Pursuing Lower Carbon Intensity Hydrocarbon Supplies

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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.

Our clients include:

Importance of Carbon Management for the Oil & Gas Industry

Markets and the public are demanding low/net zero carbon energy. Carbon Management will be essential for helping meet these demands by pursuing the following options, among others:

Source CAPP, 2017.

- Low carbon intensity domestic oil supplies with injection and storage of CO_2.
- Use of natural gas/CCUS for power generation
- Use of natural gas/CCUS for “blue” hydrogen as a transportation fuel
- Exporting lower carbon intensity LNG.

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Enabling Consumption of Lower Carbon Intensity Oil

1. **Enabling Consumption of Lower Carbon Intensity Domestic Oil.** US EIA's latest report (AEO 2021) projects that the U.S. will consume nearly 20 million barrels per day (MMB/D) of petroleum and other liquids in Year 2030, essentially the same as today.

   Even assuming new initiatives reduce petroleum demand, one of the key goals of Carbon Management will be to reduce the CO_2 footprint (carbon intensity) of oil consumption from imports and domestic oil fields, as much as possible.

2. **Displacing Higher Carbon Intensity Oil Imports.** Given that domestic oil consumption (demand) would be essentially the same, the incremental production of lower carbon intensity oil by injection and storage of CO_2 would displace an equivalent volume of higher carbon intensity oil imports, helping reduce CO_2 emissions.

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Displacing Imports of Higher Carbon Intensity Oil

Life-cycle analysis (LCA) shows that the carbon intensity of one barrel of oil produced by injection of CO_2 is 87 g CO_2/MJ, consisting of:

- 11 g CO_2/MJ for oil extraction, refining and transportation(1),
- 3 g CO_2/MJ for EOR(2), and
- 73 g CO_2/MJ when consumed.

However, a significant volume of CO_2 can be stored for every barrel of oil produced with injection and storage of CO_2 in hydrocarbon formations, enabling the production of low (and even negative) carbon intensity domestic oil.

Imported oil has a positive carbon intensity of 85 g CO_2/MJ.

1. Masnadi, M.S, et al. “Global carbon intensity of crude oil production.” Science Magazine, Vol. 361, Issue 6405, pp. 851-853. August 2018.
2. Godec, M., Carpenter, S., and Coddington, K., 2016. Evaluation of Technology and Policy Issues Associated with the Storage of Carbon Dioxide via Enhanced Oil Recovery in Determining the Potential for Carbon Negative Oil, prepared for GHGT-13, 14-18 November 2016, Lausanne, Switzerland, Energy Procedia 114 (2017) 6563-6578.

Carbon Intensity of Alternative Sources of Oil Supply (Revise)

Source of Carbon Emissions	Storing CO_2 in Hydrocarbon Basins ($g\ CO_2/MJ$)	Carbon Intensity of Other Oil Sources	
		Conventional Domestic Oil ($g\ CO_2/MJ$)	Imported Oil ($g\ CO_2/MJ$)
Conventional Production (Extraction, Transport, Refining)	11	11	12
EOR Operations	3		
Combustion	73	73	73
CO_2 Storage	(**)		
Total Carbon Intensity	**	**84**	**85**

**To be addressed by this presentation.

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Pathways Toward Producing Low Carbon Intensity Oil

Rather than taking more carbon out of the ground, lower carbon intensity oil produced by injection and storage of CO_2 would displace much higher carbon intensity oil from imports.

This is essentially the same as the installation and use of renewables for providing electricity that displaces higher carbon intensity electricity produced by fossil fuels.

In our presentation, we will discuss three pathways that would enable the production of lower carbon intensity oil by injecting and storing CO_2 into:

- Shale Formations
- Conventional Oil Formations
- Residual Oil Zones

Storing CO_2 In Shale Formations

The US Energy Association/Advanced Resources International (USEA/ARI/EORI) study -- "Increasing CO_2 Storage Options with Injection of CO_2 in US Shales" -- has defined three new, large capacity settings for geologically storing CO_2:

- Niobrara Shale, DJ Basin of Colorado
- Cana-Woodford Shale, Anadarko Basin of Oklahoma
- Mowry Shale, Powder River Basin of Wyoming.

These three shale formations would provide over 4,600 million metric tons (MMmt) of CO_2 storage capacity in areas where CO_2 storage in saline formations is limited.

