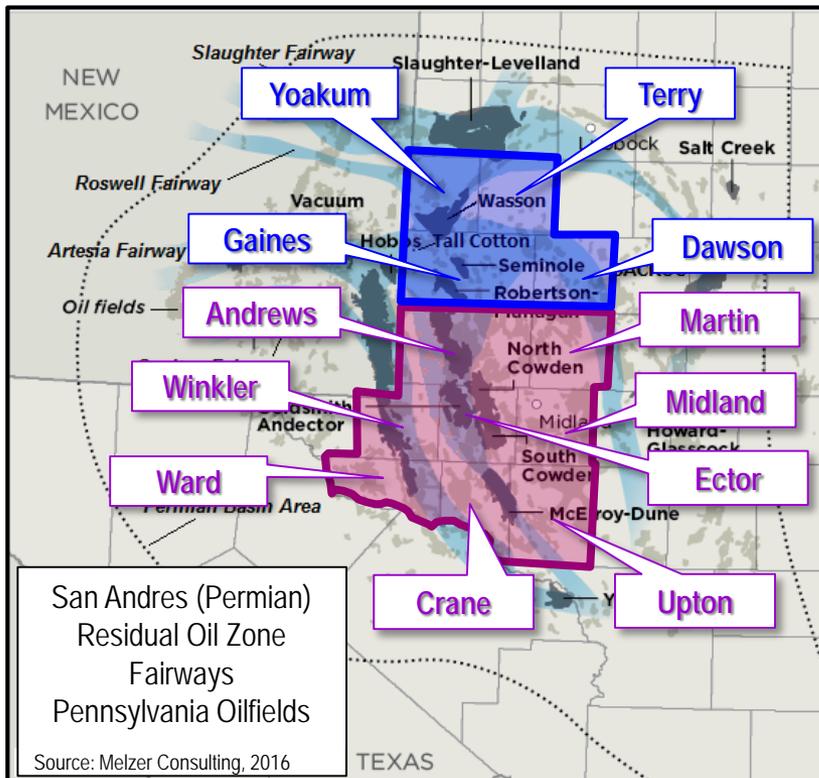
Below Oil Fields  
(3 U.S. Basins)

Source: Advanced Resources International, 2014.

# U.S. Residual Oil Zone (ROZ) Endowment

The volume of oil in-place in the twelve county San Andres ROZ “fairway” of the Permian Basin, West Texas (excluding areas under existing oil fields) is 196 billion barrels, with 137 billion barrels classified as “higher quality”\*.

The ROZ oil in-place below existing oil fields in the Permian Basin represents an additional 42 billion barrels of oil in-place, with much of this resource “higher quality”.



San Andres (Permian)  
Residual Oil Zone  
Fairways  
Pennsylvania Oilfields

Source: Melzer Consulting, 2016

\* Higher quality ROZ resources have porosity greater than 8% and oil saturation greater than 25%.

