



# Industry Opportunities for Carbon Capture, Utilization and Storage (CCUS)

Presented at:

**4th Biennial CO<sub>2</sub> for EOR as CCUS Conference 2019**

Presented by:

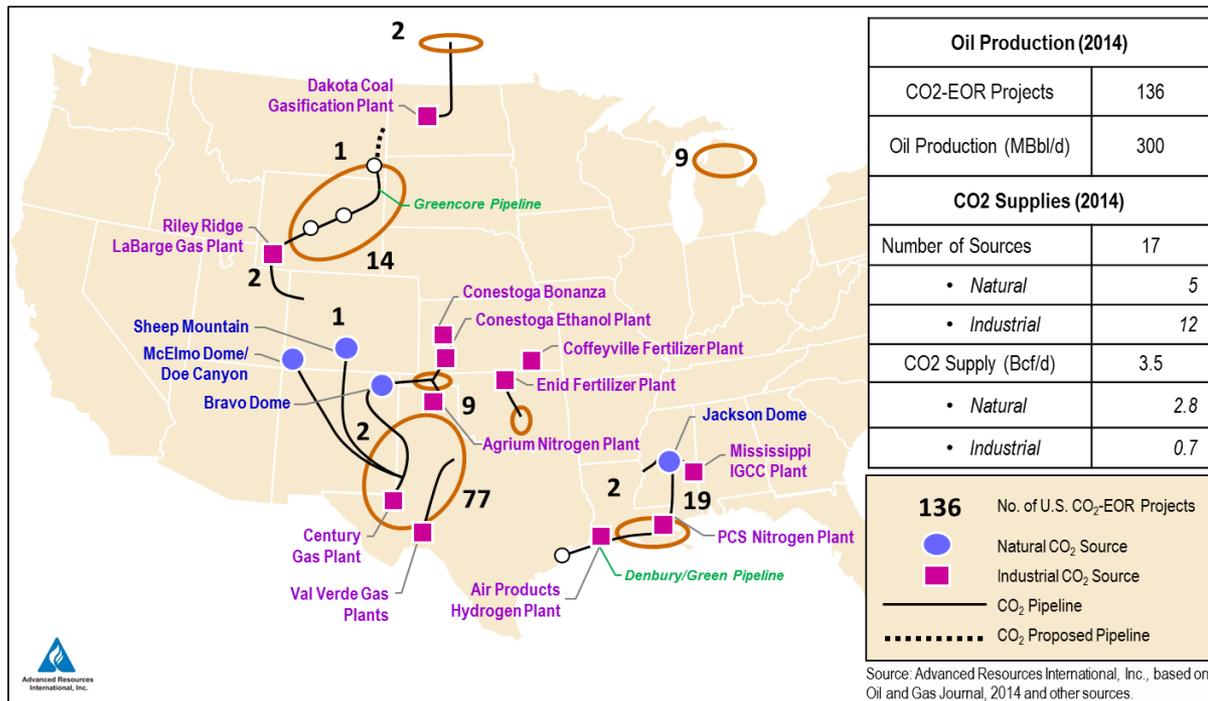
**Michael Godec, Vice President  
Advanced Resources International, Inc.**

September 25, 2019  
Houston, Texas

# Status of CO<sub>2</sub>-EOR: A Snapshot in Time

The development of large natural sources of CO<sub>2</sub> (e.g., McElmo Dome, Jackson Dome, etc.) established the foundation for the CO<sub>2</sub>-EOR industry. Capture of industrial sources of CO<sub>2</sub> is helping drive its growth.

