Industry Opportunities for Carbon Capture, Utilization and Storage (CCUS) in the U.S.

Presented at:
GWPC Underground Injection Control Conference

Presented by:
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Advanced Resources International, Inc.

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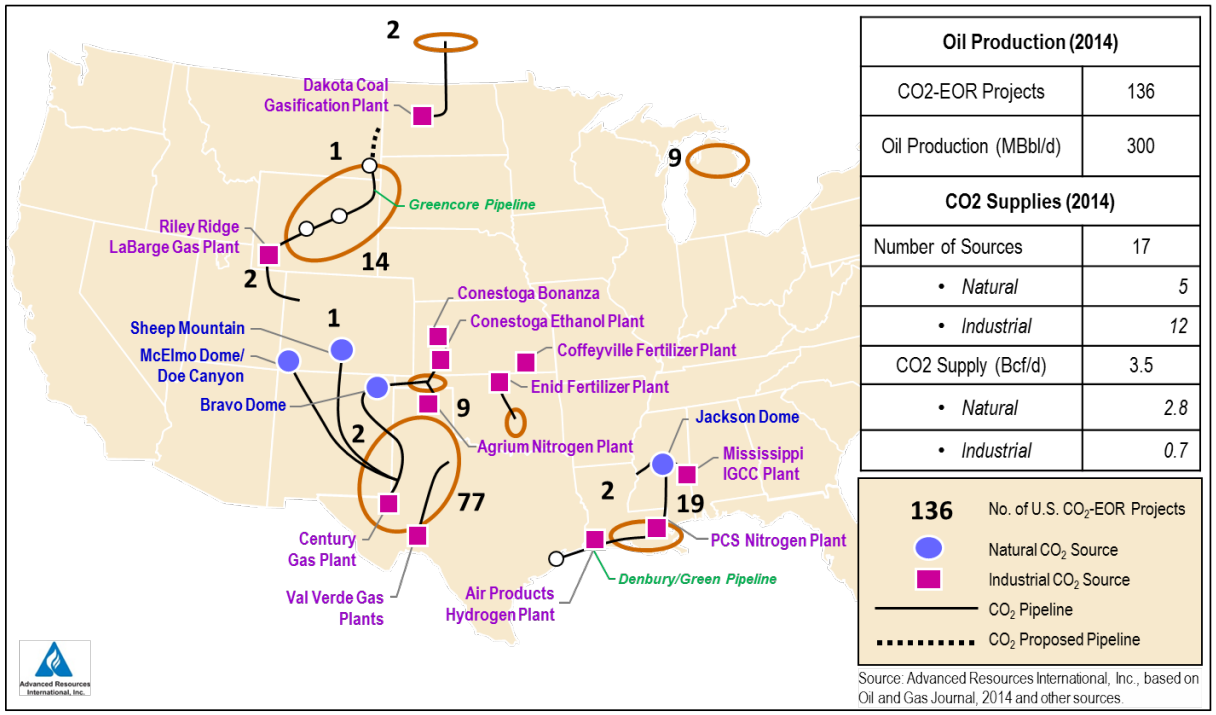
San Antonio, Texas

Status of CO_2–EOR: A Snapshot in Time

The development of large natural sources of CO_2 (e.g., McElmo Dome, Jackson Dome, etc.) established the foundation for the CO_2-EOR industry. Capture of industrial sources of CO_2 is helping drive its growth.

Current CO_2-EOR Operations and CO_2 Sources (2014)



Oil Production (2014)	
CO2-EOR Projects	136
Oil Production (MBbl/d)	300
CO2 Supplies (2014)	
Number of Sources	17
• *Natural*	*5*
• *Industrial*	*12*
CO2 Supply (Bcf/d)	3.5
• *Natural*	*2.8*
• *Industrial*	*0.7*

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

- Based on the 2014 O&GJ Survey, 136 significant CO_2-EOR projects currently produce 300,000 barrels per day in the U.S. by injecting 3.5 Bcfd of CO_2, with 0.7 Bcfd from industrial sources.
- In spite of limitations in supplies of CO_2 and lower oil prices, existing CO_2-EOR projects are being expanded and new CO_2-EOR projects started.
- We note increased CO_2-EOR activity even though the O&GJ has terminated its CO_2-EOR Survey.

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

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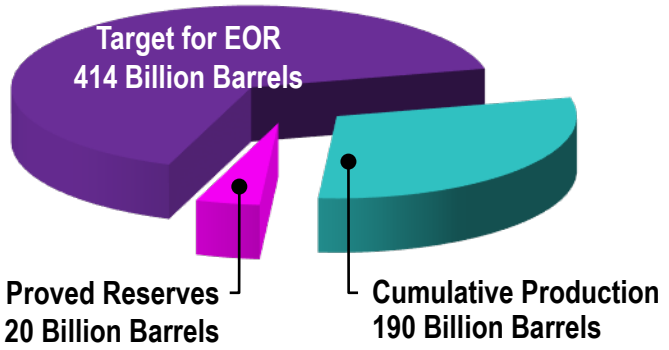
CO_2-EOR: A Niche or a Robust Carbon Management Strategy?

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.