# U. S. Oil Recovery and CO<sub>2</sub> Storage Potential 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>

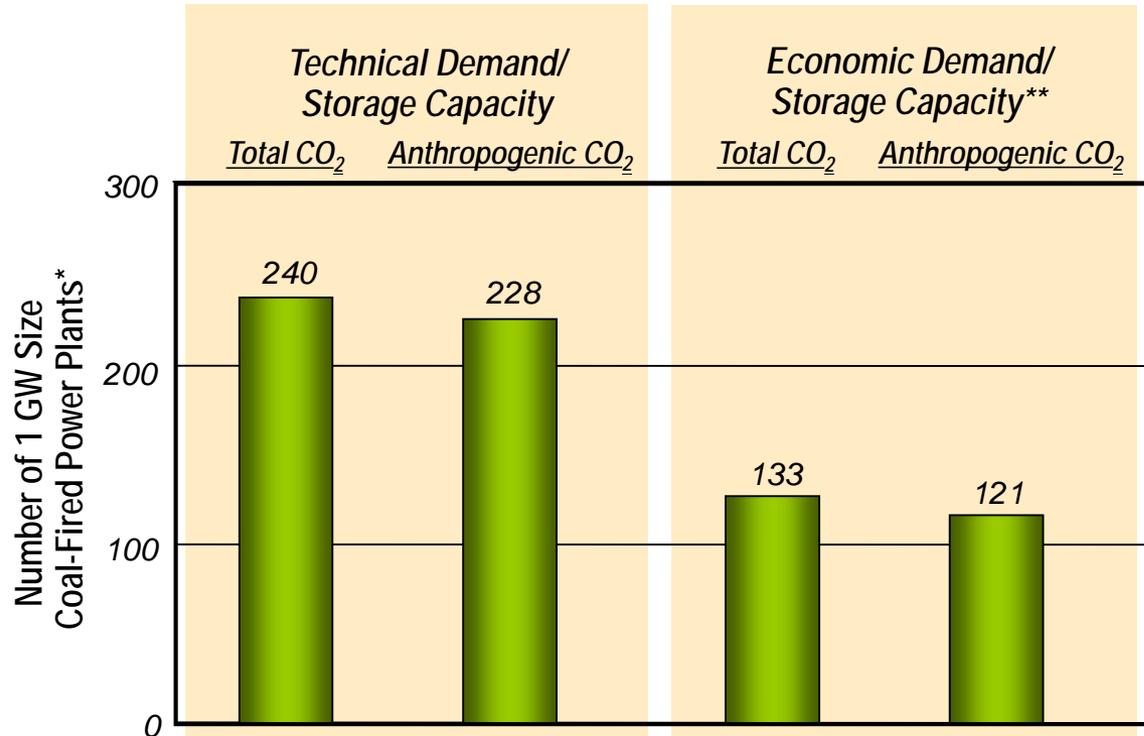
\*The values for economically recoverable oil and economic CO<sub>2</sub> demand (storage) represent an update to the numbers in the NETL/ARI report "Improving Domestic Energy Security and Lowering CO<sub>2</sub> Emissions with "Next Generation" CO<sub>2</sub>-Enhanced Oil Recovery (CO<sub>2</sub>-EOR)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

# U.S. Demand for CO<sub>2</sub>: Number of 1 GW Size Coal-Fired Power Plants



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 CO <sub>2</sub> -EOR	5	1
ROZ**	34	28
<b>Sub-Total</b>	<b>240</b>	<b>133</b>
<b>Additional From ROZ "Fairways"</b>	<b>86</b>	<b>43</b>

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

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

Source: Advanced Resources Int'l (2011).

\*At \$85 per barrel oil price and \$40 per metric ton CO<sub>2</sub> 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<sub>2</sub> 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.

# Oil Recovery and CO<sub>2</sub> Storage Potential in World's Oil Basins\*

The world's oil basins\* could produce nearly 1,300 billion barrels of oil from “next generation” CO<sub>2</sub>-EOR technology and store 35 years worth of nearly 1,800 GW of coal-fired power plant emissions.

Region	Technical CO <sub>2</sub> -EOR Oil Recovery (Billion Barrels)	Associated CO <sub>2</sub> Demand/Storage Capacity (Billion Metric Tons)
1. Asia Pacific	47	13
2. C. & S. America	93	27
3. Europe	41	12
4. FSU	232	66
5. M. East/N. Africa	595	170
6. NA/Other	38	11
7. NA/U.S.	177	51
8. S. Africa/Antarctica	74	21
<b>TOTAL</b>	<b>1,297</b>	<b>370</b>

\* Includes potential from discovered and undiscovered fields, but not future growth of discovered fields.