## Current CO<sub>2</sub>-EOR Operations and CO<sub>2</sub> Sources (2014)



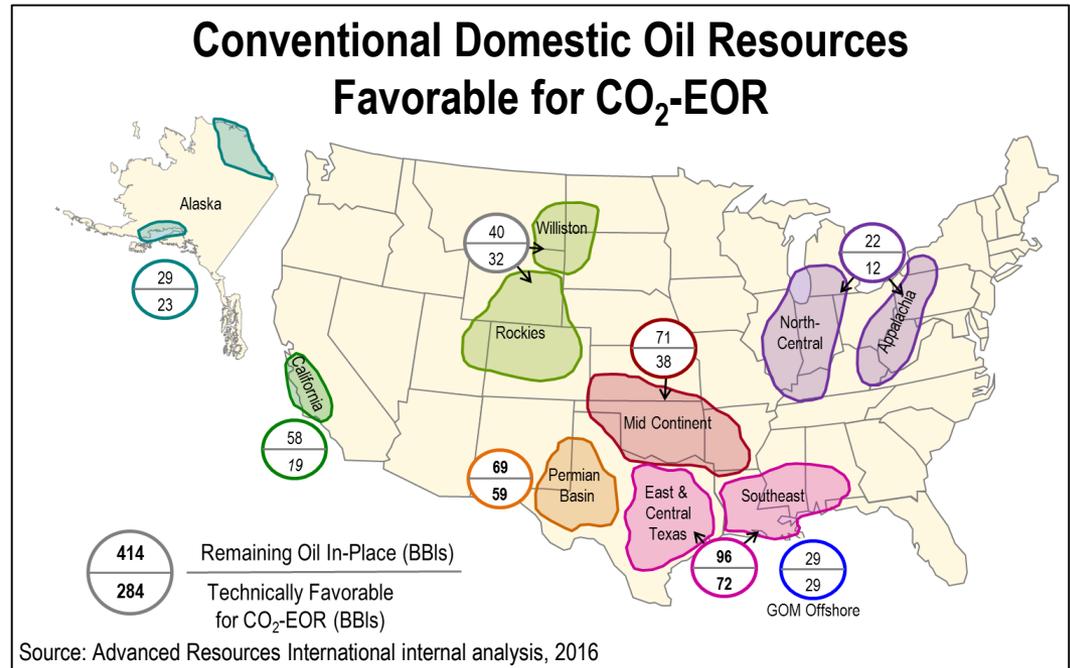
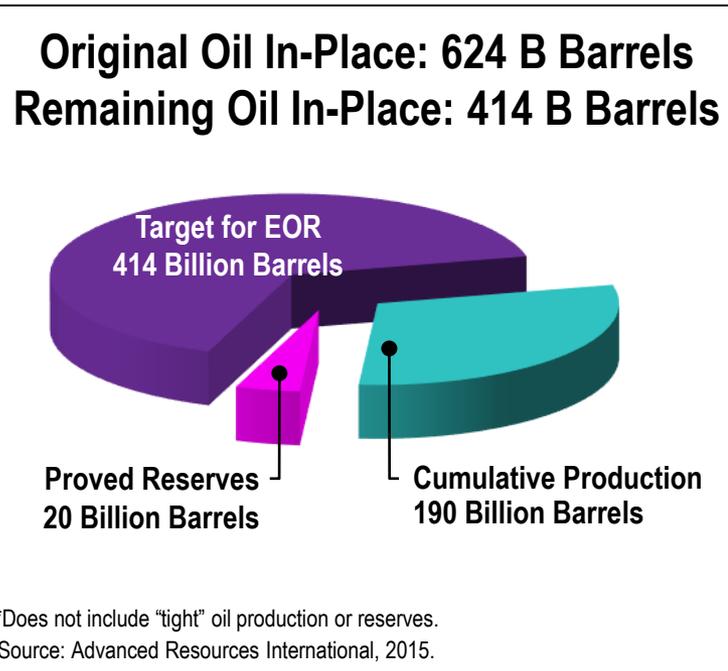
- Based on the 2014 O&GJ Survey, 136 significant CO<sub>2</sub>-EOR projects currently produce 300,000 barrels per day in the U.S. by injecting 3.5 Bcf/d of CO<sub>2</sub>, with 0.7 Bcf/d from industrial sources.
- In spite of limitations in supplies of CO<sub>2</sub> and lower oil prices, existing CO<sub>2</sub>-EOR projects are being expanded and new CO<sub>2</sub>-EOR projects started.
- We note increased CO<sub>2</sub>-EOR activity even though the O&GJ has terminated its CO<sub>2</sub>-EOR Survey.

Source: Advanced Resources International based on Oil & Gas Journal and other industry data, 2014.

# CO<sub>2</sub>-EOR: A Niche or a 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 have recovered about a third of this oil endowment, leaving behind 414 billion barrels.

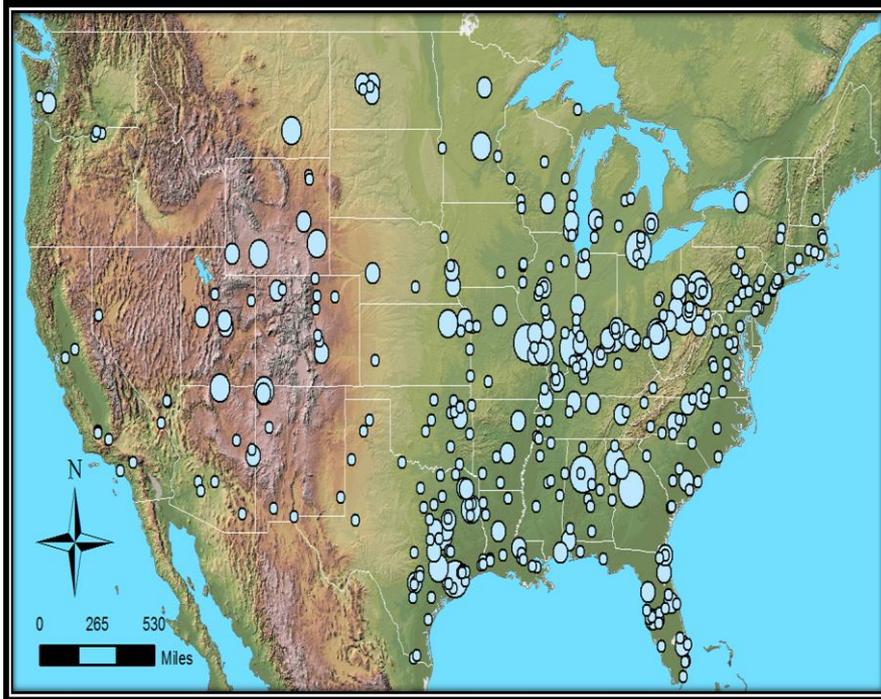
Much of this “left behind oil” (284 billion barrels) is technically favorable for CO<sub>2</sub>-EOR and is widely distributed across the U.S.