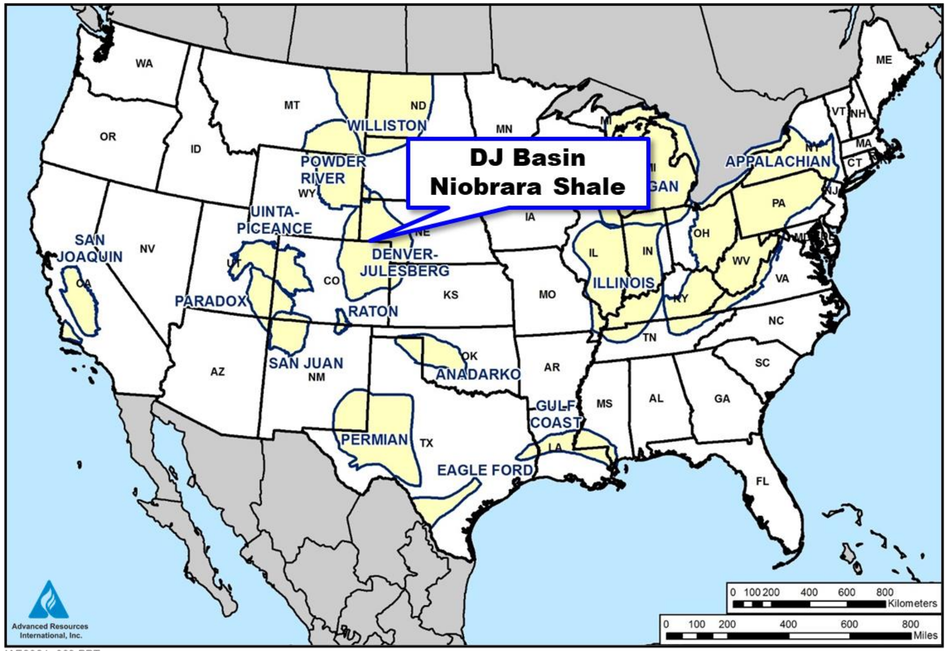
This amount of CO_2 storage is equivalent to removing the CO_2 emissions from over 1 billion passenger vehicles for one year.(1)

1. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Niobrara Shale, Denver-Julesburg (DJ) Basin

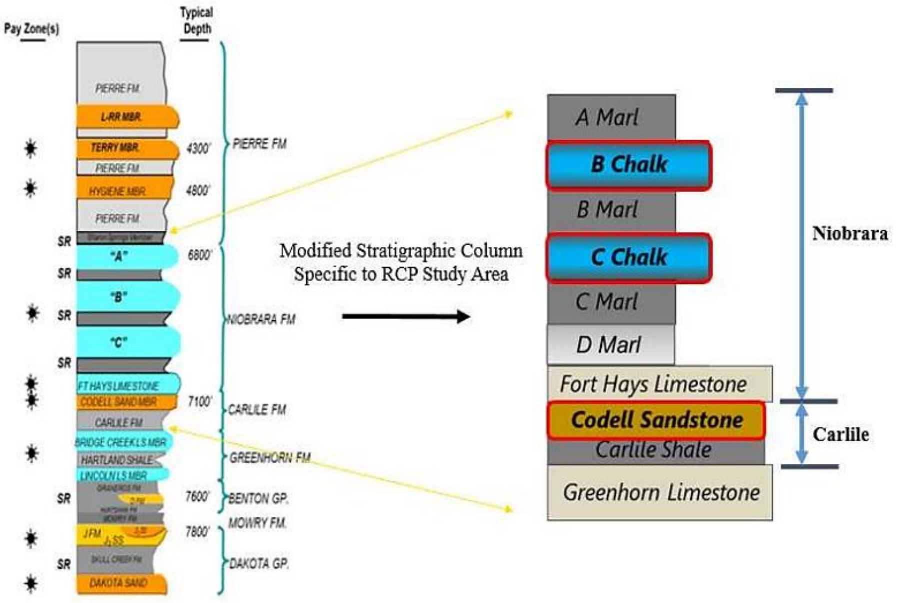
The Niobrara Shale, located in the DJ Basin of Colorado and Wyoming, produces from Cretaceous-age chalks and marls. To date, nearly 10,000 Hz wells have been completed in this shale play.

Location of Map



Source: Advanced Resources International, 2021.

Stratigraphic Column



Ning, Y. 2017. Production Potential of Niobrara and Codell: Integrating Reservoir Simulation with 4D Seismic and Micro seismic Interpretation. Colorado School of Mines.

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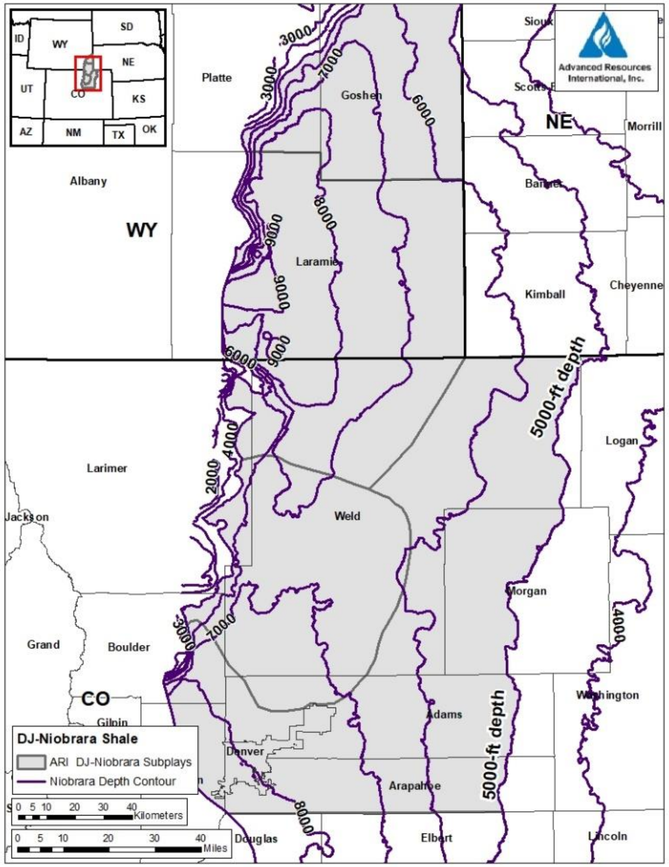
Key Reservoir Properties, DJ-Niobrara