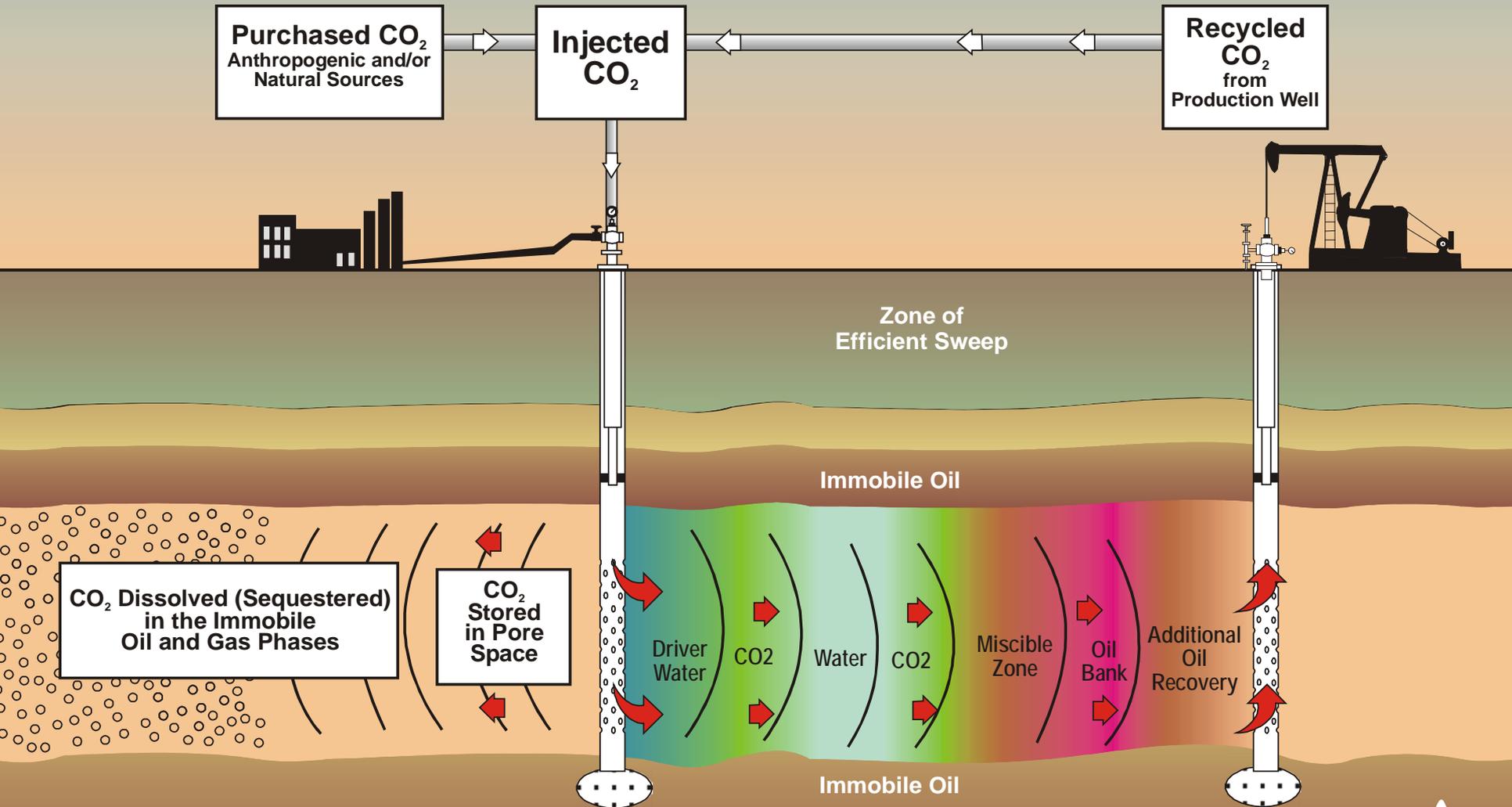
Source: IEA GHG Programme/Advanced Resources International (2009)

# CO<sub>2</sub>-EOR/CCUS Potential in Selected APEC Economies

Economy	CO <sub>2</sub> -EOR Potential				Potential CO <sub>2</sub> Storage Capacity	
	(Billion barrels)		(Billion tonnes)		(Billion tonnes)	
	Low	High	Low	High	Low	High
Brunei Darussalam	0.8	1.9	0.1	0.3	0.3	0.6
People's Republic of China	0.5	43.3	0.1	5.9	0.3	12.4
Indonesia	0.3	4.3	0.0	0.6	0.0	1.0
Malaysia-Thailand (Malay Basin)*	1.0	1.0	0.1	0.1	0.0	0.2
Vietnam	0.6	0.7	0.1	0.1	0.2	0.4
Mexico	14.1	23.9	1.9	3.3	4.6	8.9
Peru	1.1	2.6	0.1	0.4	0.3	0.8
<b>TOTAL</b>	<b>18.4</b>	<b>77.7</b>	<b>2.5</b>	<b>10.6</b>	<b>5.8</b>	<b>24.2</b>