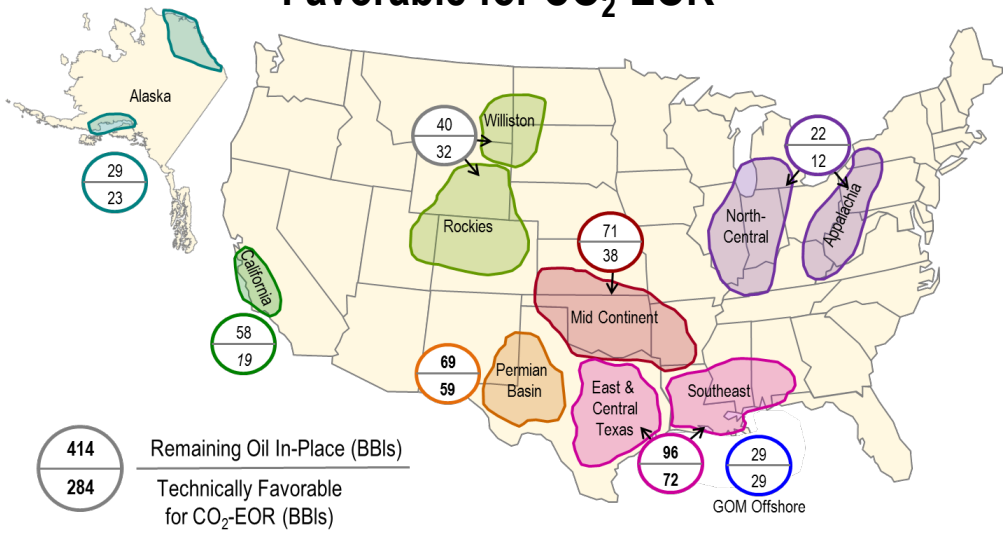
Much of this "left behind oil" (284 billion barrels) is technically favorable for CO_2-EOR and is widely distributed across the U.S.

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_2-EOR



Source: Advanced Resources International internal analysis, 2016

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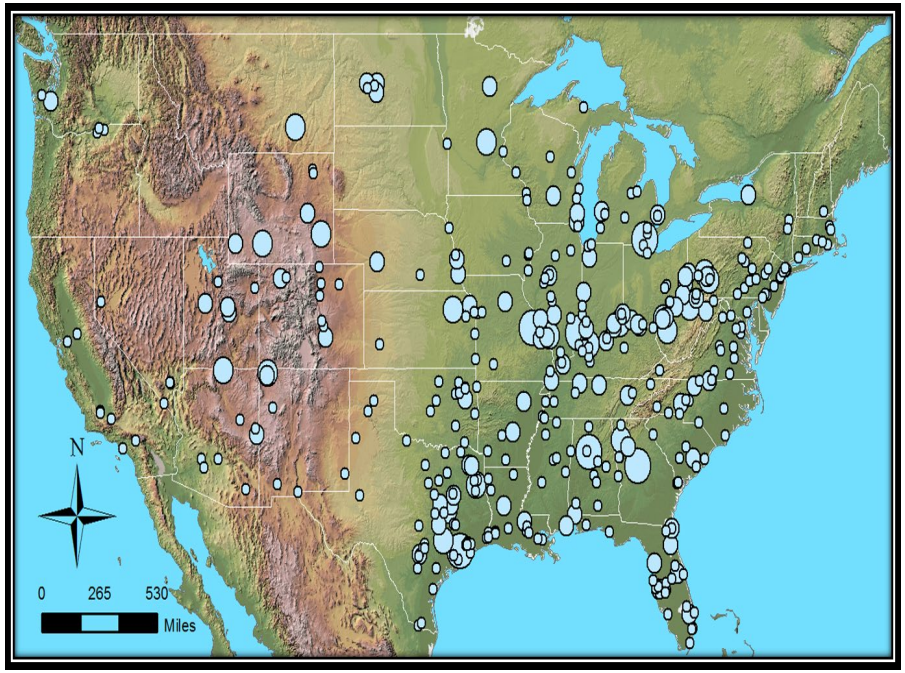
Potential CO_2 Sources

Potential Electric Generation CO_2 Sources Above 1 Million Tonnes/Year



Source: Advanced Resources International, 2019.

Legend

Source

Electricity Generation

CO_2 Emissions (Metric Tons CO_2)