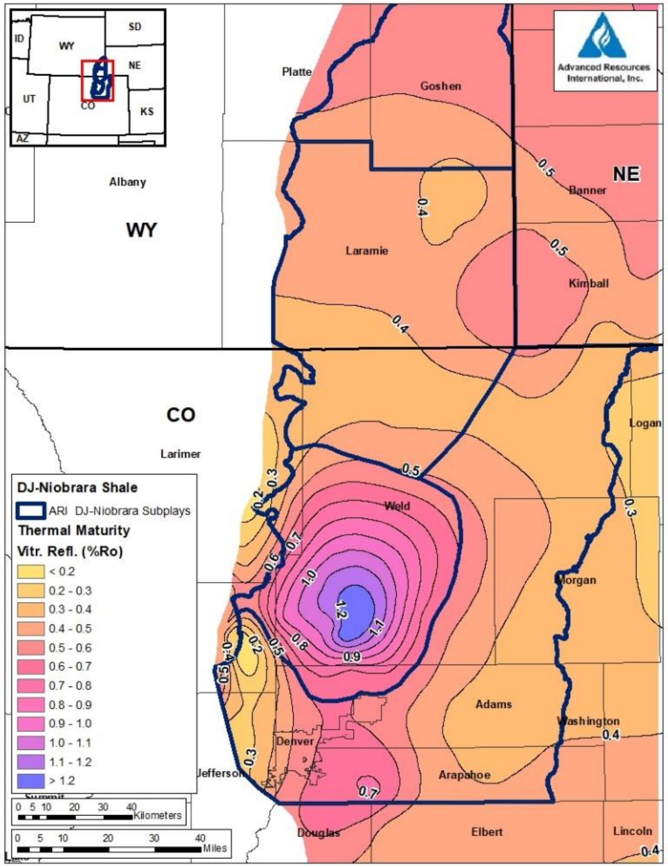
Shale depth, thermal maturity, and other key reservoir properties were used to partition the Niobrara Shale in the DJ Basin into three geologically distinct areas.

Shale Depth



Source: Advanced Resources International, 2021.

Shale Thermal Maturity



Source: Advanced Resources International, 2021.

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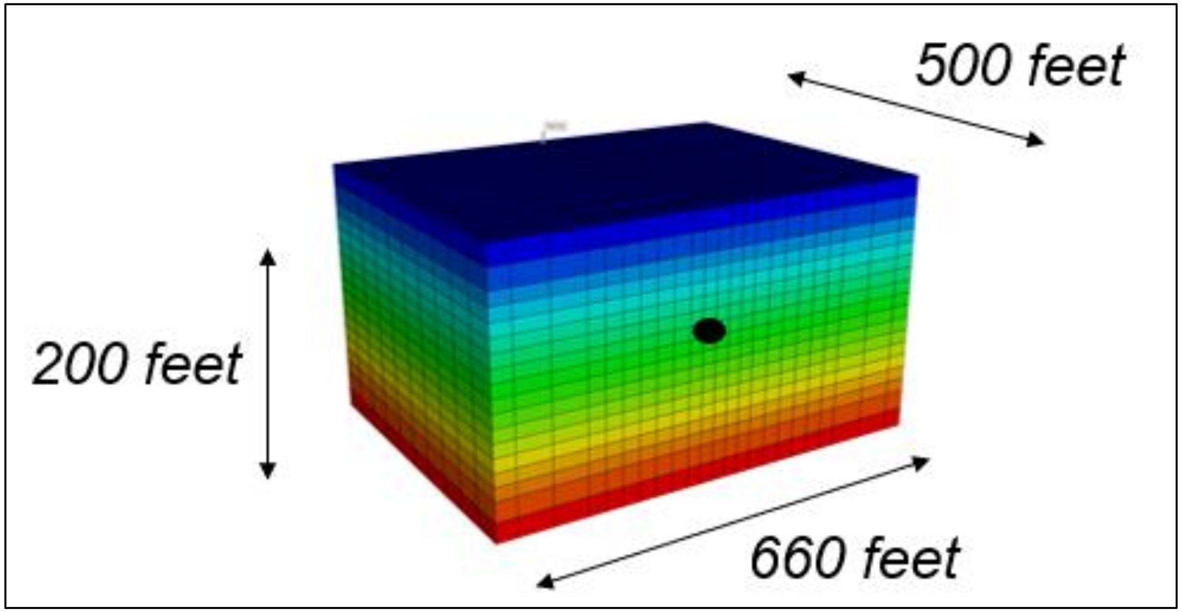
Reservoir Simulation

The Study used The GEM reservoir simulator (from CMG) to history match past production and then evaluate the application of cyclic CO2 injection using history matched reservoir properties and SRV dimensions.