\* Also includes resources from the Baram Delta/Brunei Sabah Basin reported for Brunei Darussalam

# CO<sub>2</sub>-EOR Technology: A Closed-Loop System



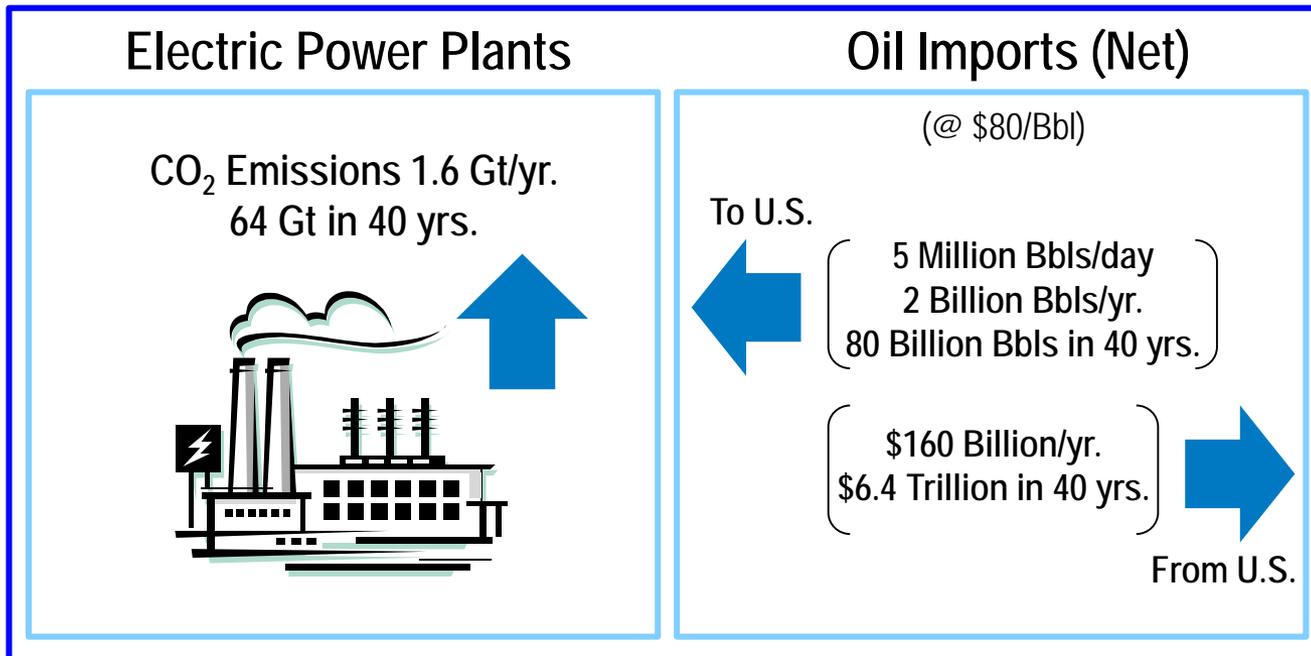
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# Current U.S. Situation

Today, because of high costs of CO<sub>2</sub> capture, CO<sub>2</sub> emissions from power plants are released to the atmosphere, while oil produced by conventional means is imported and consumed based on demand.