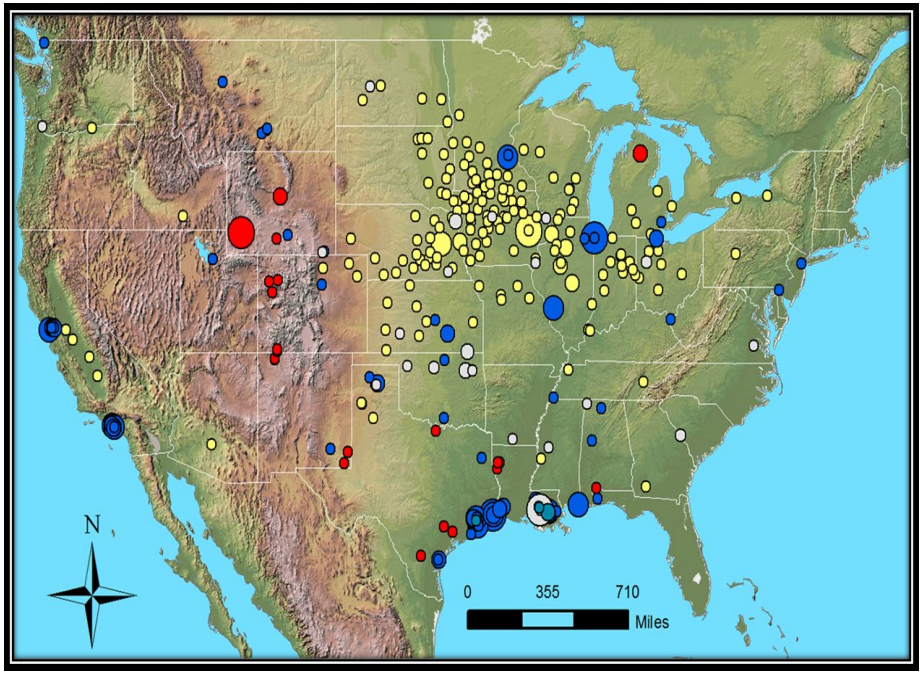
1,000,000 – 5,000,000

5,000,000 – 10,000,000

10,000,000 – 15,000,000

15,000,000 – 20,000,000+

The Low-Hanging Fruit: High Purity Stream Potential CO_2 Sources



Legend

High Purity Source

Ammonia

Ethanol

Ethylene Oxide

Hydrogen

Natural Gas Processing

CO_2 Emissions (Metric Tons CO_2)

100,000 – 500,000

500,000 – 1,000,000

1,000,000 – 1,500,000

1,5000,000 – 5,000,000+

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"Next Generation" CO_2 Enhanced Oil Recovery

Use of more efficient CO_2-EOR technologies and extension of these technologies to new oil resource settings constitutes "next generation" CO_2-EOR:

1. Scientifically-based advances in CO_2-EOR technology
2. Integrating CO_2 capture with CO_2 utilization by CO_2-EOR
3. Application of CO_2-EOR to residual oil zones (ROZs)
4. Deployment of CO_2-EOR in offshore oil fields.
5. Deployment of CO_2-EOR in tight (shale) oil formations.

Use of "next generation" CO_2-EOR will expand oil production and CO_2 storage capacity in the U.S.

U. S. 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**

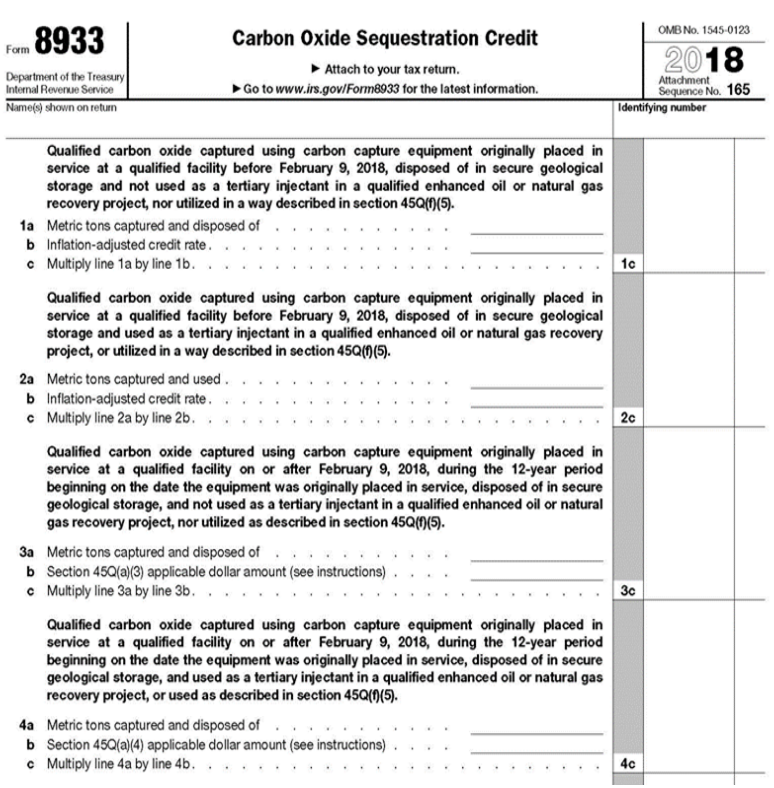
*The values for economically recoverable oil and economic CO_2 demand (storage) represent an update to the numbers in the NETL/ARI report "Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (CO_2-EOR) (June 1, 2011).
**At $85 per barrel oil 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.

BBA Enhancements to IRC Section 45Q -- Highlights

Previous 45Q	Bipartisan Budget Act of 2018
▪ 75 million metric ton cap	▪ Eliminates 75 million metric ton cap; applies to new facilities that **"break ground" by EOY 2023.**
▪ Credit based on "captured qualified CO_2"	▪ After enactment, credit based on captured "qualified carbon oxide" (CO_2 and **other carbon oxides**). ▪ Allows for the **transfer** of qualified credits
▪ $20/metric ton for CO_2 stored and not used for EOR ▪ $10/metric ton for CO_2 stored and used for EOR	▪ **$50/mt for geologic storage and $35/mt for EOR (each rate phases up over 10-year period from 2017 to 2026**). ▪ Existing qualified facilities would continue to receive the original inflation adjusted $20 and $10 credit rates.
▪ Available to facility with capture equipment capturing at least 500,000 metric tons CO_2/year.	▪ Capture > **500,000** metric tons CO_2/year for electric generating units; > **100,000** metric tons CO_2 /year for other. ▪ Credit goes to the **owner of the capture equipment**. ▪ Available to "**direct air capture" and "beneficial use** (with 25,000 metric ton threshold)"
▪ Credit available until the 75-million-ton cap is reached.	▪ Credit available for **12 years** from the date the carbon capture equipment is placed in service.

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 - ??????**



Form **8933** — Carbon Oxide Sequestration Credit

Department of the Treasury
Internal Revenue Service

▶ Attach to your tax return.
▶ Go to *www.irs.gov/Form8933* for the latest information.

