Role of CO_2 EOR for Carbon Management

Prepared for:
United States Energy Association

CCUS Deployment Training

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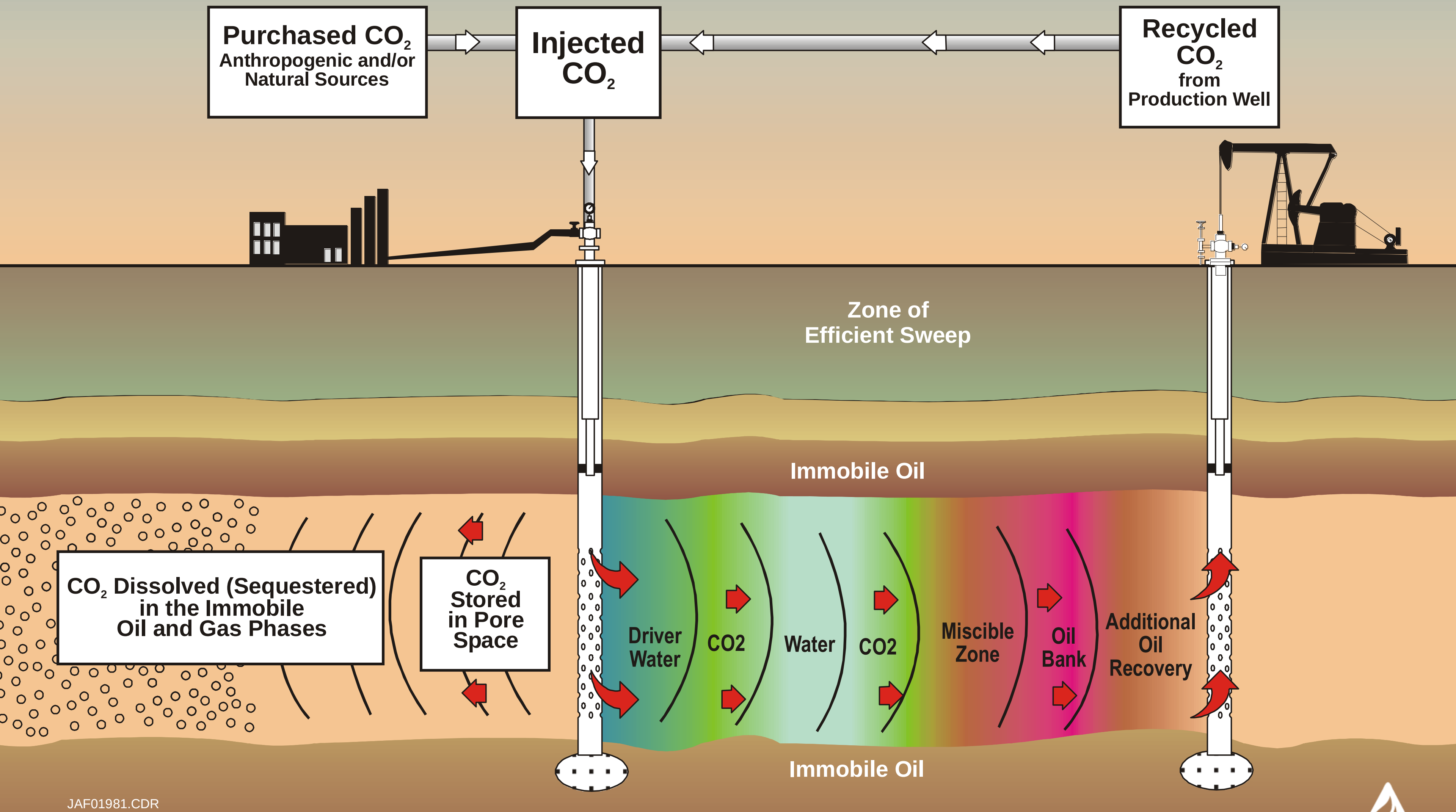
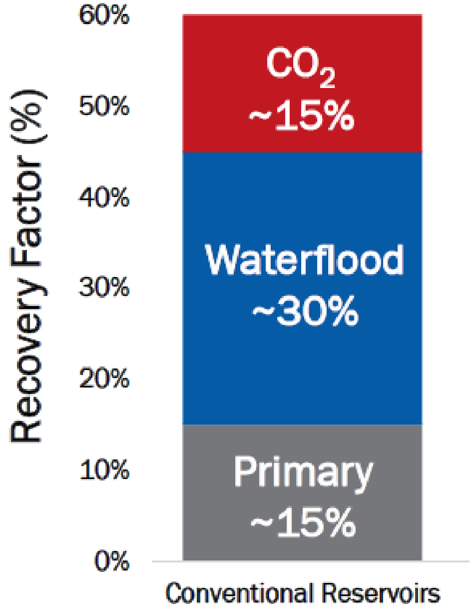
CO_2-EOR Technology: A Closed-Loop System