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# Potential CO<sub>2</sub> Sources

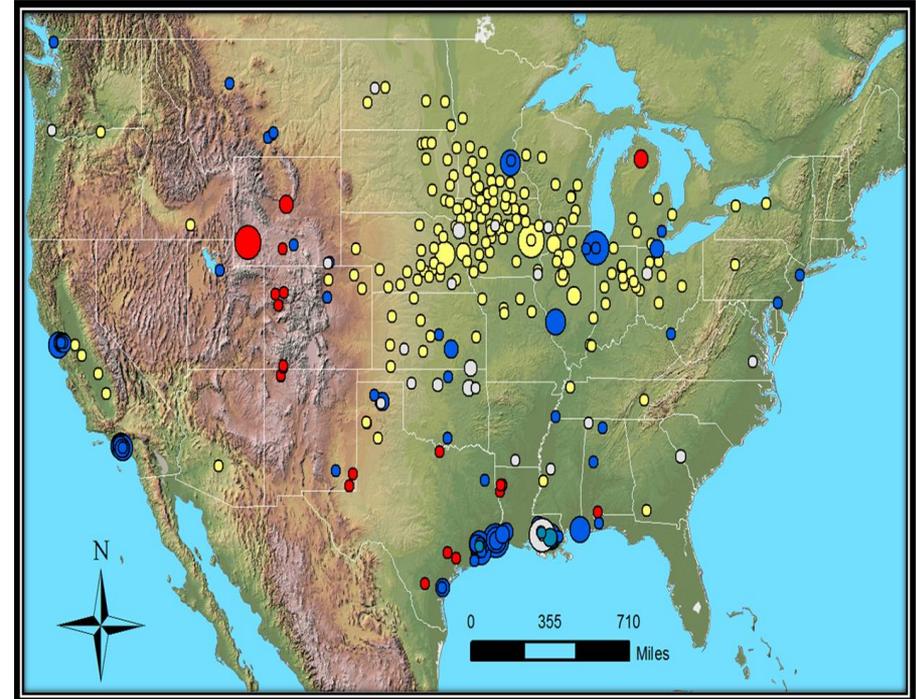
## Potential Electric Generation CO<sub>2</sub> Sources Above 1 Million Tonnes/Year



Source: Advanced Resources International, 2019.

<b>Legend</b>	
<u>Source</u>	
Electricity Generation	
<u>CO<sub>2</sub> Emissions (Metric Tons CO<sub>2</sub>)</u>	
1,000,000 – 5,000,000	(Small bubble)
5,000,000 – 10,000,000	(Medium bubble)
10,000,000 – 15,000,000	(Large bubble)
15,000,000 – 20,000,000+	(Very large bubble)

## The Low-Hanging Fruit: High Purity Stream Potential CO<sub>2</sub> Sources



<b>Legend</b>	
<u>High Purity Source</u>	
Ammonia	
Ethanol	
Ethylene Oxide	
Hydrogen	
Natural Gas Processing	
<u>CO<sub>2</sub> Emissions (Metric Tons CO<sub>2</sub>)</u>	
100,000 – 500,000	(Small bubble)
500,000 – 1,000,000	(Medium bubble)
1,000,000 – 1,500,000	(Large bubble)
1,500,000 – 5,000,000+	(Very large bubble)

# Capturing CO<sub>2</sub> from Industrial Facilities for EOR

Over 20 million metric tons of industrial/power plant CO<sub>2</sub> emissions are captured and used annually for enhanced oil recovery.

	MMcfd	MMmt/Yr.
▪ Power Plants	205*	4
▪ Fertilizer Plants	100	2
▪ Hydrogen Plants	40	1
▪ Ethanol Plants	15	*
▪ Gas Processing Plants	850	16
	<u>1,210</u>	<u>23</u>

Three high visibility projects - - Weyburn, Boundary Dam and Petra Nova - - utilize CO<sub>2</sub>-EOR for carbon management.

\*Includes NGP Coal Gasification plant.

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

# “Next Generation” CO<sub>2</sub> Enhanced Oil Recovery

**Use of more efficient CO<sub>2</sub>-EOR technologies and extension of these technologies to new oil resource settings constitutes “next generation” CO<sub>2</sub>-EOR:**

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.

**Use of “next generation” CO<sub>2</sub>-EOR will expand oil production and CO<sub>2</sub> storage capacity in the U.S.**

# 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)

# 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	<b>NYMEX Oil Price</b>	<b>\$80.00</b>				
2	Transportation/Quality Differential	(\$3.00)				<b>\$3.00</b>
	<b>Realized Oil Price</b>	<b>\$77.00</b>				
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	<b>Income Taxes</b>	<b>(\$7.10)</b>	<b>(\$3.60)</b>	<b>\$10.70</b>	-	-
	<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/Bbl, equal to \$37/mt.
- The power industry receives \$13.50/Bbl, equal to \$30/mt.
- The U.S. economy receives \$30/Bbl, supporting well paying jobs and manufacturing.

# Historical Business Models

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- Natural sources. The earliest projects leveraged their proximity to large, natural sources of CO<sub>2</sub>.
- Industrial capture. Commoditization of products at industrialized centers have recognized the value of CO<sub>2</sub>.
- Government subsidized. Some projects were government subsidized in order to achieve commercial viability.
- Infrastructure development. Field operators can link to major pipeline sources of CO<sub>2</sub>.