OMB No. 1545-0123
2018
Attachment Sequence No. 165

Name(s) shown on return | 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 . . . 1c

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 . . . 2c

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 . . . 3c

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 . . . 4c

Other Issues of Concern with 45Q

- 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, direct air capture) projects?
- What impact will CCS have on electricity dispatch?

Are the 45Q Enhancements Enough?

- **Continued RD&D**
  - Reduce costs of CO_2 capture
  - Pursue "next generation" CO_2-EOR; especially targeting "carbon negative oil"
- **Further incentives beyond 45Q?**
  - Tax-exempt private activity bonds
  - Master limited partnerships
  - Incentives for CO_2 pipelines/pipeline expansions/buildout
  - Ensuring Parity for CCS in the power markets
    - Feed-in tariffs, CCS in "Clean Energy" Portfolio Standards
  - State incentives

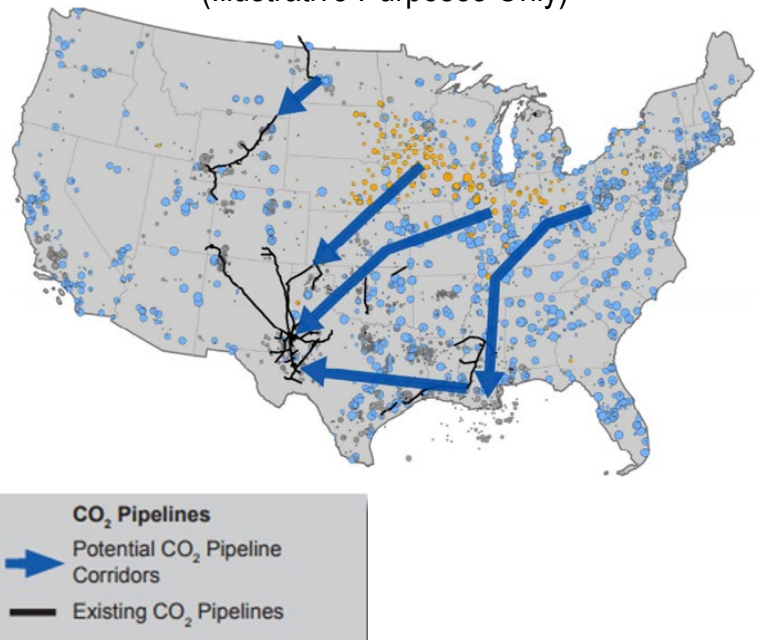
Possible State Policy Approaches/Incentives

- **Supportive state regulatory policies**
- **Clear rules for long term storage**
  - CO_2 storage trust funds; rules for CO_2/pore space ownership and responsibility
- **CO_2 pipelines – common carrier/eminent domain**
- **Financial incentives for carbon capture**
  - Financial assistance, off-take priority, cost recovery, eligibility under “clean energy” standards, assumption of long-term liability
- **Tax incentives/optimization**
  - Additional tax credits for CO_2-EOR + storage, tax exemptions for “pollution control equipment” associated with CO_2 capture.

Support for CO_2 Pipeline Infrastructure

- **Regional Initiative co-convened by Governors of Wyoming and Montana.**
- **Launched in 2015:**
  - Officials from 15 states*
  - With industry and NGO stakeholders and experts
- **Objectives:**
  - Help policymakers better understand states' potential for CCS, CO_2-EOR and utilization
  - Recommend state and federal strategies and policies
- **Support implementation of policy recommendations and project deployment.**
- **Funding from MacArthur Foundation, Hewlett Foundation and Spitzer Charitable Trust**.

Potential Regional CO_2 Pipeline Corridors
(Illustrative Purposes Only)



*State participation varies and includes governors' staff, cabinet secretaries, utility commissioners and agency and commission staff.

Historical Business Models

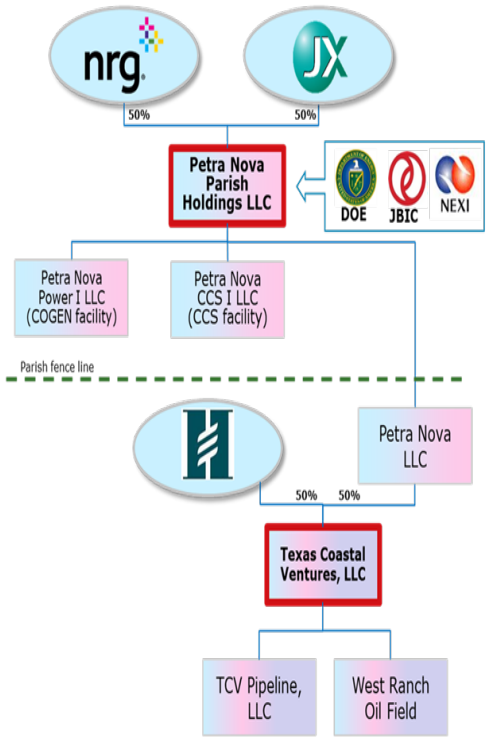
- Natural sources. The earliest projects leveraged their proximity to large, natural sources of CO_2.
- Industrial capture. Commoditization of products at industrialized centers have recognized the value of CO_2.
- Government subsidized. Some projects were government subsidized in order to achieve commercial viability.
- Infrastructure development. Field operators can link to major pipeline sources of CO_2.

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

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_2 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.