CO_2-EOR Performance

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

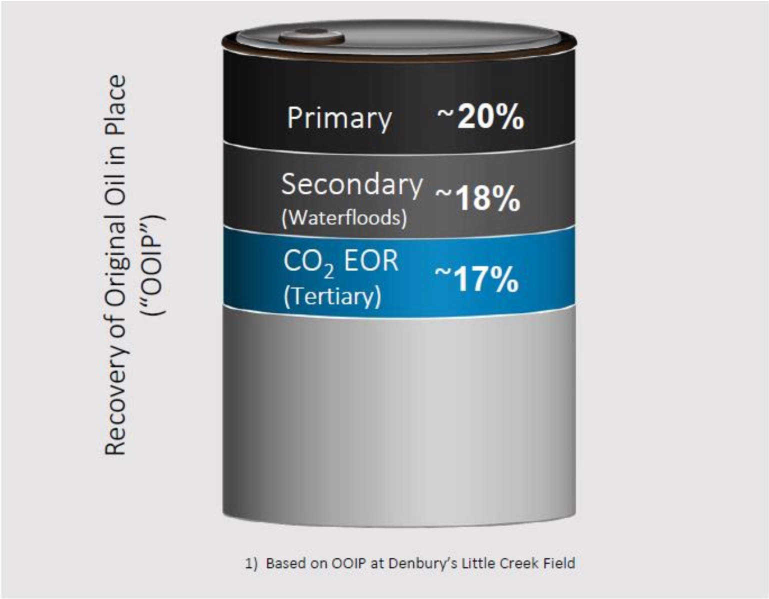
Recovery of OOIP – Permian Basin



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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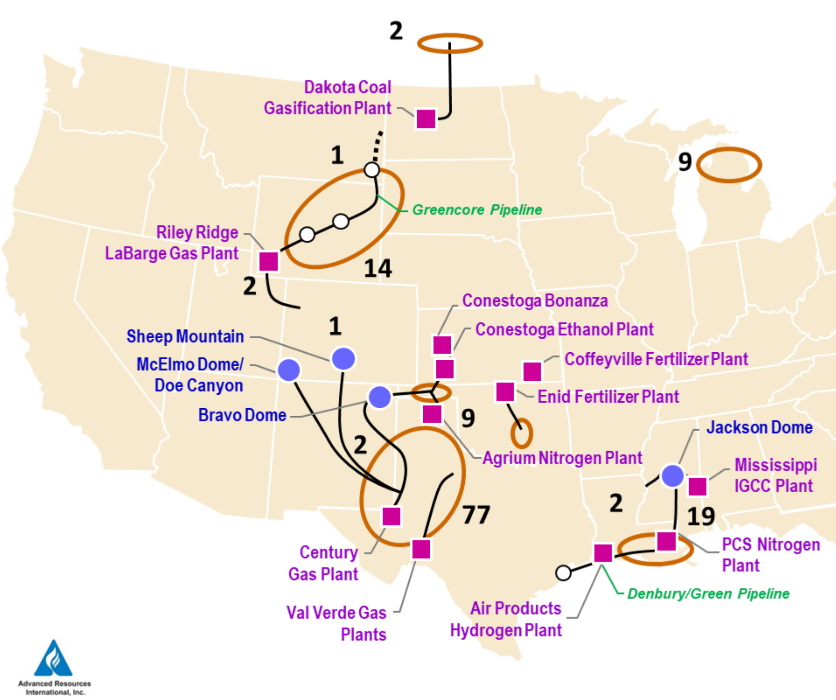
Status of CO_2 EOR: A Snapshot in Time

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 will be essential for supporting growth.

Current CO_2 EOR Operations and CO_2 Sources (2014/2019)



Oil Production (2014)	
CO_2-EOR Projects	136
Oil Production (MBbl/d)	300
CO_2 Supplies (2019)	
Number of Sources	17
• *Natural*	*5*
• *Industrial*	*12*
CO_2 Supply (Bcf/d)	3.3
• *Natural*	*2.2*
• *Industrial*	*1.1*

136 No. of U.S. CO_2-EOR Projects
Natural CO_2 Source
Industrial CO_2 Source
CO_2 Pipeline
CO_2 Proposed Pipeline

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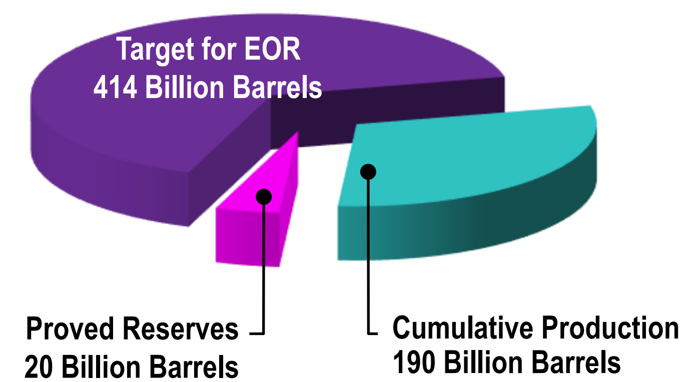
- Based on the 2014 O&GJ Survey, 136 significant CO_2 EOR projects currently produce 300,000+ barrels per day in the U.S. by injecting 3.3 Bcfd of CO_2, with 1.2 Bcfd (~ 22 million metric tons per year) from industrial sources.
- In spite of limitations in supplies of CO_2 and lower oil prices, existing CO_2-EOR projects are being expanded and new CO_2 EOR projects started.

Source: Advanced Resources International based on Oil & Gas Journal and other industry data, 2014/2019.

Size of the US CO_2-EOR Prize

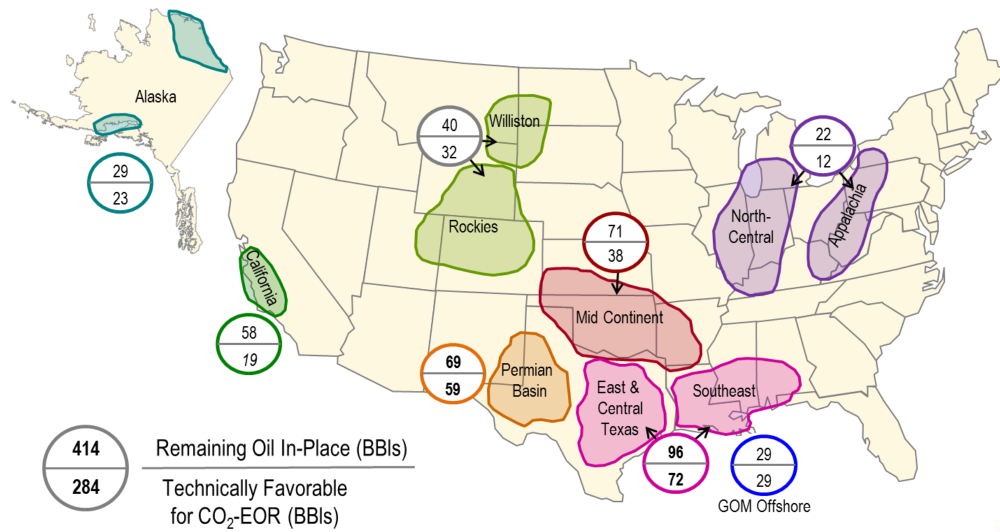
- 1/3 of the 624 billion barrel conventional oil endowment will be produced with primary/secondary technologies, leaving behind 414 billion barrels.
- Much of this "left behind oil" -- 284 billion barrels, is technically favorable for CO_2-EOR and is widely distributed across the U.S.
- At least 80 billion barrels is economic at today's prices, and would require 40 billion metric tons of CO_2 to produce.