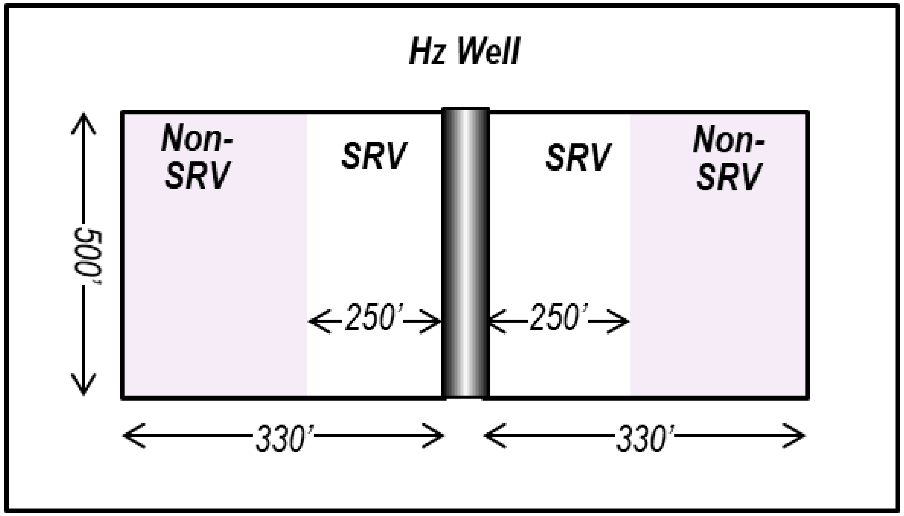
Reservoir Model Used for Evaluating Niobrara Shale "Core" Area (1/17th of Full Well)



Source: Advanced Resources International, 2021.

SRV Dimensions and Properties for History Match of Well Performance During Primary Production

A. SRV Dimensions, Plan View



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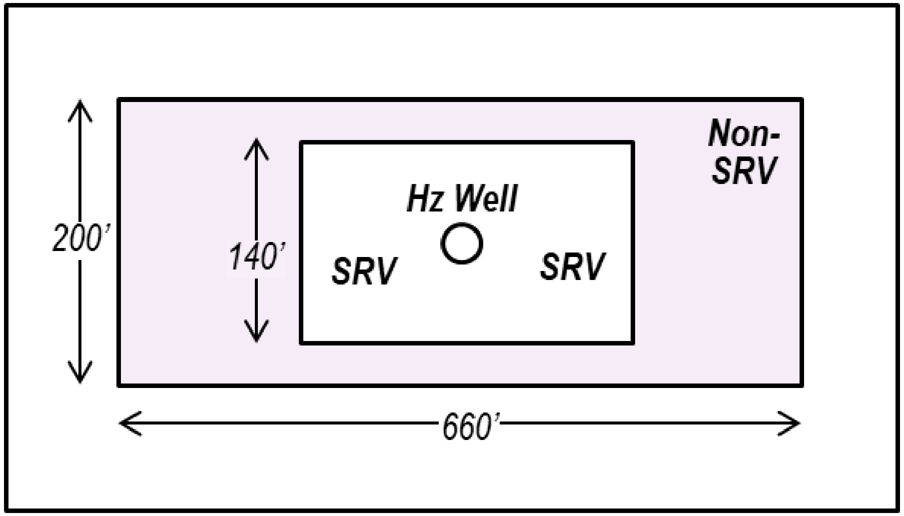
B. SRV Dimensions, Side View



Source: Advanced Resources International, 2021.