Commercial Structure



Our Partners

JX Holdings is a leading integrated energy, resources, and materials company

NRG Energy, Inc. is the largest independent power company in the US

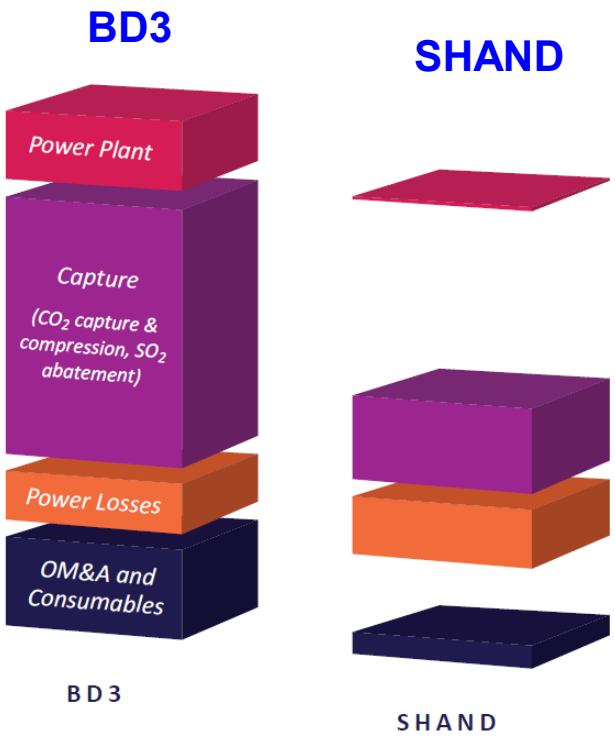
Hilcorp Energy is one of the largest privately-held oil and natural gas E&P companies in the US

JBIC and NEXI combined on a $250 million project loan.

US DOE awarded $190 MM grant funded through Clean Coal Power Initiative

Capital Costs for Retrofitting Coal-Fueled Power Plant with CO_2 Capture

Cost Comparison of BD3 and Shand CCS Facilities



Source: Summary for Decision Makers on Second Generation CCS, Based on the Shand CCS Feasibility Study, International CCS Knowledge Centre, ccsknowledge.com.

Engineering study post BD3 re adding post-combustion CO_2 capture to SaskPower's Shand Power Station.

Capital costs can be significantly reduced capital costs per MWh

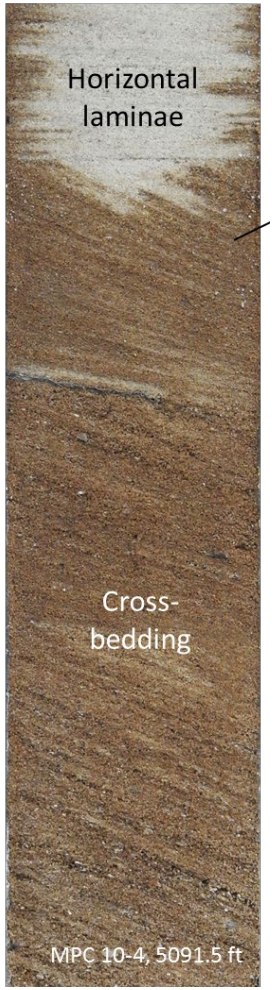
- Construction at larger-scale using extensive modularization
- Improved integration of the capture facility with the power unit
- Incorporating lessons learned from building and operating BD3.

"Next Generation" CO_2-EOR and Carbon Negative Oil – Is it Possible?

- **Most life-cycle analyses (LCA) of CO_2-EOR are based on historical operations:**
  - Where CO_2 use was minimized per incremental barrel because of the high costs for CO_2
- **Such LCAs often do not represent the emerging paradigm where CO_2 storage is a co-objective.**
- **Such LCAs often do not represent current efficiencies in CO_2-EOR operations.**
- **Such LCAs often do not represent current refining operations.**
  - An increasing portion of crude today is transformed into non-combustible products, like asphalt, lubricants, waxes, and chemical feedstocks.