**New business models likely to evolve as incentives spur new deployment.**

# U.S. Efforts to Incentivize CCS May Lead to Evolving Business Models

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- **Bipartisan Budget Act of 2018 (BBA)**
  - Enhancements to IRC Section 45Q
- **California Low Carbon Fuel Standards (LCFS)**
- **Regional Incentives/Regulatory Frameworks**
- **State Incentives/Regulatory Frameworks**

# BBA Enhancements to IRC Section 45Q -- Highlights

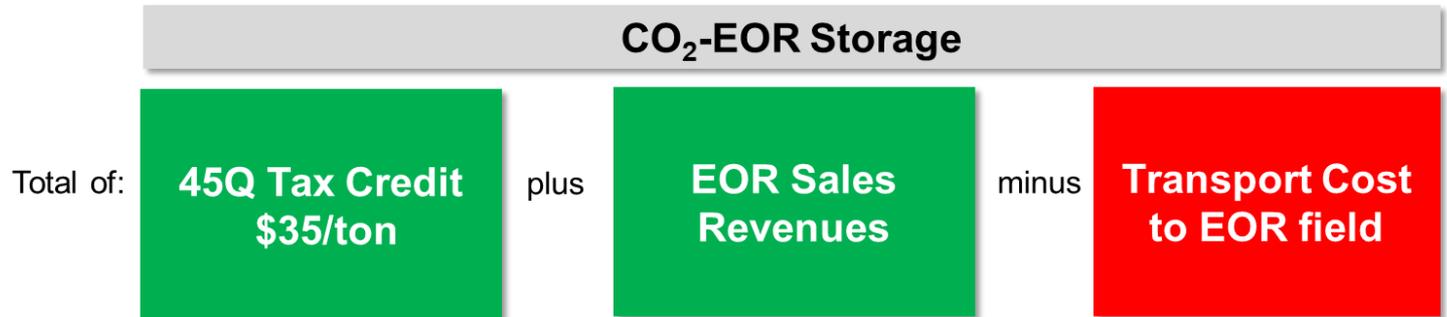
Previous 45Q	Bipartisan Budget Act of 2018
<ul style="list-style-type: none"> <li>75 million metric ton cap</li> </ul>	<ul style="list-style-type: none"> <li>Eliminates 75 million metric ton cap; applies to new facilities that “<b>break ground</b>” by <b>EOY 2023</b>.</li> </ul>
<ul style="list-style-type: none"> <li>Credit based on “captured qualified CO<sub>2</sub>”</li> </ul>	<ul style="list-style-type: none"> <li>After enactment, credit based on captured “qualified carbon oxide” (CO<sub>2</sub> and <b>other carbon oxides</b>).</li> <li>Allows for the <b>transfer</b> of qualified credits</li> </ul>
<ul style="list-style-type: none"> <li>\$20/metric ton for CO<sub>2</sub> stored and not used for EOR</li> <li>\$10/metric ton for CO<sub>2</sub> stored and used for EOR</li> </ul>	<ul style="list-style-type: none"> <li><b>\$50/mt for geologic storage and \$35/mt for EOR (each rate phases up over 10-year period from 2017 to 2026)</b>.</li> <li>Existing qualified facilities would continue to receive the original inflation adjusted \$20 and \$10 credit rates.</li> </ul>
<ul style="list-style-type: none"> <li>Available to <u>facility</u> with capture equipment capturing at least 500,000 metric tons CO<sub>2</sub>/year.</li> </ul>	<ul style="list-style-type: none"> <li>Capture &gt; <b>500,000</b> metric tons CO<sub>2</sub>/year for electric generating units; &gt; <b>100,000</b> metric tons CO<sub>2</sub>/year for other.</li> <li>Credit goes to the <u><b>owner of the capture equipment</b></u>.</li> <li>Available to “<b>direct air capture</b>” and “<b>beneficial use</b> (with 25,000 metric ton threshold)”</li> </ul>
<ul style="list-style-type: none"> <li>Credit available until the 75-million-ton cap is reached.</li> </ul>	<ul style="list-style-type: none"> <li>Credit available for <b>12 years</b> from the date the carbon capture equipment is placed in service.</li> </ul>