SRV and Non-SRV Permeability Used to Match Well Performance

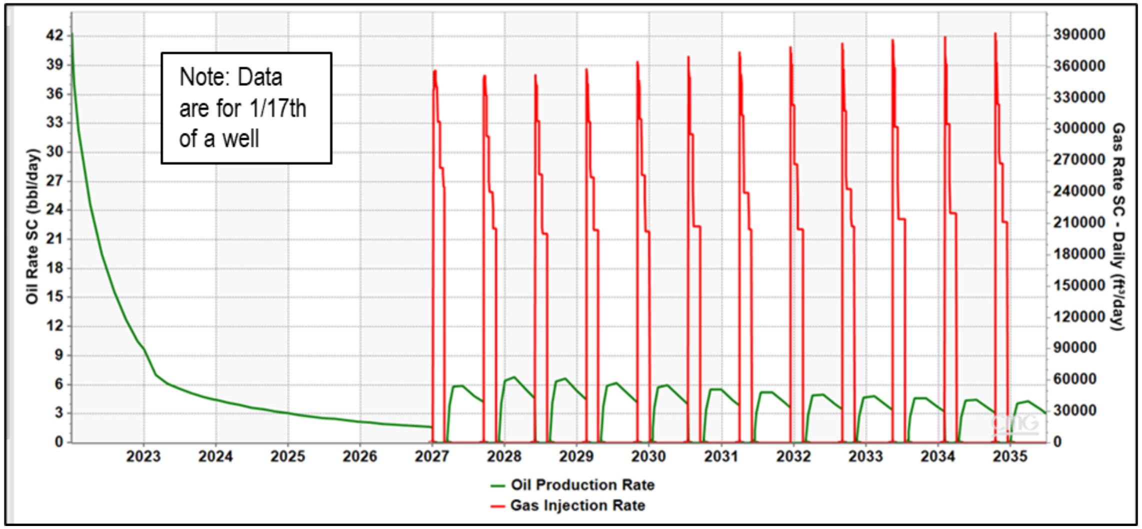
	Chalk	Marl
Non-SRV		
Horizontal	$5.6 * 10^{-3}$ mD	$5.8 * 10^{-5}$ mD
SRV	0.14 mD	0.14 mD

Source: Advanced Resources International, 2021.

Performance of Cyclic CO_2 Injection

Cyclic CO_2 injection was initiated in the Core Area type well after five years of primary production after the well had produced 193,000 barrels, equal to 80% of its estimated ultimate oil recovery (EUR).

Cyclic CO_2 Injection Rates and By-Product Oil Production: 1/17th of Total Well



Source: Advanced Resources International, 2021.

- In cycle one, CO_2 was injected at an average rate of 5,100 Mcfd/well for 2 months (BHP limit of 4,300 psia).
- CO_2 injection was followed by 2-weeks of soak and 6 months of production.
- Eleven additional cycles of CO_2 injection, soak and production followed.
- In the 13th and final cycle, all of the CO_2 produced during the 12th cycle was reinjected and the well was shut in.

Study Findings for the Niobrara Shale

1. **The Study Identified a Large Capacity CO_2 Storage Option.** Cyclic injection of CO_2 into the DJ-Niobrara Shale provides opportunities to store 1,530 million metric tons (MMmt) of CO_2 while producing 3,340 million barrels (MMB) of oil.

2. **The CO_2 Storage Option is Close to Large Point Sources of CO_2.** Establishing a new, large capacity CO_2 storage setting will be important for commercial scale implementation of carbon capture at large, point sources of CO_2 in the Rockies.

3. **The Shale Oil Produced with Cyclic Injection of CO_2 Has Low Carbon Intensity.** The carbon intensity of one barrel of oil produced with cyclic injection of CO_2 is 87 g CO_2/MJ. However, 75 g CO_2/MJ is stored for every barrel of oil produced, enabling this oil to have a carbon intensity of 12 g CO_2/MJ.

Shale Formation/Basin		CO_2 Storage with Shale EOR	Oil Recovery with Shale EOR	Carbon Intensity of Shale EOR*			
		(MMmt)	(MMB)	CO_2/Oil Ratio (mt/B)	Total (g/MJ)	Storage (g/MJ)	Net (g/MJ)
▪	**Niobrara Shale / DJ Basin**	1,530	3,340	0.46	87	(75)	12

*The conversion of metric tons per barrel oil (mt/B) uses 10^6 grams per metric ton (g/mt) and 6,120 Mega Joules per barrel (MJ/B) oil.

CO_2 Storage and Oil Recovery from Application of Cyclic Injection of CO_2: Three Shale Basins

Three Shale Formations / Basins		CO_2 Storage with Shale EOR	Low Carbon Intensity Oil Recovery with Shale EOR	CO_2 Storage with Shale EOR*	
		(MMmt)	(MMB)	(mt/B)	(g/MJ)
▪	Niobrara Shale / DJ Basin	1,530	3,340	0.46	75
▪	Cana-Woodford Shale / Anadarko Basin	960	1,710	0.56	92
▪	Mowry Shale / Powder River Basin	2,145	1,903	1.1	180
Total/Average		**4,635**	**6,953**	**0.67**	**109**

*The conversion of metric tons per barrel oil (mt/B) uses 10^6 grams per metric ton (g/mt) and 6,120 Mega Joules per barrel (MJ/B) oil.