Project ECO$_2$S Storage Zone Properties

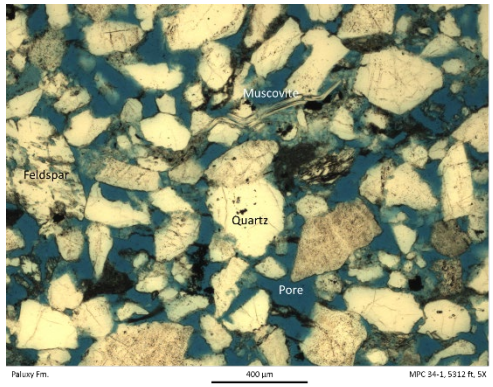
Paluxy sandstone

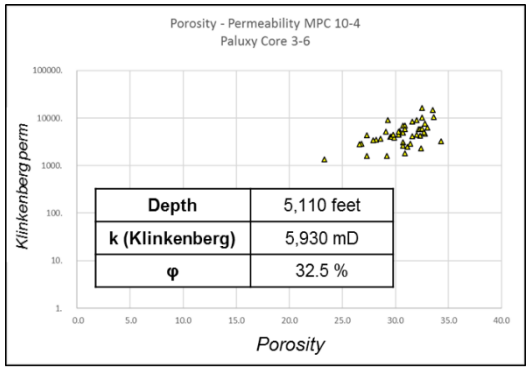


Interpretation: sandy braided stream deposit

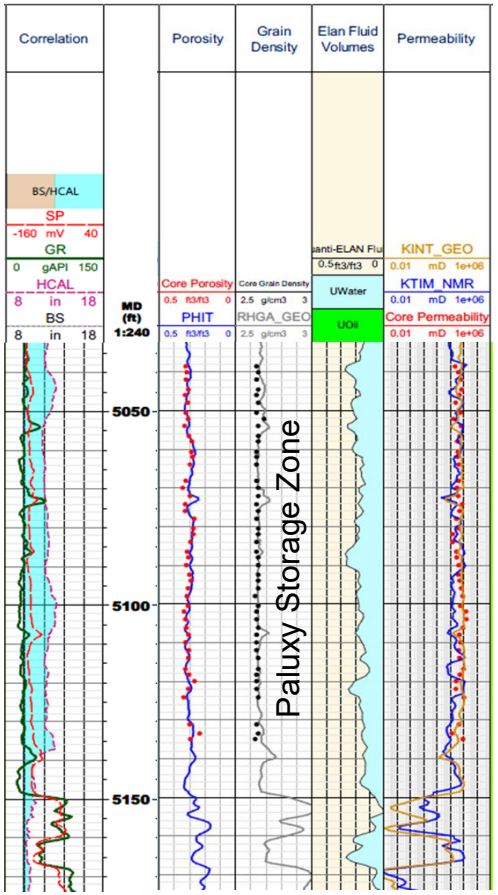
- **Goal: Demonstrate the subsurface at Kemper can safely/permanently store commercial volumes of CO_2**
- Abundant stacked saline sandstone bodies in Paluxy, Wash-Fred, and lower Tuscaloosa.
- 350 meters of net sand. Logs and core show sandstone average porosity of 30%(!!)
- Core analysis indicates 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*

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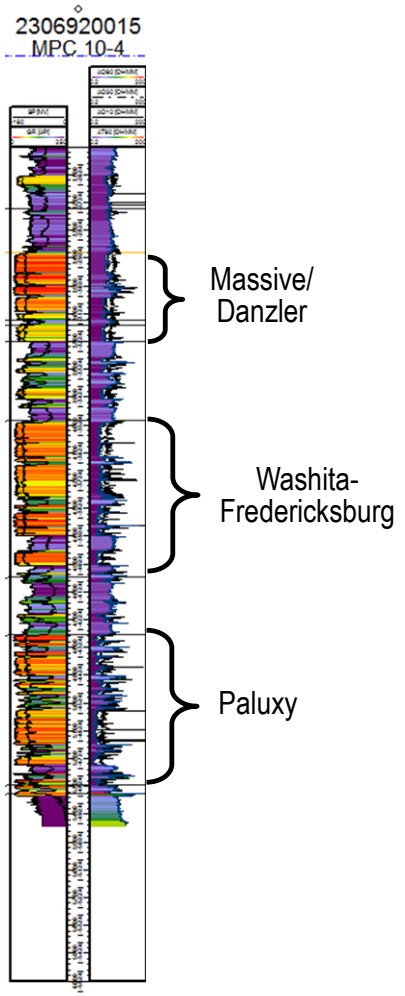
Storage Complex Capacity

- 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_2 Storage Reservoir	P_{10} Capacity (MMmt)	P_{50} Capacity (MMmt)	P_{90} 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_{10}), 14% (P_{50}) and 24% (P_{90}) (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_2 captured (*after DOE investment*)
- Drives the value proposition where existing infrastructure could be utilized for CO_2 capture, compression, transportation and storage

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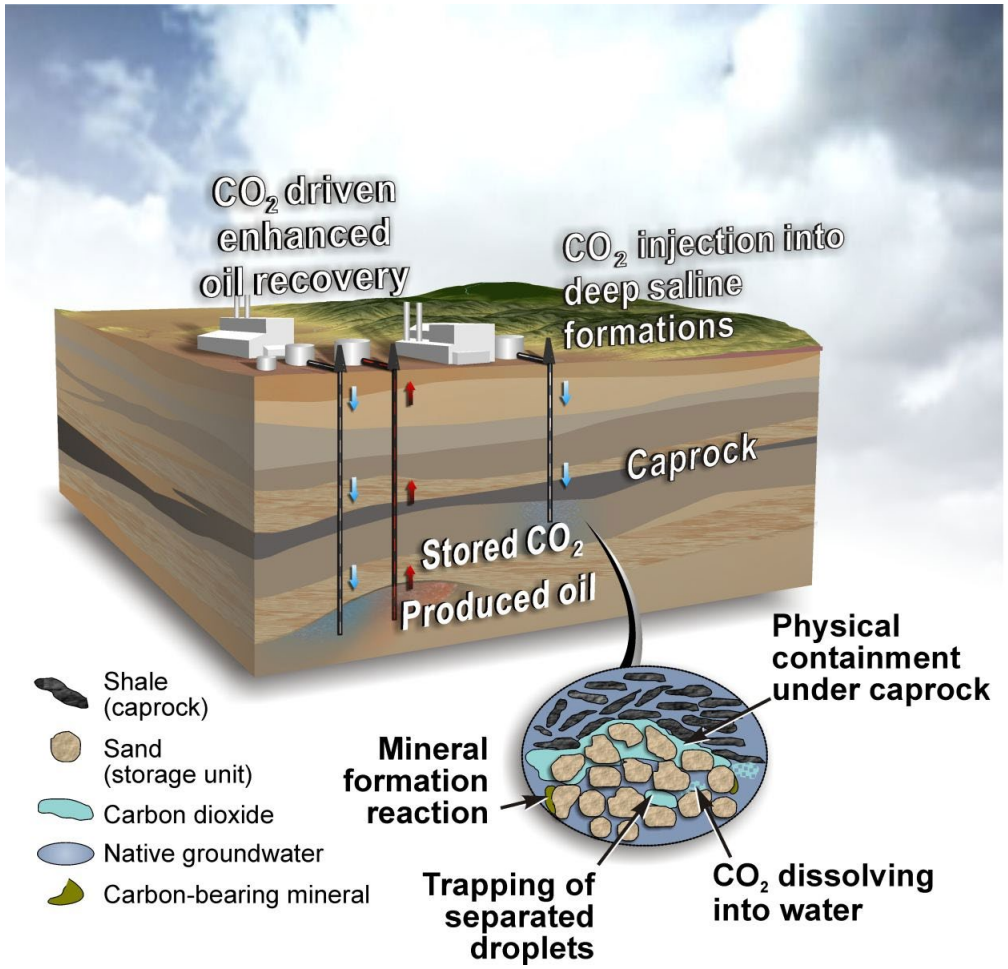
"Stacked" Storage/Combined CO_2-EOR Plus Storage