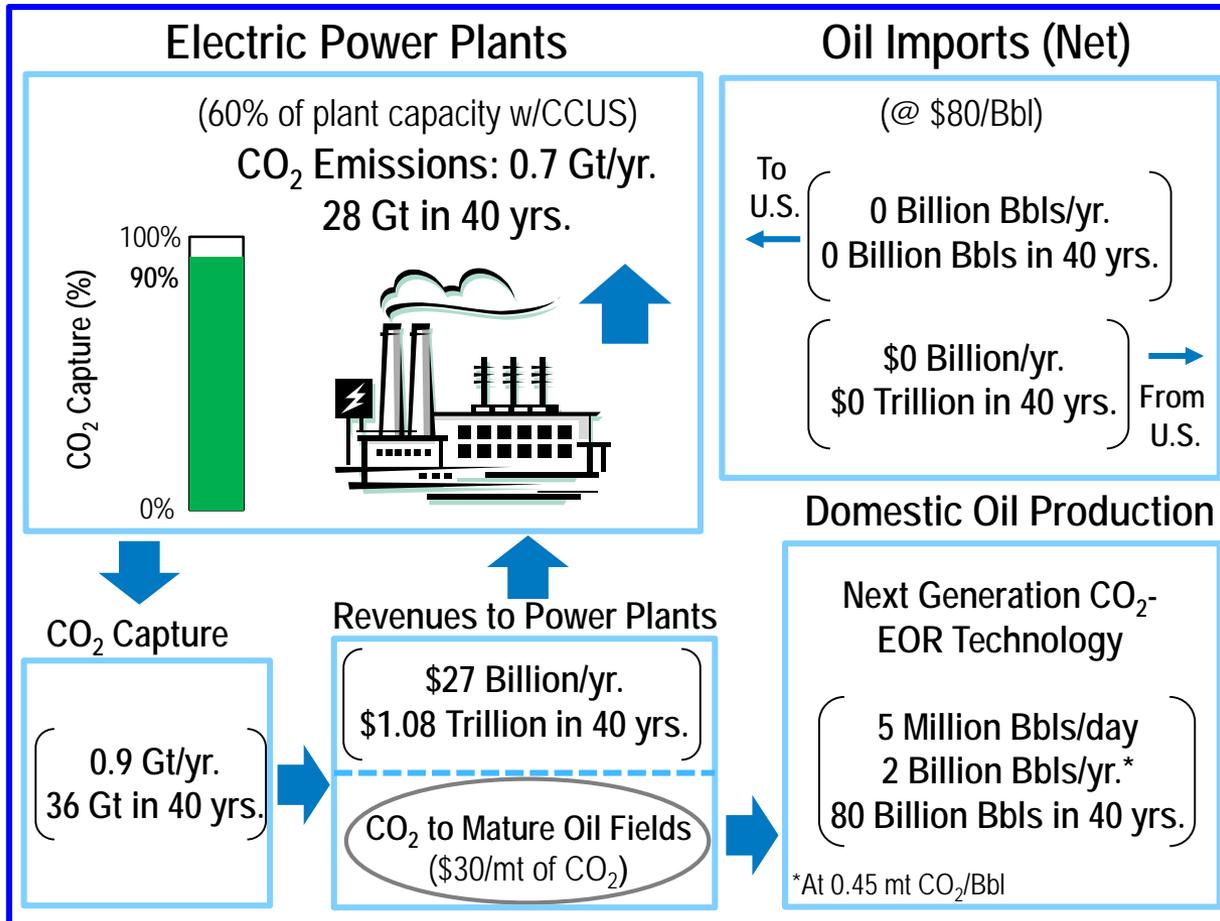
Current Situation (No CCUS) - - Years 2021-2060



- U.S. electric power sector (without CCUS) emits 1.6 Gt of CO<sub>2</sub>/yr, 64 Gt in 40 years.
- U.S. imports 5+ million barrels per day (net) of crude oil and petroleum products, 80 billion barrels in 40 years.
- U.S. spends \$160 billion per year on oil imports, \$6.4 trillion in 40 years.

# Alternative Case – Thought Experiment

Alternative Case (Use of CCUS) - - - Years 2021 to 2060



- Revenues from sale of CO<sub>2</sub> to the EOR industry plus financial incentives\* support installation of CO<sub>2</sub> capture on 60% of current U.S. coal and natural gas power plant capacity.
- Approximately 0.9 Gt/yr of CO<sub>2</sub> is captured and sold to the EOR industry for \$30/m ton, providing \$27 billion/yr (\$1.08 trillion in 40 years) to the power industry.
- CO<sub>2</sub> purchased from the power industry enables production of 5+ million barrels/day of additional domestic oil (80 billion barrels in 40 years).