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Low Carbon Intensity Oil from Use of Cyclic Injection of CO_2: Three Shale Basins

Three Shale Formations / Basins		Carbon Intensity of Shale EOR*		
		Total (g/MJ)	Storage (g/MJ)	Net (g/MJ)
▪	Niobrara Shale / DJ Basin	87	(75)	12
▪	Cana-Woodford Shale / Anadarko Basin	87	(92)	(5)
▪	Mowry Shale / Powder River Basin	87	(180)	(93)
	Average	**87**	**(109)**	**(22)**

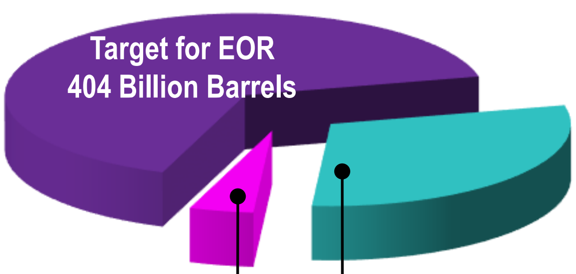
*The conversion of metric tons per barrel oil (mt/B) uses 10^6 grams per metric ton (g/mt) and 6,120 Mega Joules per barrel (MJ/B) oil.

Storing CO_2 with EOR in Conventional Onshore Fields

In the U.S., primary recovery and waterflooding have recovered about a third of the 614 billion barrels of OOIP, leaving behind 404 billion barrels.

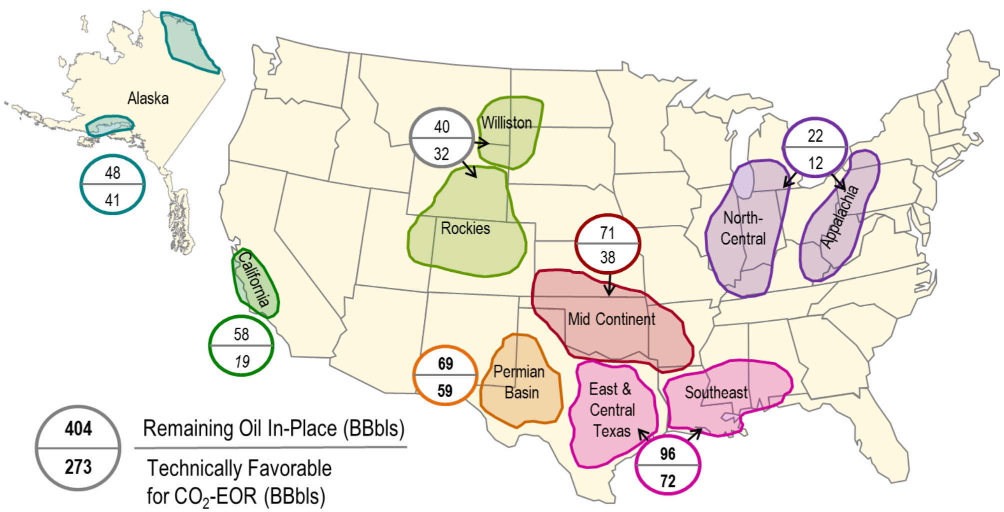
Much of this “left behind oil”, equal to 273 billion barrels, is technically favorable for CO_2 EOR and is widely distributed across the U.S.

Original Oil In-Place: 614 B Barrels
Remaining Oil In-Place: 404 B Barrels



*Does not include “tight” oil production or reserves.
Source: Advanced Resources International, 2015.