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

In a carbon constrained emissions world, associated storage with CO_2-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.

U.S. Regulatory Experience – Class VI

- Concerns remain that obstacles exist to allow CO_2-EOR to be viable source for CO_2 emissions reduction.
- To date, the timeline for obtaining Class VI permits approval has been too long – as much as four years or more.
- 50-year "default" for post-injection site care (PISC) hinders possible CCS project financing
- EPA's inconsistent application of financial responsibility instruments is hindering permitting and deployment.
- The process for allowing states to acquire primacy for Class VI well permitting has been very slow.
- Greater Class VI regulatory certainty is necessary to encourage new Class VI projects.

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. **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."
3. **CO_2-EOR Needs CCUS.** Large-scale implementation of CO_2-EOR is dependent on CO_2 supplies from industrial sources.
4. **Both CCUS and CO_2-EOR Still Need Supportive Policies and Actions.** R&D investment, supportive policies and expedited CO_2 pipelines can accelerate integration of CO_2-EOR and CCUS.
5. **Business Models Likely to Evolve Given New Market and Policy Realities**.

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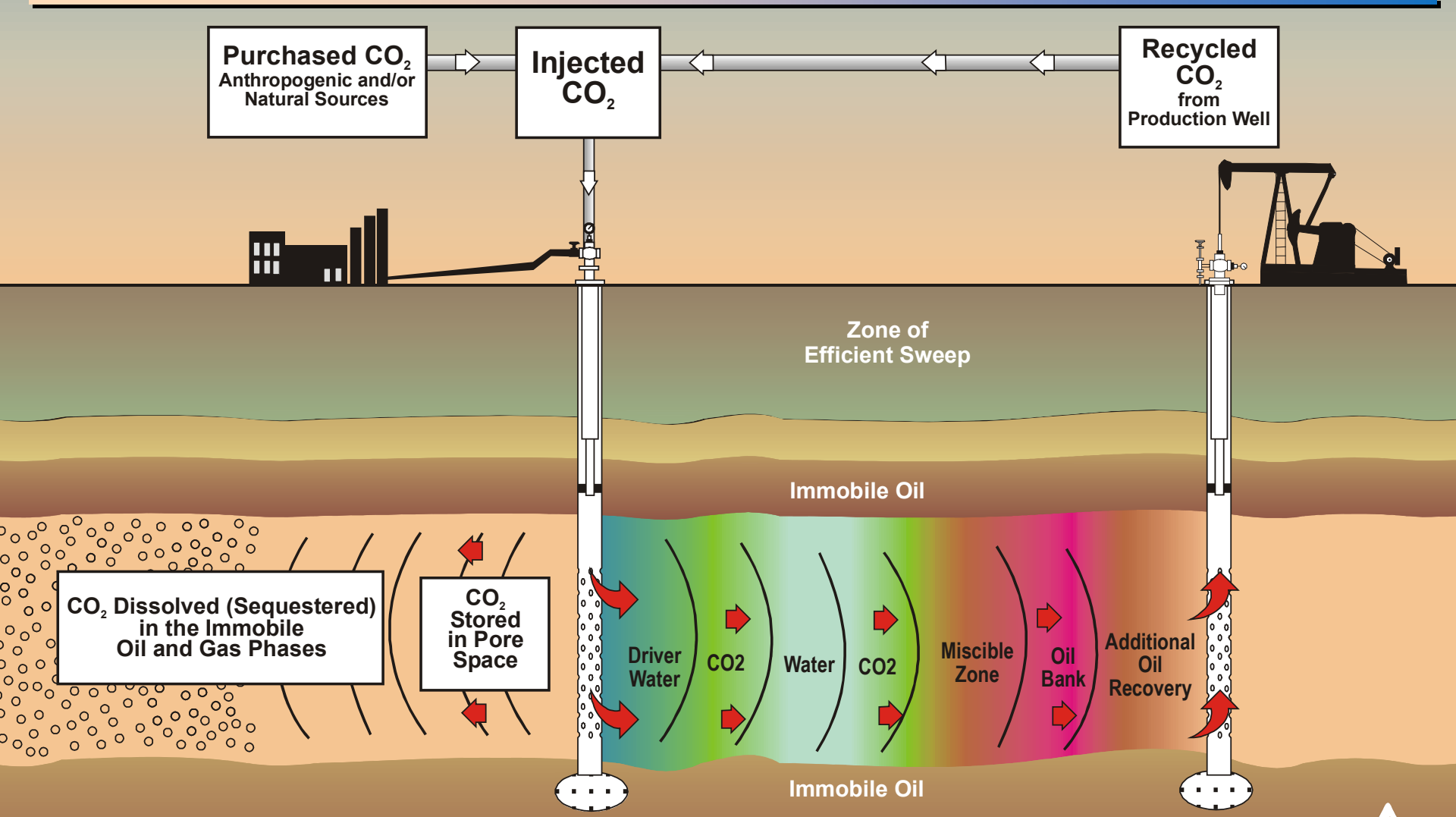
CO_2-EOR Technology: A Closed-Loop System