# Whose Oil Will Be “Left In The Ground?”

- Given this potential, along with expectations for “peak oil demand” -, a significant portion of the oil resource and its carbon content will ultimately be “left in the ground.”
- *The question is - - will the oil “left in the ground” be oil that is conventionally produced and currently imported into the U.S. or oil produced in the U.S. by the injection and storage of CO<sub>2</sub> captured from power/industrial plants?*
- With CCUS and CO<sub>2</sub>-EOR, a potential 80 billion barrels of conventionally produced oil will not be imported into the U.S., displacing oil that may eventually be “left in the ground”.
- Moreover, studies by ARI/University of Wyoming and IEA show that the potential exists for CO<sub>2</sub>-EOR to result in “carbon negative oil.”

# Distribution of Benefits of CO<sub>2</sub>-EOR

Notes		CO <sub>2</sub> -EOR Industry	Mineral Owners	Federal/ State Treasuries	Power Plant/ Other Capturers of CO <sub>2</sub>	General Economy
1	NYMEX Oil Price	\$80.00				
2	Transportation/Quality Differential	(\$3.00)				\$3.00
	Realized Oil Price	\$77.00				
3	Less: Royalties	(\$13.10)	\$10.90	\$2.20		
4	Production Taxes	(\$3.20)	(\$0.50)	\$3.70		
5	CO <sub>2</sub> Purchase Costs	(\$13.50)			\$13.50	
6	CO <sub>2</sub> Recycle Costs	(\$5.00)				\$5.00
7	O&M/G&A Costs	(\$15.00)				\$15.00
8	CAPEX	(\$7.00)				\$7.00
	<b>Total Costs</b>	<b>(\$56.80)</b>	<b>\$10.40</b>	<b>\$5.90</b>	<b>\$13.50</b>	<b>\$30.00</b>
	<b>Net Cash Margin</b>	<b>\$20.20</b>				
9	Income Taxes	(\$7.10)	(\$3.60)	\$10.70	-	-
	<b>Net Income (\$/B)</b>	<b>\$13.10</b>	<b>\$6.80</b>	<b>\$16.60</b>	<b>\$13.50</b>	<b>\$30.00</b>

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- 1 Assumes an oil price of \$80 per barrel (WTI) based on EIA AEO 2017 oil price for year 2022.
  - 2 Assumes \$3 per barrel for transportation.
  - 3 Royalties are 17%; 1 of 6 barrels produced are from Federal and state lands.
  - 4 Production and ad valorem taxes of 5% from FRS data.
  - 5 CO<sub>2</sub> sales price of \$30/metric ton including transport; 0.45 metric tons of purchased CO<sub>2</sub> per barrel of oil.
  - 6 CO<sub>2</sub> recycle cost of \$10/metric ton; 0.5 metric tons of recycled CO<sub>2</sub> per barrel of oil.
  - 7 O&M/G&A costs from ARI CO<sub>2</sub>-EOR cost models.
  - 8 CAPEX from ARI CO<sub>2</sub>-EOR cost models.
  - 9 Combined Federal and state income taxes of 35%, from FRS data.
- Source: Advanced Resources International internal study, 2017.

## CO<sub>2</sub>-EOR provides a wide distribution of benefits:

- Federal and state treasuries receive \$16.60/B, equal to \$37/mt.
- The power industry receives \$13.50/B, equal to \$30/mt.
- The U.S. economy receives \$30/B, supporting well paying jobs and manufacturing, a topic we are examining for a CURC\*/ClearPath Foundation supported study.

\*Carbon Utilization Research Council,.

# Steps to Achieving Lower Cost, Publicly-Acceptable CO<sub>2</sub> Supply for CO<sub>2</sub>-EOR

- Sell more CO<sub>2</sub> to CO<sub>2</sub>-EOR projects
  - Through better utilization and better economics with “next generation” CO<sub>2</sub>-EOR technologies
- Pursue economies of scale for CO<sub>2</sub> transport; using existing infrastructure to the extent possible
- Gain public acceptance
  - Requires rigorous site selection, monitoring, and public outreach
  - But without imposing regulatory requirements that inhibit CO<sub>2</sub>-EOR deployment
- Reduce the costs of CO<sub>2</sub> capture!!!
  - Requires doing projects, which cannot happen today w/o CO<sub>2</sub>-EOR

# Concluding Thoughts and Observations

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



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