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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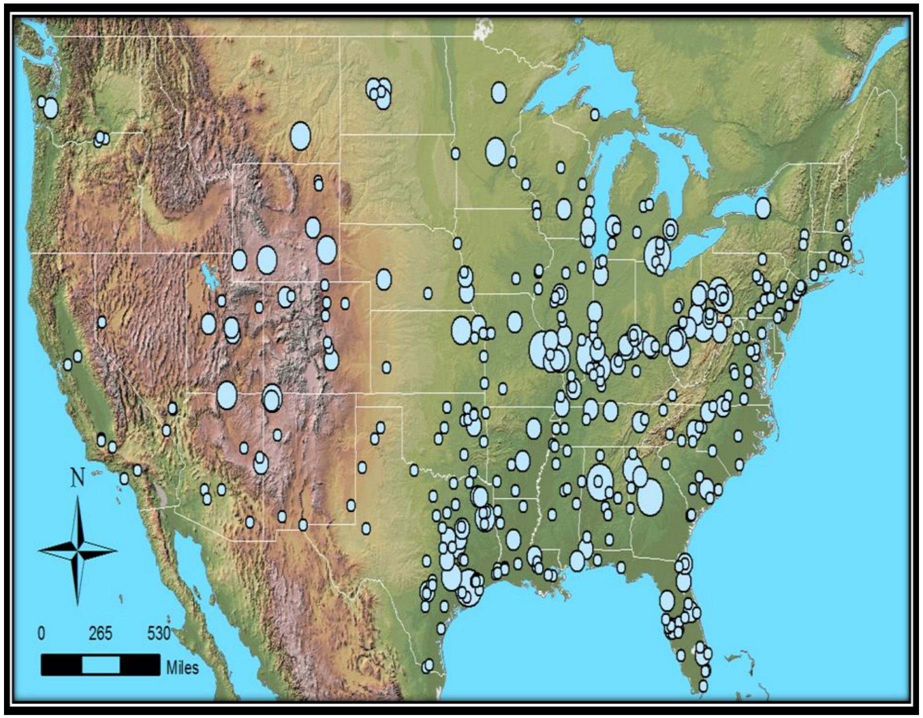
Potential CO_2 Sources

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)

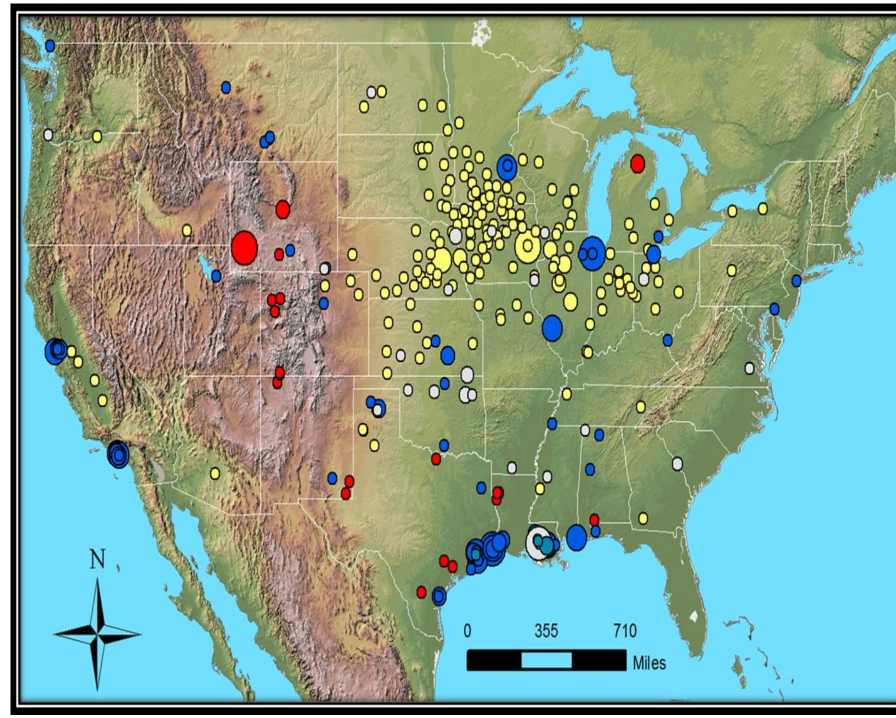
1,000,000 – 5,000,000

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+

Conventional Oil CO_2 EOR

Our assessment of the conventional oil CO_2 EOR “prize” is based on a data base of over 2,000 onshore oil reservoirs. It involves evaluating the technical and economic potential of each of these oil reservoirs using our CO_2 EOR PROPHET stream-tube simulator and our CO_2 EOR economics model.

At an oil price of $60/barrel and with “best practices” technology, CO_2 EOR offers the potential for 38 billion barrels of economically viable oil recovery creating 18,300 million mt of demand (and storage) for CO_2, for a CO_2 injected to oil produced ratio of 0.48 mt per barrel.

Basin/Area	OOIP Favorable for CO_2 EOR	Technically Recoverable Oil (Billion Barrels)	Technical Demand for CO_2 (Million Metric Tons)	Economically Recoverable Oil* (Billion Barrels)	Economic Demand For CO_2* (Milion Metric Tons)
Lower-48 Onshore	232	72	38,400	33	16,000
Alaska	41	9	4,600	5	2,300
Total	**273**	**81**	**43,000**	**38**	**18,300**

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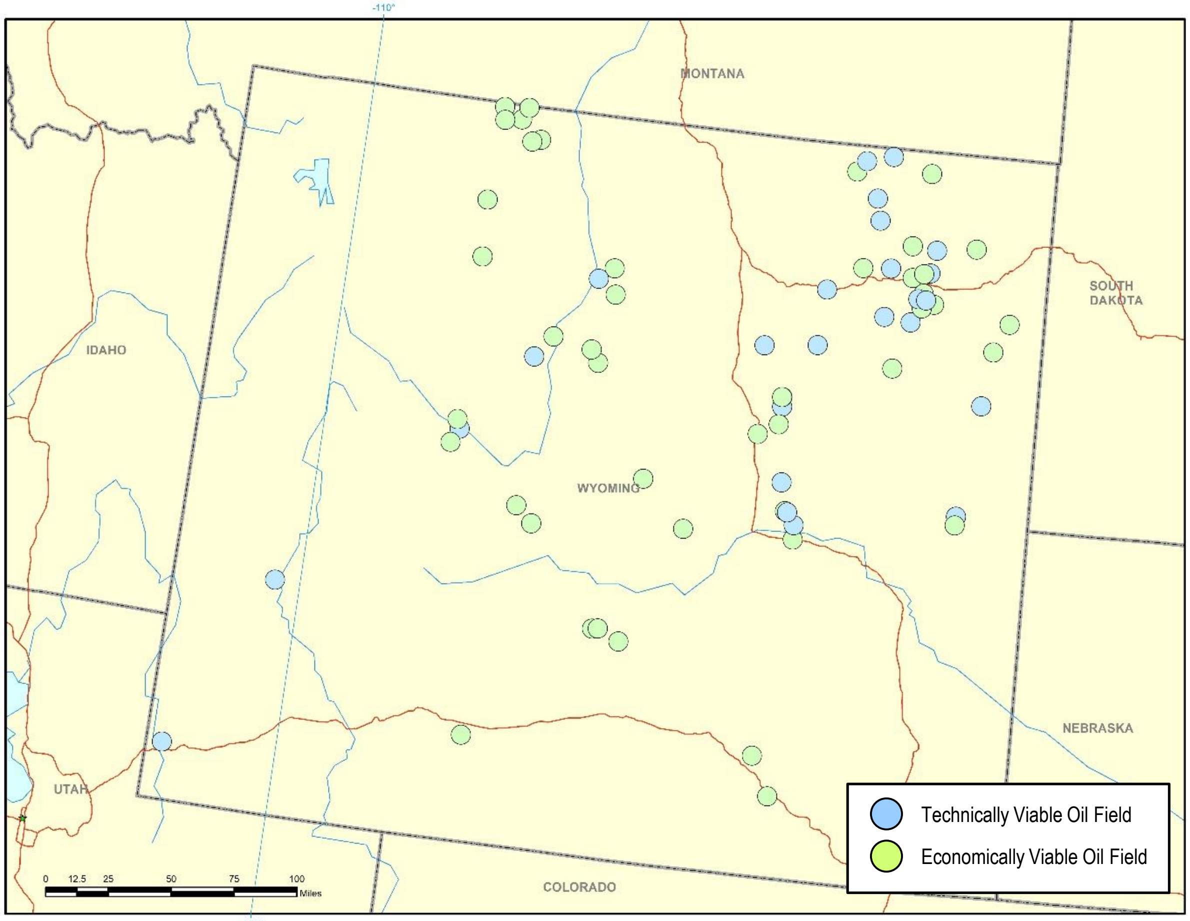
*At an oil price of $60/B (WTI), a CO2 price of $25 per metric ton, and 15% ROR (before tax).
Source: “Improving Domestic Energy Security and Lowering CO2 Emissions with “Next Generation” CO2-Enhanced Oil Recovery (CO2-EOR)”, DOE/NETL-2011/1504, July 2011, prepared by Advanced Resources International, Inc., updated in 2019 by Advanced Resources International, Inc.