# CCUS Economics 101 – 45Q Example

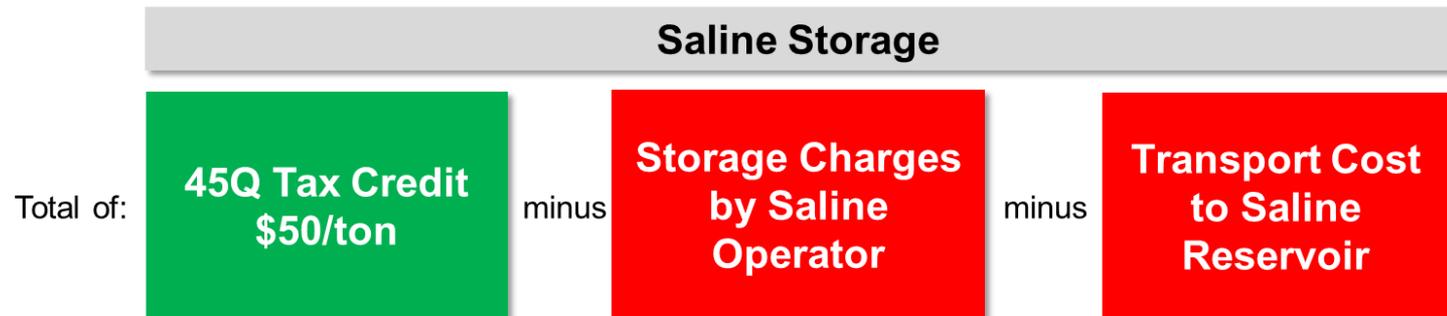
**Cost of Capture**

- Equipment x Financing % Rate
- O&M
- Energy penalties

↳ **Less than:**



**OR**



# Request for Comments by IRS on 45Q

- On 5/20, IRS issued Request for Comments on 45Q enhancements.
- Areas of comment included:
  - Establishing “secure geologic storage”
  - Leakage after credit award – “recapture”
  - Defining “qualifying facilities”
  - Defining “commence construction”
  - Credit transferability, timing, flexibility
  - Allowable structures/partnerships
- 90+ comments received
- Guidance - late 2019/early 2020



Form <b>8933</b> Department of the Treasury Internal Revenue Service Name(s) shown on return	<b>Carbon Oxide Sequestration Credit</b> ▶ Attach to your tax return. ▶ Go to <a href="http://www.irs.gov/Form8933">www.irs.gov/Form8933</a> for the latest information.	OMB No. 1545-0123 <b>2018</b> Attachment Sequence No. <b>165</b>
		Identifying number
Qualified carbon oxide captured using carbon capture equipment originally placed in service at a qualified facility before February 9, 2018, disposed of in secure geological storage and not used as a tertiary injectant in a qualified enhanced oil or natural gas recovery project, nor utilized in a way described in section 45Q(f)(5).		
1a Metric tons captured and disposed of . . . . . b Inflation-adjusted credit rate . . . . . c Multiply line 1a by line 1b. . . . .		<b>1c</b>
Qualified carbon oxide captured using carbon capture equipment originally placed in service at a qualified facility before February 9, 2018, disposed of in secure geological storage and used as a tertiary injectant in a qualified enhanced oil or natural gas recovery project, or utilized in a way described in section 45Q(f)(5).		
2a Metric tons captured and used . . . . . b Inflation-adjusted credit rate . . . . . c Multiply line 2a by line 2b. . . . .		<b>2c</b>
Qualified carbon oxide captured using carbon capture equipment originally placed in service at a qualified facility on or after February 9, 2018, during the 12-year period beginning on the date the equipment was originally placed in service, disposed of in secure geological storage, and not used as a tertiary injectant in a qualified enhanced oil or natural gas recovery project, nor utilized as described in section 45Q(f)(5).		
3a Metric tons captured and disposed of . . . . . b Section 45Q(a)(3) applicable dollar amount (see instructions) . . . . . c Multiply line 3a by line 3b. . . . .		<b>3c</b>
Qualified carbon oxide captured using carbon capture equipment originally placed in service at a qualified facility on or after February 9, 2018, during the 12-year period beginning on the date the equipment was originally placed in service, disposed of in secure geological storage, and used as a tertiary injectant in a qualified enhanced oil or natural gas recovery project, or used as described in section 45Q(f)(5).		
4a Metric tons captured and disposed of . . . . . b Section 45Q(a)(4) applicable dollar amount (see instructions) . . . . . c Multiply line 4a by line 4b. . . . .		<b>4c</b>

# Other Issues of Concern with 45Q

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- Is 12 years of credits enough for commercial viability?
- What types of business models will involve?
- What will be the role and appetite for financial institutions and tax equity players?
- Is the 12/31/2023 deadline achievable for large, complex (e.g., power generation or direct air capture) projects?
- What impact will CCS have on electricity dispatch?

# Are the 45Q Enhancements Enough?

- **Continued RD&D**
  - Reduce costs of CO<sub>2</sub> capture
  - Pursue “next generation” CO<sub>2</sub>-EOR; especially targeting “carbon negative oil”
- **Further incentives beyond 45Q?**
  - Tax-exempt private activity bonds
  - Master limited partnerships
  - Incentives for CO<sub>2</sub> pipelines/pipeline expansions/buildout
  - Ensuring Parity for CCS in the power markets
    - Feed-in tariffs, CCS in “Clean Energy” Portfolio Standards
  - State incentives

