The Growing CO_2-EOR Oil Recovery and CO_2 Utilization "Prize"

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Opening Keynote Address

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Introduction

Utilizing and Storing CO_2 with EOR is Finally Gaining Traction. After nearly a decade of analyses and presentations, utilizing and storing anthropogenic (industrial) CO_2 with enhanced oil recovery is finally “gaining traction”.

Overcoming the “Niche Opportunity” Mindset. However, many still believe that CO_2 utilization and storage will play only a small, “niche” role.

Our view, based on detailed field-level studies, is that the size of the oil recovery and CO_2 storage potential offered by CO_2-EOR is “quite large and growing”, particularly as we begin to recognize its full potential.

The Billion Metric Ton CO_2 Anthropogenic Utilization and Storage “Prize.” Based on our latest research, the currently active and estimated to come on-line (by 2020) CO_2-EOR projects would provide nearly a billion metric tons of anthropogenic CO_2 utilization and storage by year 2030.

Onshore, Lower-48 CO_2-EOR and CO_2 Utilization Prize

Last year, as part of my "Size of the Prize" talk, I discussed the oil recovery and CO_2 demand (utilization/storage) potential from applying CO_2 enhanced oil recovery (CO_2-EOR) to Lower-48 onshore oil fields.

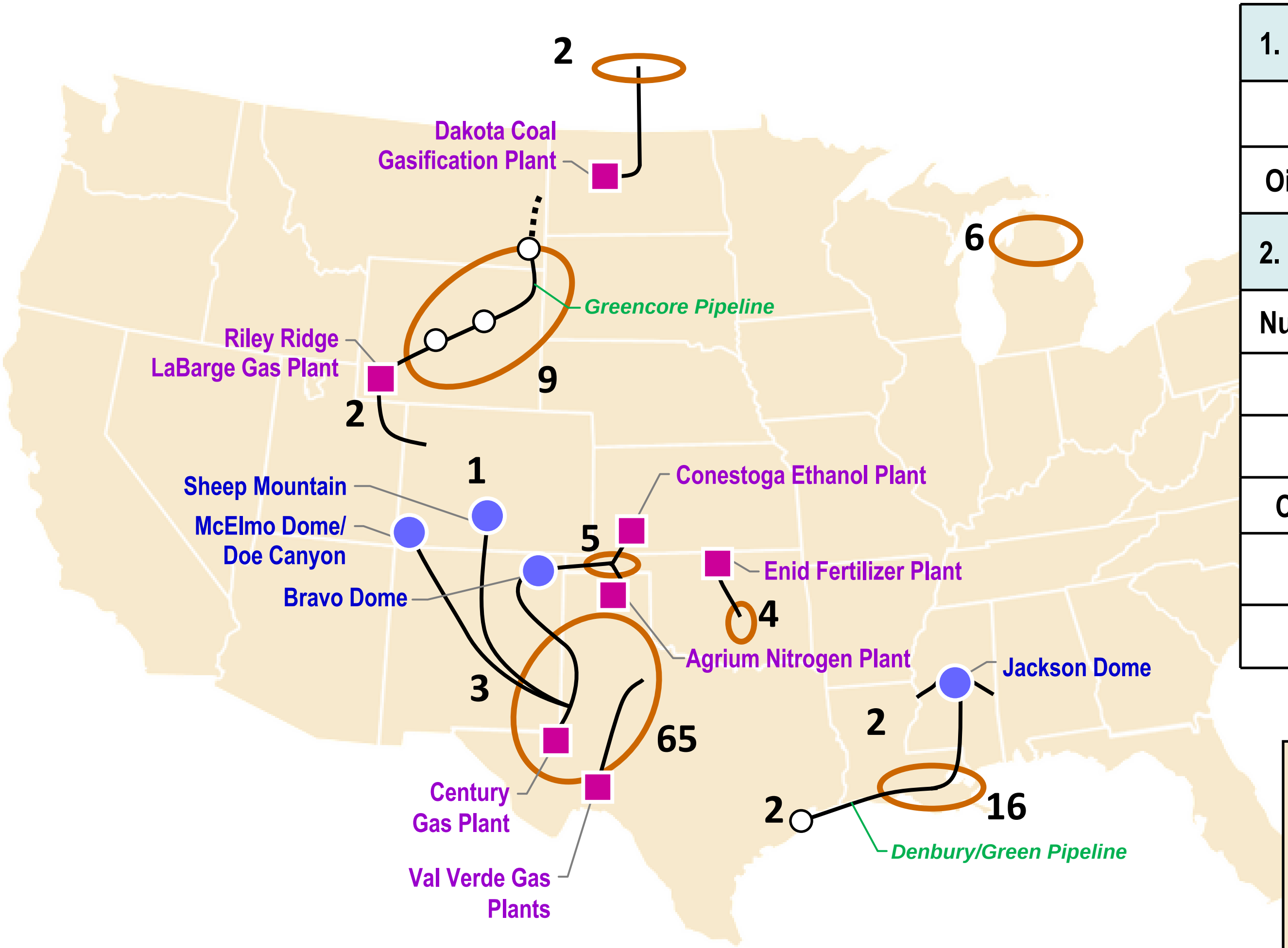
A recent update to that analysis shows that the economically viable* oil recovery and CO_2 demand potentials remain large.