Wyoming CO_2 EOR Resource Potential



Wyoming CO_2 EOR Resource Potential					
Oil Field Viability	Fields	OOIP (MMBbl)	Oil Recovery (MMBbl)	Purchased CO_2 (Bcf)	Purchased CO_2 (MMmt)
Technically Viable	89	12,030	2,100	18,430	975
Economically Viable*	60	10,470	1,810	15,960	844

*At an oil price of $60/bbl; CO_2 purchase price of $25/mt; 15% IRR before tax

Wyoming has a total of 89 large oil fields viable for CO_2 EOR. These oil fields have a total of 12 billion barrels of OOIP.

Incremental oil recovery of 2 billion barrels is technically viable with CO_2 EOR, requiring a total of 975 million metric tons of CO_2.

Economically viable CO_2 EOR could recover 1.8 billion barrels of oil, requiring 844 million metric tons of CO_2.

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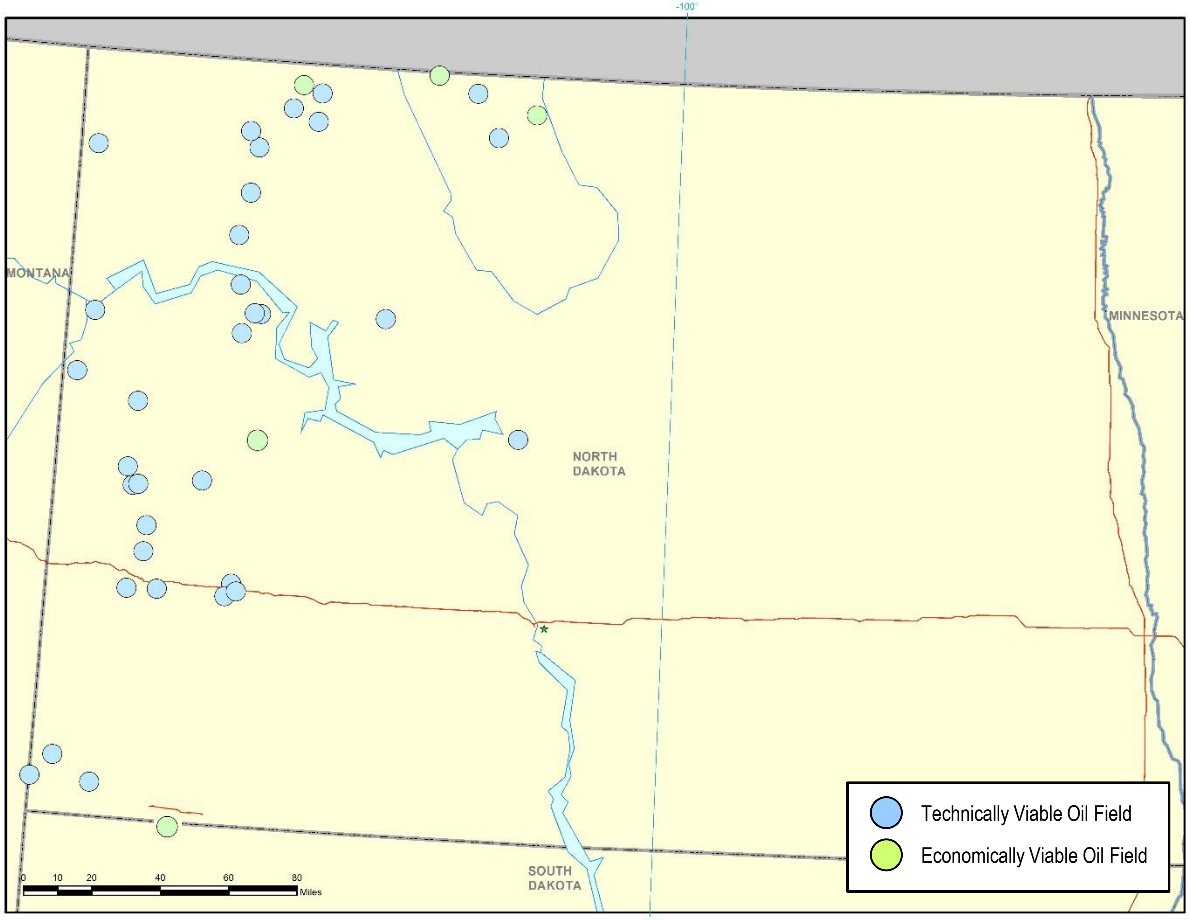
North Dakota CO_2 EOR Resource Potential



North Dakota CO_2 EOR Resource Potential					
Oil Field Viability	Fields	OOIP (MMBbl)	Oil Recovery (MMBbl)	Purchased CO_2 (Bcf)	Purchased CO_2 (MMmt)
Technically Viable	42	3,610	770	6,410	339
Economically Viable*	5	530	110	820	43

*At an oil price of $60/bbl; CO_2 purchase price of $25/mt; 15% IRR before tax

North Dakota has a total of 42 large oil fields viable for CO_2 EOR. These oil fields have a total of 3.6 billion barrels of OOIP.

Incremental oil recovery of 770 million barrels is technically viable with CO_2 EOR, requiring a total of 339 million metric tons of CO_2.

Economically viable CO_2 EOR could recover 110 million barrels of oil, requiring 43 million metric tons of CO_2.