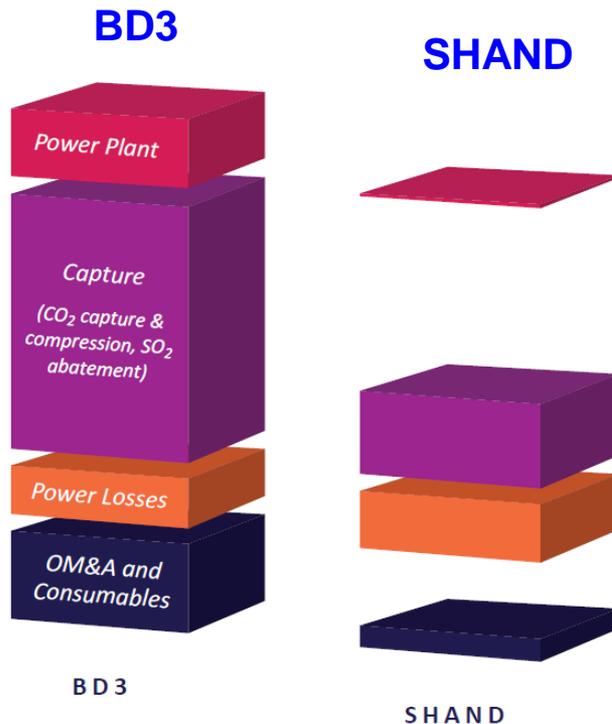
# Assessing Integrated Business Models

**Identifying the most advantageous integrated CCUS business model requires information on four key topics.**

- **Operational Change for the Capture Facility.** For example, CO<sub>2</sub> capture and 45Q tax credits, electricity generation will likely have a significantly higher annual capacity utilization factor (due to reduced net incremental cost) compared to other units in the system.
- **Cost of CO<sub>2</sub> Capture.** Assessing potential cost reductions from 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> of-a-kind projects.
- **Cost of CO<sub>2</sub> Storage.** Recognizing that a high-quality storage complex located close to a power plant provides considerable value.
- **Value of CO<sub>2</sub> for EOR.** Incorporating key variables (e.g., price of oil, costs of transport, quality of EOR project, etc.) into the value proposition.

# Capital Costs for Retrofitting Coal-Fueled Power Plant with CO<sub>2</sub> Capture

## Cost Comparison of BD3 and Shand CCS Facilities



Engineering study post BD3 re adding post-combustion CO<sub>2</sub> capture to SaskPower's Shand Power Station.

Capital costs can be significantly reduced capital costs per MWh

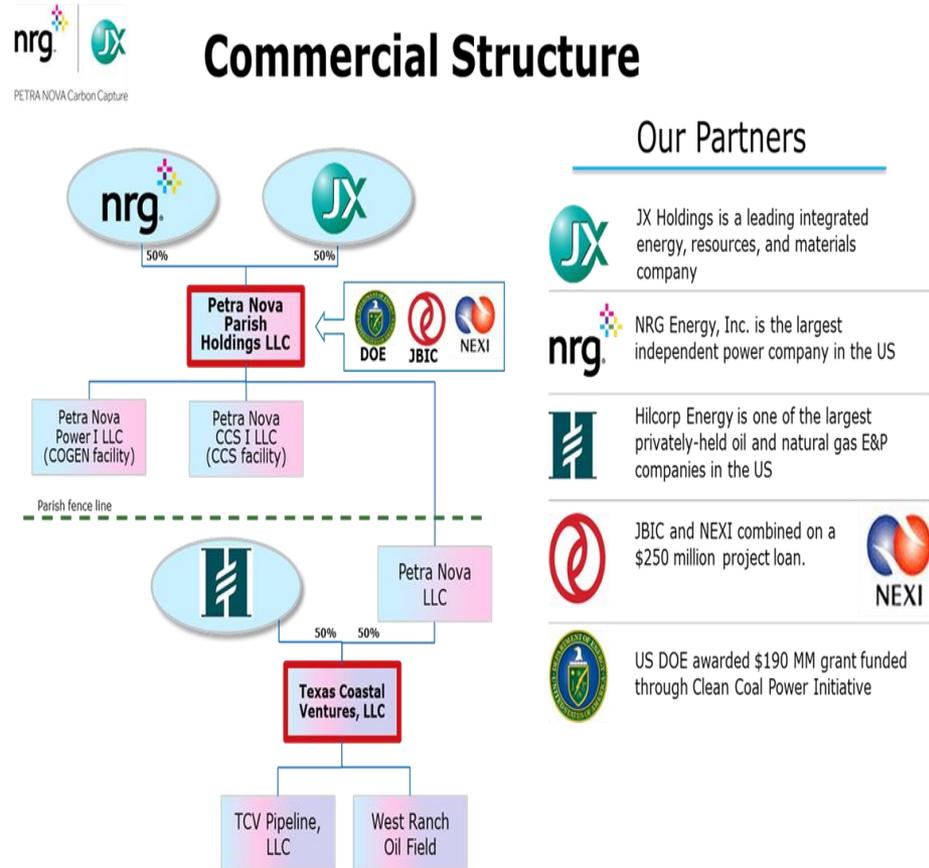
- Construction at larger-scale using extensive modularization
- Improved integration of the capture facility with the power unit
- Incorporating lessons learned from building and operating BD3.