Conventional Onshore Domestic Oil Resources Favorable for CO_2-EOR



Source: Advanced Resources International internal analysis, 2016

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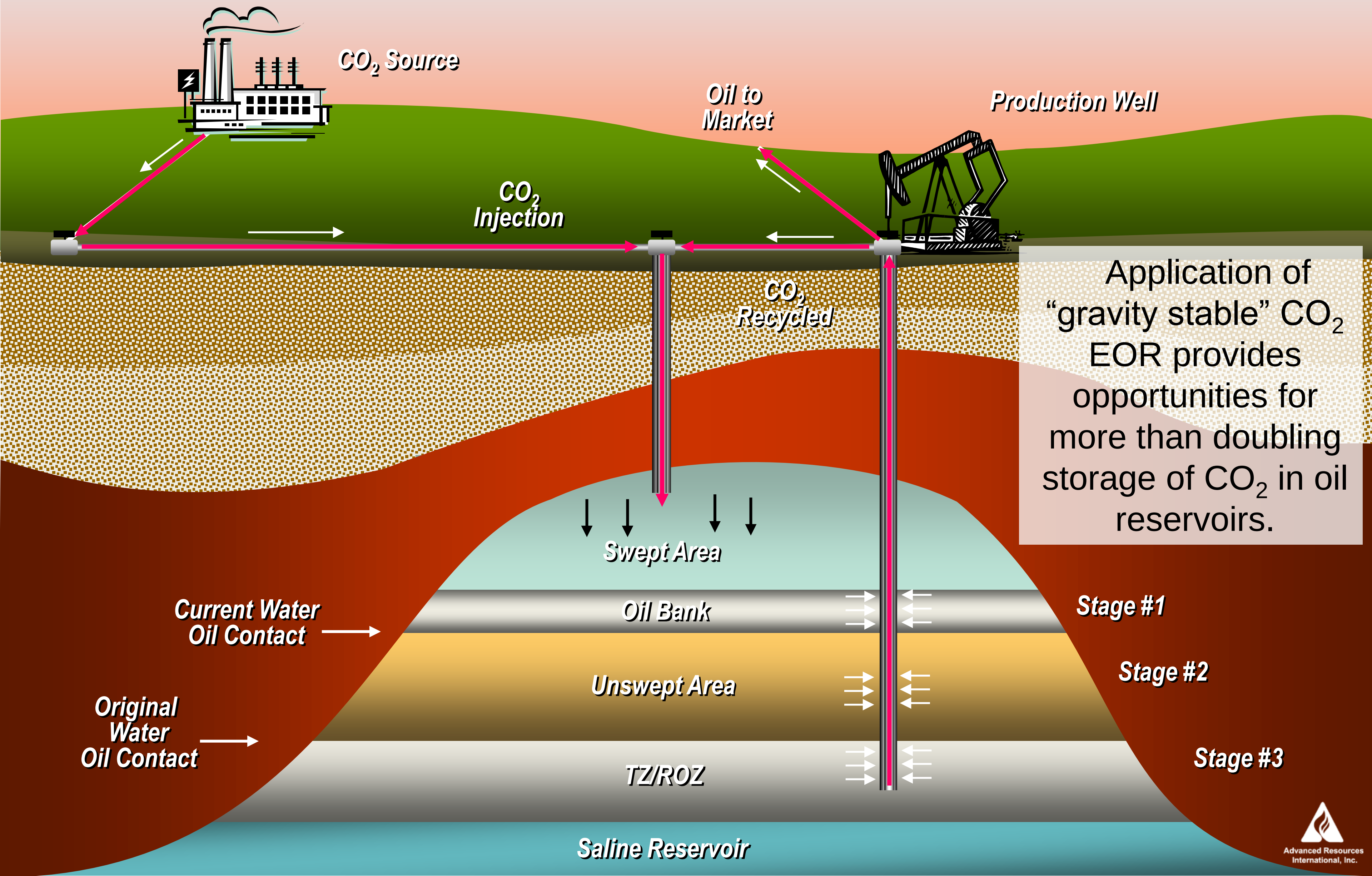
Storing CO_2 with EOR in Conventional Onshore Oil Fields (Revise)

CO_2 EOR could store 18,300 million mt of CO_2 while recovering 38 billion barrels of economically viable domestic oil. With a CO_2 stored to oil produced ratio of 0.48 mt/bbl, the net Carbon Intensity of this oil is 9 g/MJ.

Basin/Area	Economically Recoverable Oil* (Billion bbl)	CO_2 Storage (Million mt)	CO_2 / Oil Ratio (mt bbl)	Carbon Intensity (g/MJ)		
				Total	Storage	Net
Lower-48 Onshore	33	16,000	-			
Alaska	5	2,300	-			
Total	**38**	**18,300**	**0.48**	**87**	**(78)**	**9**

*At an oil price of $60/B (WTI), a CO_2 price of $25 per metric ton, and 15% ROR (before tax).
Source: "Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (CO_2-EOR)", DOE/NETL-2011/1504, July 2011, prepared by Advanced Resources International, Inc., updated in 2019 by Advanced Resources International, Inc.

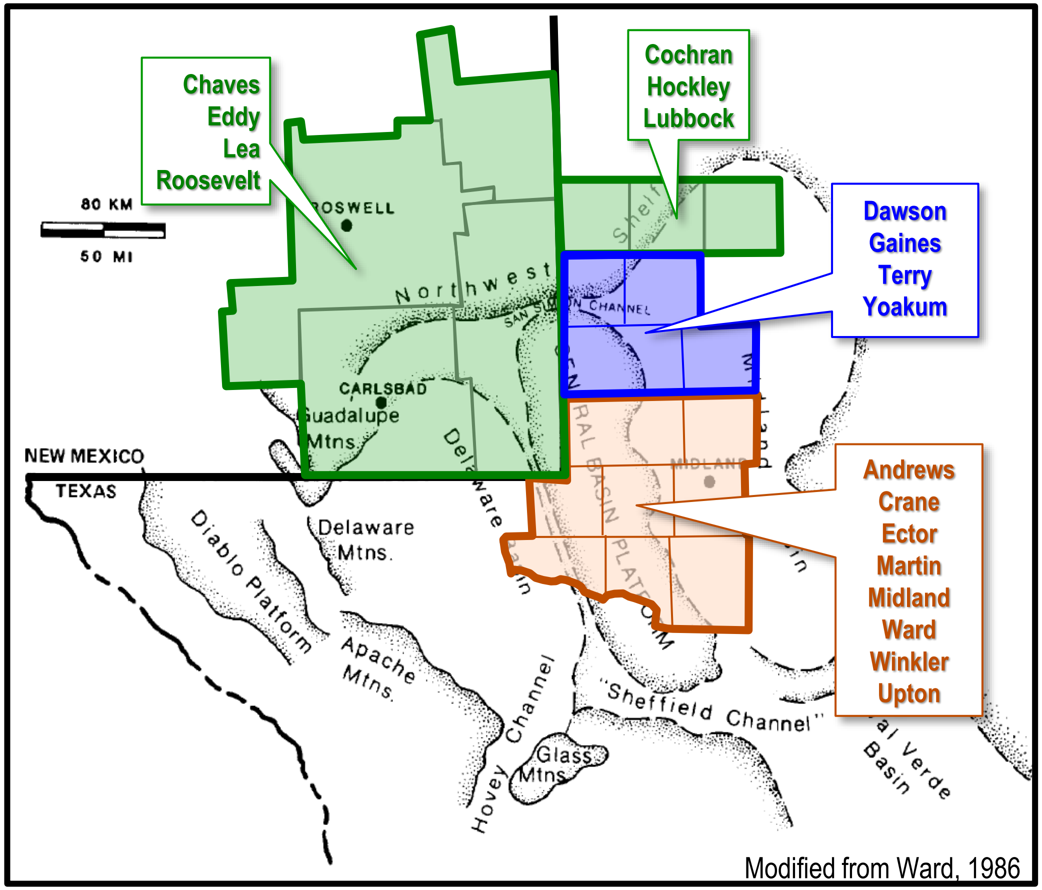
"Next Generation" CO_2 EOR and Storage Technology