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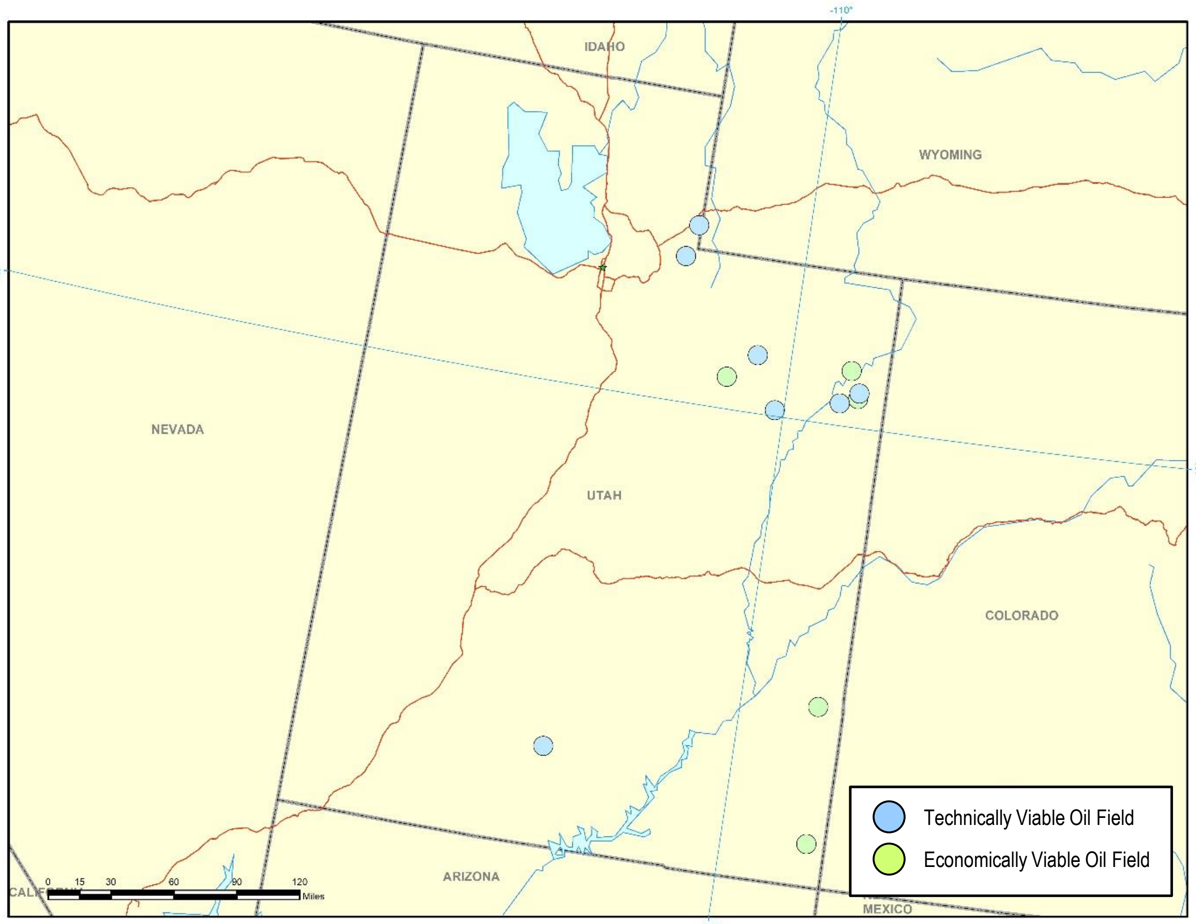
Utah CO_2 EOR Resource Potential



Utah CO_2 EOR Resource Potential					
Oil Field Viability	Fields	OOIP (MMBbl)	Oil Recovery (MMBbl)	Purchased CO_2 (Bcf)	Purchased CO_2 (MMmt)
Technically Viable	17	4,970	980	9,070	480
Economically Viable*	9	2,320	500	3,990	211

*At an oil price of $60/bbl; CO_2 purchase price of $25/mt; 15% IRR before tax

Utah has a total of 17 large oil fields viable for CO_2 EOR. These oil fields have a total of 5 billion barrels of OOIP.

Incremental oil recovery of 980 million barrels is technically viable with CO_2 EOR, requiring a total of 480 million metric tons of CO_2.

Economically viable CO_2 EOR could recover 500 million barrels of oil, requiring 211 million metric tons of CO_2.

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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**

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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 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.

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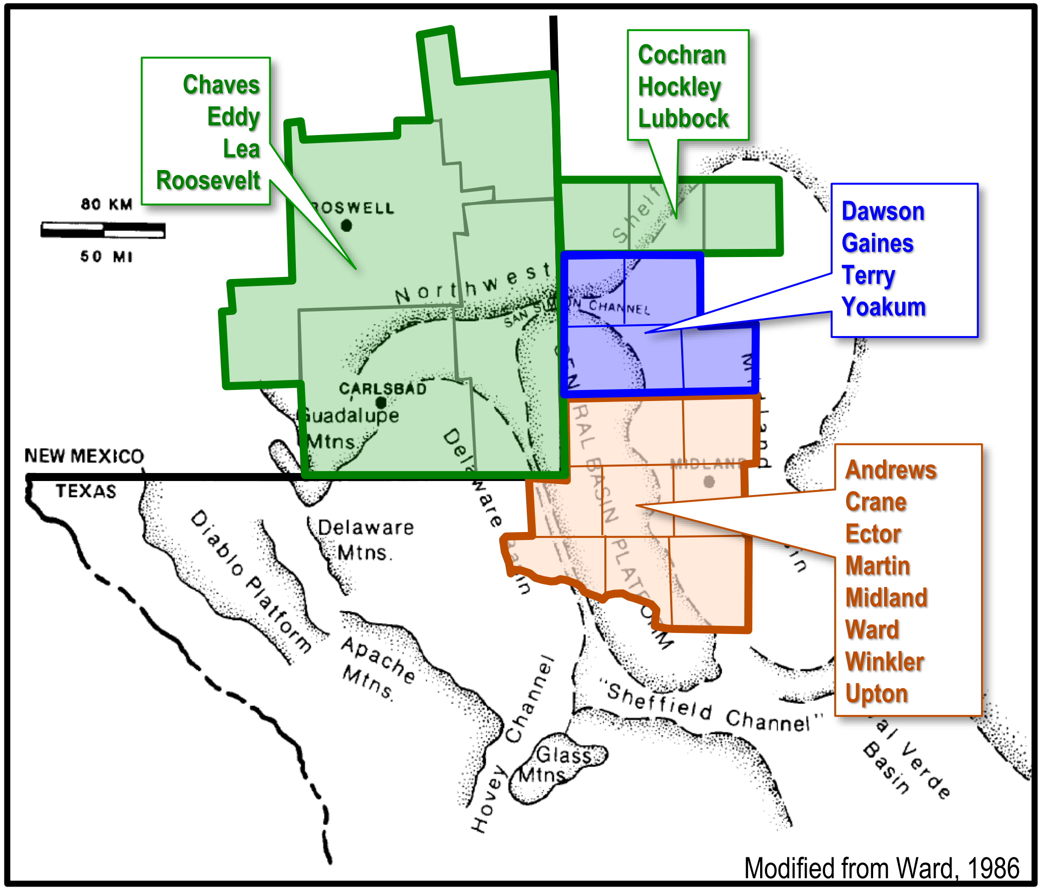
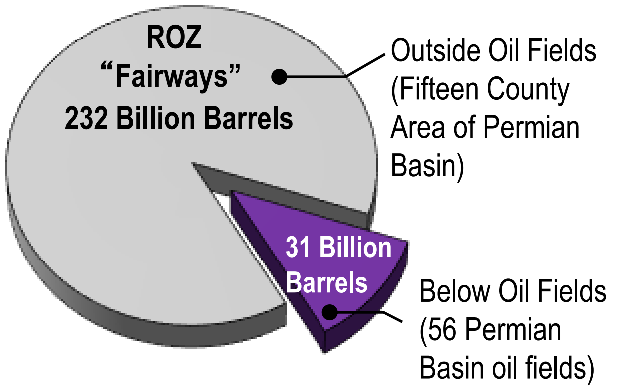
ROZ CO_2 EOR and Demand (Storage) for CO_2