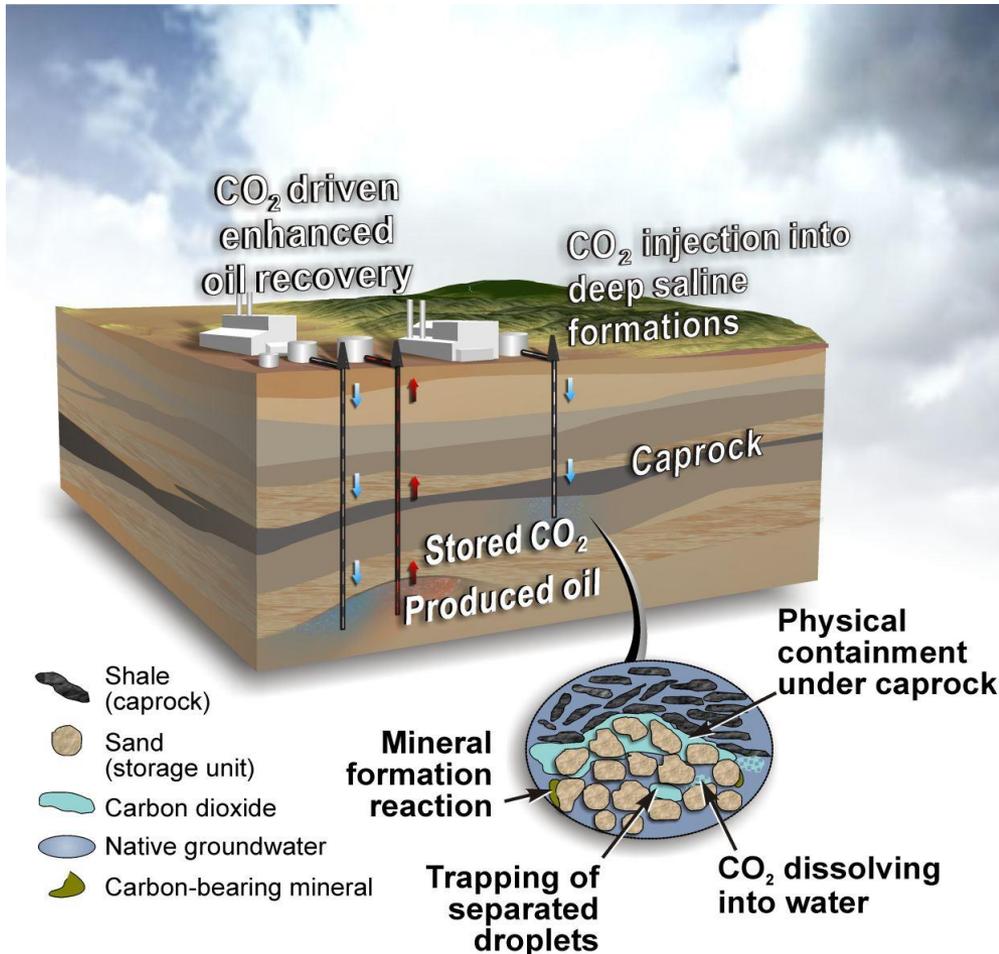
Source: Summary for Decision Makers on Second Generation CCS, Based on the Shand CCS Feasibility Study, International CCS Knowledge Centre, [ccsknowledge.com](http://ccsknowledge.com).

# Petra Nova Carbon Capture Project: Closer Look at a New Business Model

- \$1 billion project 50-50 joint venture between NRG Energy's Carbon 360 unit and JX Nippon Oil & Gas Exploration.
- Financing Petra Nova required creative combination of partners.
  - US DOE awarded a \$167 million grant as part of a competitive solicitation under the DOE's Clean Coal Power Initiative.
  - NRG decided to build/own the CO<sub>2</sub> delivery pipeline and take a 50% equity stake in the West Ranch oil field.
  - JX Nippon eventually matched NRG's \$300 million equity stake.
  - \$250 million in loans from Japanese banks.



# “Stacked” Storage/Combined CO<sub>2</sub>-EOR Plus Storage



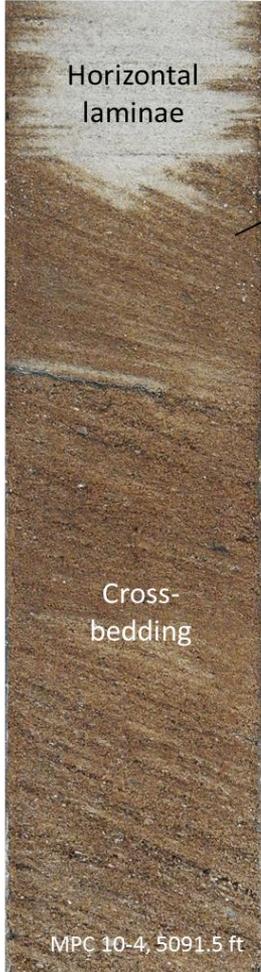
<https://www.arb.ca.gov/cc/sequestration/seq.htm>

In a carbon constrained emissions world, associated storage with CO<sub>2</sub>-EOR may not achieve emissions reduction targets. In association with the EOR project, “pure” storage may be conducted in a high permeability saline formation above or below the oil reservoir.

This could require regulation mandates or steep incentives to push forward.

# Project ECO<sub>2</sub>S Storage Zone Properties

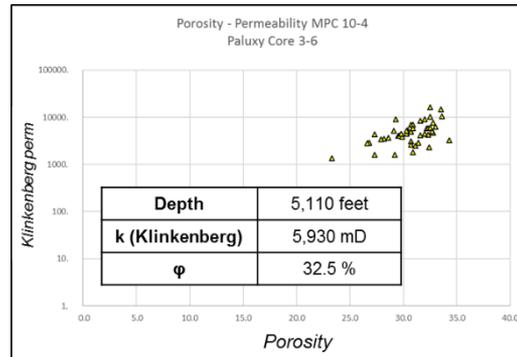
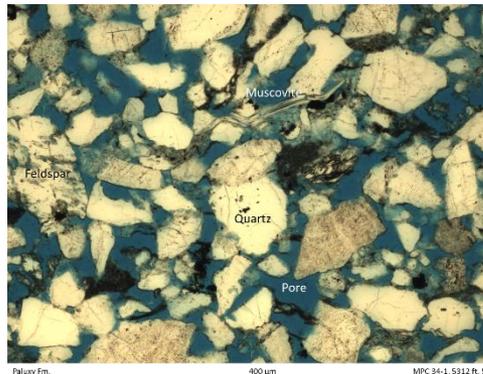
## Paluxy sandstone