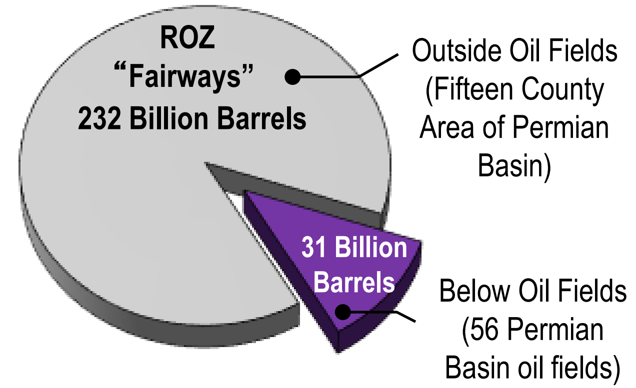
Application of "gravity stable" CO_2 EOR provides opportunities for more than doubling storage of CO_2 in oil reservoirs.

Storing CO_2 with EOR in Residual Oil Zones (ROZs)

The San Andres Fm ROZ in the Permian Basin of Texas and New Mexico holds about 260 billion barrels of "Left Behind" oil.



Modified from Ward, 1986



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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Storing CO_2 with EOR in the San Andres ROZ "Fairway" of the Permian Basin (Revise)

The San Andres ROZ could store 18,400 million mt of CO2 and recover 40 billion barrels of economical domestic oil. With a CO_2 stored to oil recovered ratio of 0.46 mt/bbl, the net carbon Intensity of this oil is 12 g/MJ.

	Economically Recoverable Oil*	CO_2 Storage	CO_2/ Oil Ratio	Carbon Intensity (g/MJ)		
	(Billion Bbls)	(Million mt)	(mt/bbl)	Total	Storage	Net
West Texas	**34**	**15,400**				
▪ 4 County Study [1]	17	8,000				
▪ 8 County Study [2]	15	6,300				
▪ 3 County Study [3]	2	1,100				
New Mexico	**6**	**3,000**				
Total**	**40**	**18,400**	**0.46**	**87**	**(75)**	**12**

*Using $60/B (WTI) oil price, a CO_2 cost of $25/mt, and 10% ROR (after tax). **Totals may not add due to rounding.

1. "Defining an Overlooked Domestic Oil Resource: A Four-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin" prepared by Advanced Resources International for U.S. DOE/NETL, 2016.
2. "San Andres ROZ "Fairway" Resources of the Permian Basin: An Eight-County Resource Assessment", prepared by Advanced Resources International for U.S. DOE/NETL, 2016.
3. "Permian Basin San Andres ROZ Resources Assessment: West Texas and New Mexico" prepared by Advanced Resources International for U.S. DOE/NETL, 2018.

Producing Low Carbon Intensity Oil

Over 40 billion metric tons (Gt) of CO_2 could be stored with enhanced oil recovery technology in a variety of domestic hydrocarbon settings.

	Hydrocarbon Settings	CO_2/Oil Ratio (mt/bbl)	Carbon Intensity (g/MJ)		
			Total	Storage	Net
1	Three Shale Oil Formations [1]	0.67	87	(109)	(22)
2	Conventional Onshore Oil Fields [2]	0.53	87	(78)	9
3	Residual Oil Zones [3]	0.63	87	(75)	12

All three settings can provide low (some even negative) carbon intensity domestic oil when evaluated using Life Cycle Analysis (LCA).

1. "The "Increasing CO2 Storage Options with Injection of CO2 in Shales," USEA Webinar presented by Vello Kuuskraa (ARI) and Graeme Finley, (EORI), November 16, 2021.
2. "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.
3. A series of reports addressing the "San Andres ROZ Fairway Resources of the Permian Basin" prepared by Advanced Resources International for U.S. DOE, 2016-2018.

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