Advanced Resources assessment of the San Andres Fm ROZ resource in the Permian Basin of West Texas and SE New Mexico.



Modified from Ward, 1986

Over 260 Billion Barrels of Oil "Left Behind" in Residual Oil Zones (ROZs)



Source: Advanced Resources International, 2018.

The "ROZ fairway" resource assessment entailed analysis of <u>384 logs</u>, <u>use of core data from 10 locations</u>, and <u>construction of 95 regional cross-sections</u>.

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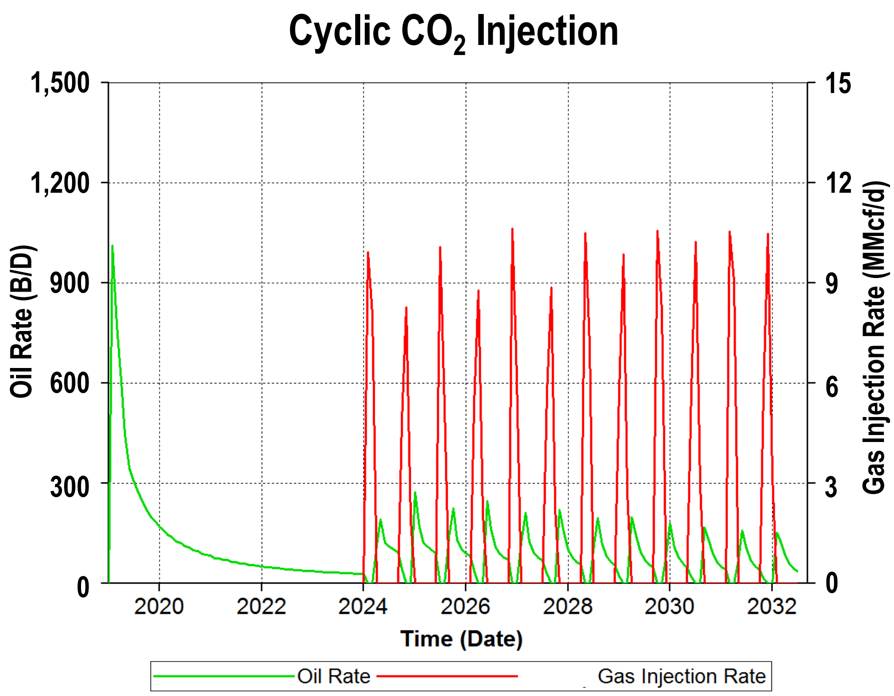
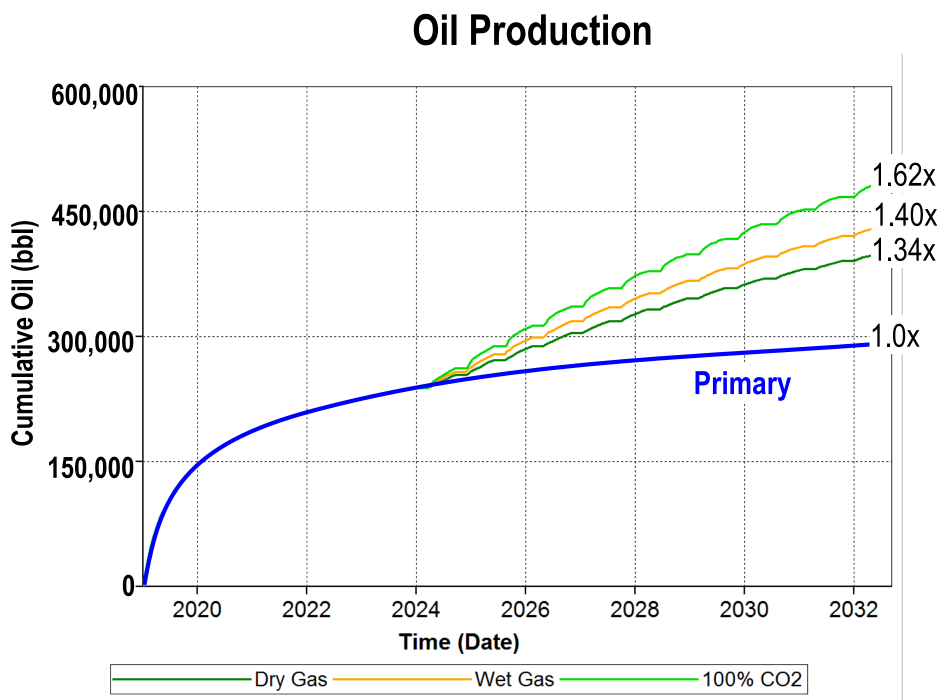
Eagle Ford Shale - Modeling Cyclic CO_2 Injection

Cyclic CO_2 was initiated after five years of primary production. CO_2 was injected at about 10 MMcfd for 2 months (BHP limit of 7,000 psia), followed by 2 weeks of soak, and by 6 months of production.





Source: Advanced Resources International, 2019.