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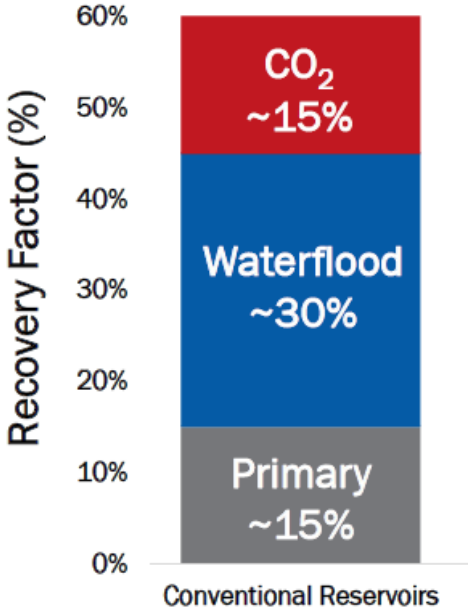
CO_2-EOR Performance

While relatively simple in concept, successful application of CO_2-EOR entails sophisticated design, process/flow modeling, and continuous monitoring.

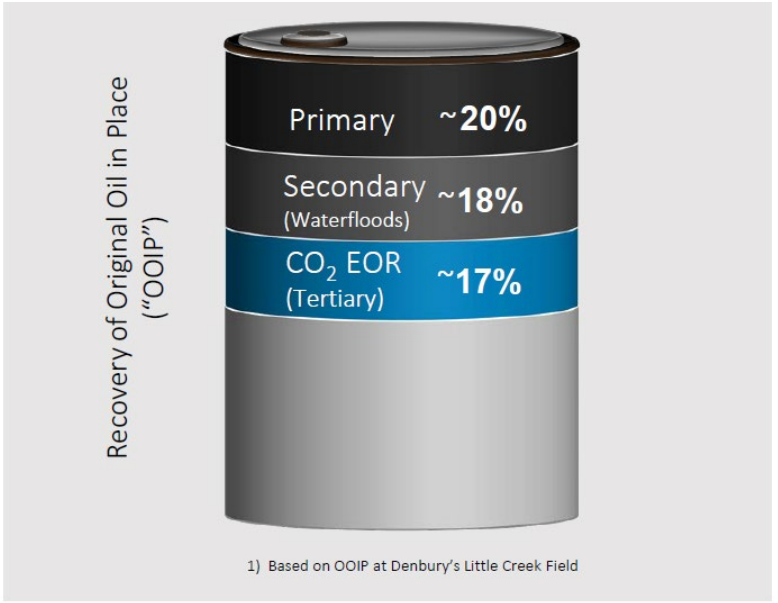
Recovery of OOIP – Permian Basin



Source: Oxy, 2017.

In the Permian Basin, CO_2 EOR can recover 15% of OOIP.

Recovery of OOIP - - Gulf Coast



Source: Denbury Resources, 2018.

In Gulf Coast oil fields, CO_2-EOR can produce as much oil as primary or secondary recovery.

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CCUS Economics 101 – 45Q Example

Cost of Capture
- Equipment x Financing % Rate
- O&M
- Energy penalties

↳ **Less than:**

CO_2-EOR Storage

Total of: **45Q Tax Credit $35/ton** plus **EOR Sales Revenues** minus **Transport Cost to EOR field**

OR

Saline Storage

Total of: **45Q Tax Credit $50/ton** minus **Storage Charges by Saline Operator** minus **Transport Cost to Saline Reservoir**

Distribution of Benefits of CO_2-EOR

Notes		CO_2-EOR Industry	Mineral Owners	Federal/ State Treasuries	Power Plant/ Other Capturers of CO_2	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	CO2 Purchase Costs	($13.50)			$13.50	
6	CO2 Recycle Costs	($5.00)				$5.00
7	O&M/G&A Costs	($15.00)				$15.00
8	CAPEX	($7.00)				$7.00
	Total Costs	**($56.80)**	**$10.40**	**$5.90**	**$13.50**	**$30.00**
	Net Cash Margin	**$20.20**				
9	**Income Taxes**	**($7.10)**	**($3.60)**	**$10.70**	**-**	**-**
	Net Income ($/B)	**$13.10**	**$6.80**	**$16.60**	**$13.50**	**$30.00**

JAF2017_016.xls

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 CO2 sales price of $30/metric ton including transport; 0.45 metric tons of purchased CO2 per barrel of oil.
6 CO2 recycle cost of $10/metric ton; 0.5 metric tons of recycled CO2 per barrel of oil.
7 O&M/G&A costs from ARI CO2-EOR cost models.
8 CAPEX from ARI CO2-EOR cost models.
9 Combined Federal and state income taxes of 35%, from FRS data.
Source: Advanced Resources International internal study, 2017.

CO_2-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.