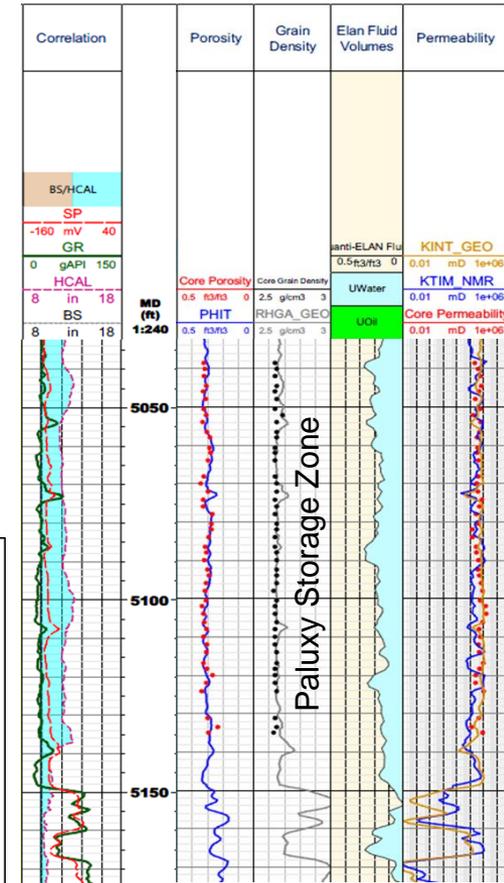
Interpretation: sandy braided stream deposit

- **Goal: Demonstrate the subsurface at Kemper can safely/permanently store commercial volumes of CO<sub>2</sub>**
- Abundant stacked saline sandstone bodies in Paluxy, Wash-Fred, and lower Tuscaloosa.
- 350 meters of net sand. Logs and core show sandstone average porosity of 30%(!!)
- Core analysis indicates all sandstones water-saturated
- Darcy-class permeability common (up to 16 Darcies)

### High-porosity sandstone in Paluxy Formation



## Elemental Log Analysis (ELAN\*) interpretation



\*ELAN is a mark of Schlumberger

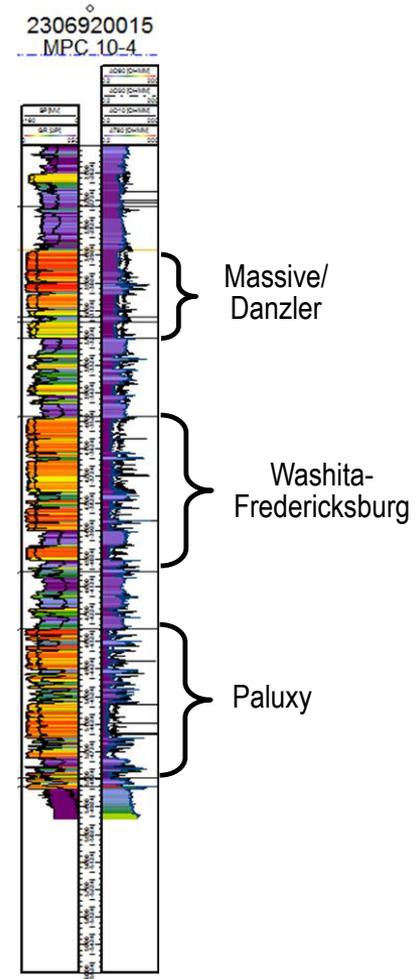
# Storage Complex Capacity

- Each of the three potential storage zones have commercial capacity
- Together the three storage zones result in a gigatonne capacity storage complex that has the potential to act as a regional hub

CO <sub>2</sub> Storage Reservoir	P <sub>10</sub> Capacity (MMmt)	P <sub>50</sub> Capacity (MMmt)	P <sub>90</sub> Capacity (MMmt)
Massive/Dantzler	60	120	200
Wash.-Fred.	280	540	920
Paluxy	160	310	530

DOE methodology for site-specific saline storage efficiency calculation based on fluid displacement factors for clastic reservoirs where net pay, net thickness and net porosity are known of 7.4% (P<sub>10</sub>), 14% (P<sub>50</sub>) and 24% (P<sub>90</sub>) (Goodman et al., 2011)

- Low-cost storage options occur beneath the energy facility -- \$2.00 - \$4.00 USD per metric ton depending on volume of CO<sub>2</sub> captured (*after DOE investment*)
- Drives the value proposition where existing infrastructure could be utilized for CO<sub>2</sub> capture, compression, transportation and storage



# Concluding Thoughts and Observations

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- 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. 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.”
- 3. 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.
- 4. Both CCUS and CO<sub>2</sub>-EOR Still Need Supportive Policies and Actions.** R&D investment, supportive policies and expedited CO<sub>2</sub> pipelines can accelerate integration of CO<sub>2</sub>-EOR and CCUS.
- 5. Business Models Likely to Evolve Given New Market and Policy Realities.**



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