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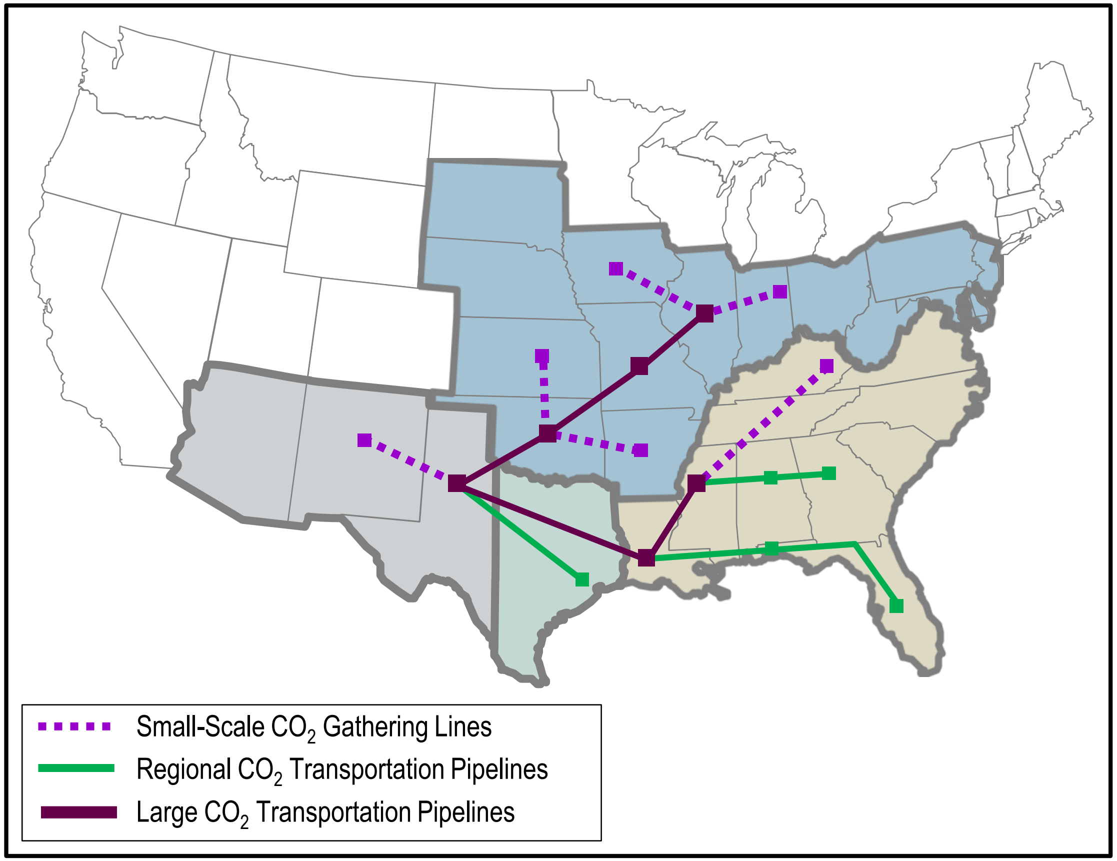
The Missing Link: CO_2 Transportation

Lack of CO_2 transportation between sources and oil fields is the critical "missing link" for producing oil and storing CO_2 with EOR.



Source: Making Carbon a Commodity: The Potential of Carbon Capture RD&D (analysis by Advanced Resources International, 2018). Sponsored by the Carbon Utilization Research Council and ClearPath Foundation (2018).

The study – **"Making Carbon a Commodity"** – proposed a comprehensive U.S. CO_2 pipeline system linking CO_2 captured from power plants with oil fields.

In Scenario #1,* the pipeline system would transport about 450 MMmt of CO_2 in Year 2040 and 950 MMmt of CO_2 in Year 2050.

*Scenario #1 represented the most aggressive CO_2 capture outlook for new coal- and gas-fueled power plants.

"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 latest 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.

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Concluding Observations

- **The opportunity for productively using (and storing) CO_2 for EOR (the "size of the prize") is vast – conventional onshore and offshore oil fields, the ROZ, and shale oil formations.**
- With a comprehensive CO_2 pipeline system and stronger incentives for CO_2 capture, in our view, CO_2 EOR could use (and store) 500 million metric tons annually in the 2040 to 2050 time period.
- While the 45Q tax credit provides a valuable first step, to achieve this, extending the number of years of eligibility, and providing support for 1st of a kind (FOAK) projects will be required.
- Doing so would enable large volumes of CO_2 to be cost-effectively captured from retrofit of coal-fueled power plants and from installation of CO_2 capture on new NGCC power plants.*

*Esposito, R.A., Kuuskraa, V.A., Rossman, C.G., and M.M. Corser, 2019, Reconsidering CCS in the US fossil-fuel fired electricity industry under section 45Q tax credits, Wiley Publications, Greenhouse Gases: Science and Technology, Modeling and Analysis, https://onlinelibrary.wiley.com/doi/full/10.1002/ghg.1925, 11 September 2019.

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Advanced Resources International, Inc.

Our history of services:

Since 1971*, we have added value to hundreds of oil and gas E&P projects in the U.S. and in over 30 countries, from Australia to Zimbabwe.

Our approach integrates geology and geophysics, petroleum engineering, and strategic and economic analysis.

We specialize in enhanced oil and gas recovery and the geological storage of CO_2.

*From 1971 – 1987, the company was called Lewin & Associates; from 1987 – 1991, the company was a subsidiary of ICF Consulting/Kaiser Engineers; since 1991, the company is stand alone and called Advanced Resources International, Inc.

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equinor
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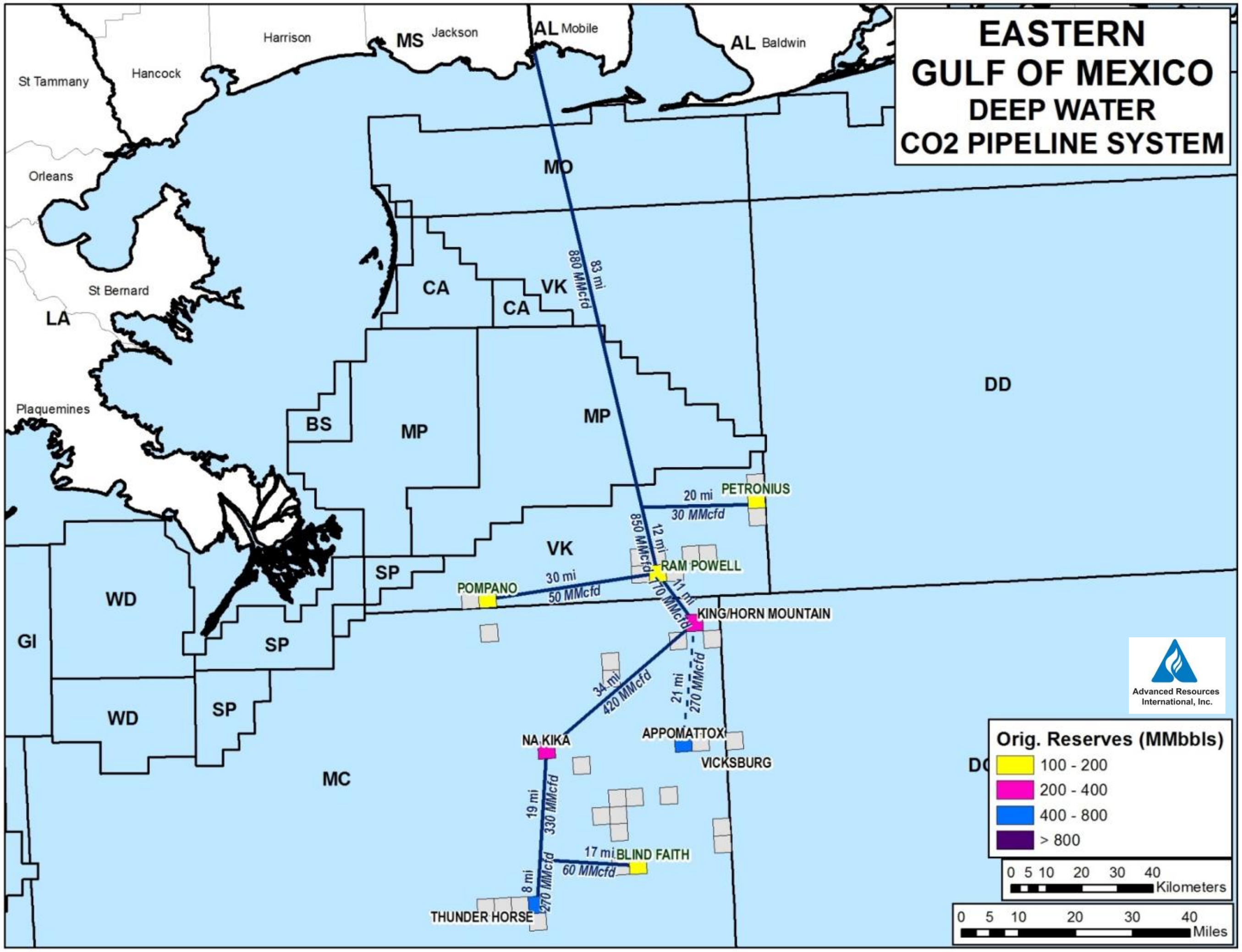
Taking CO_2 EOR to the Deepwater Offshore GOM



Source: Advanced Resources International, 2018

Advanced Resources prepared a conceptual design for a Deepwater Gulf of Mexico CO_2 pipeline system.

The Eastern GOM Deepwater CO_2 Pipeline is a 255-mile system with an initial 83-mile line delivering 880 MMcfd (17 Mmt per year).

Additional large-scale CO_2 pipeline systems are needed to serve East-Central and Central Deepwater GOM.

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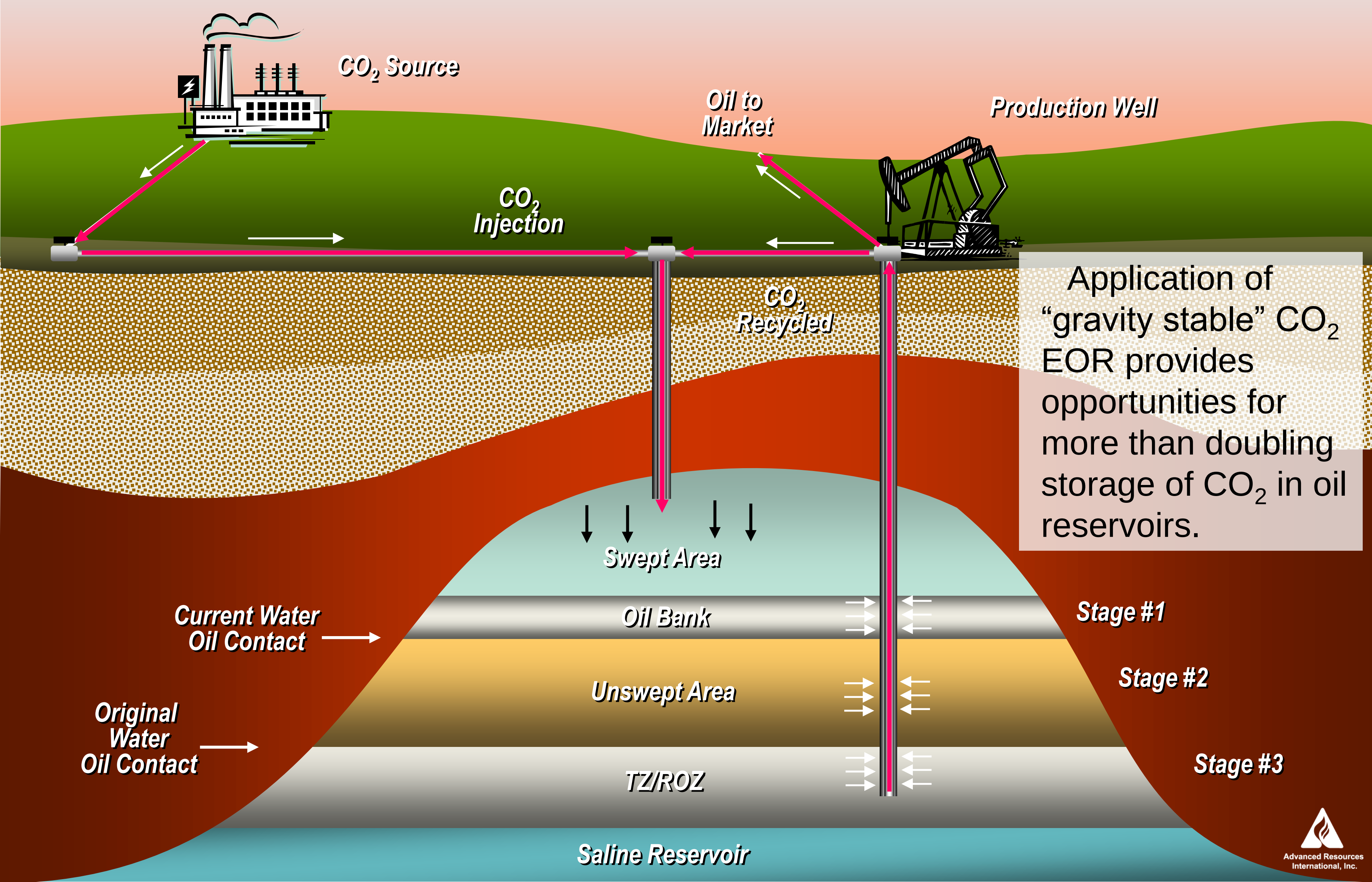
"Next Generation" CO_2 EOR and Storage Technology



Application of "gravity stable" CO_2 EOR provides opportunities for more than doubling storage of CO_2 in oil reservoirs.