CO_2-EOR Technology Status	Economic* Oil Recovery/CO_2 Demand - - Lower-48 Onshore		
	Economic Oil Fields	**Crude Oil**	**CO_2 Demand****
	(No. of Fields)	(Billion Barrels)	(Gt)
Current Technology	458	19.0	7.5
"Next Generation" Technology***	948	59.6	15.2

*At $90/B oil price, $40/mt CO_2 price, and 20% (BT) ROR. **Includes 2.7 Gt of natural CO_2 Supply.

***Detailed discussion of "next generation" CO_2-EOR technology is available on http://www.netl.doe.gov/: (1) "Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (CO_2-EOR)", DOE/NETL-2011/1504 , report (June 2011) and (2) "An In-Depth Look at "Next Generation" CO_2 EOR Technology" , presentation, (September 2013).

Current CO_2-EOR Operations and CO_2 Sources (2012)

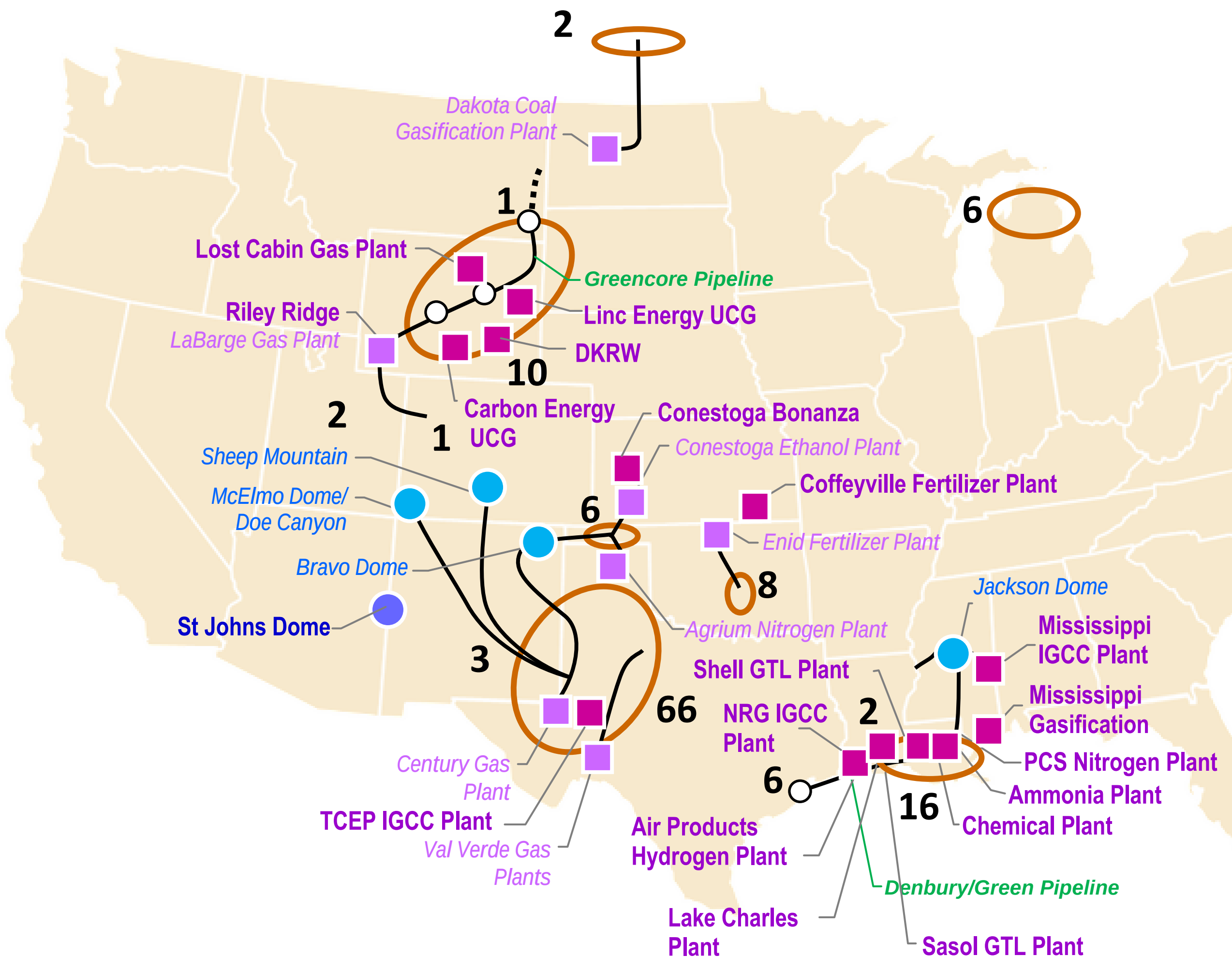


1. Oil Production (2012)	
CO_2-EOR Projects	117
Oil Production (MB/D)	282
2. CO_2 Supplies (2012)	
Number of Sources	12
Natural	*5*
Anthropogenic	*7*
CO_2 Supply (MMcfd)	3,100
Natural	*2,520*
Anthropogenic	*580*

117	Number of CO_2-EOR Projects
●	Natural CO_2 Source
■	Industrial CO_2 Source
—	CO_2 Pipeline
▪▪▪▪▪▪▪	CO_2 Proposed Pipeline

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2012 and other sources.

Projected CO_2-EOR Operations and CO_2 Sources (2020)



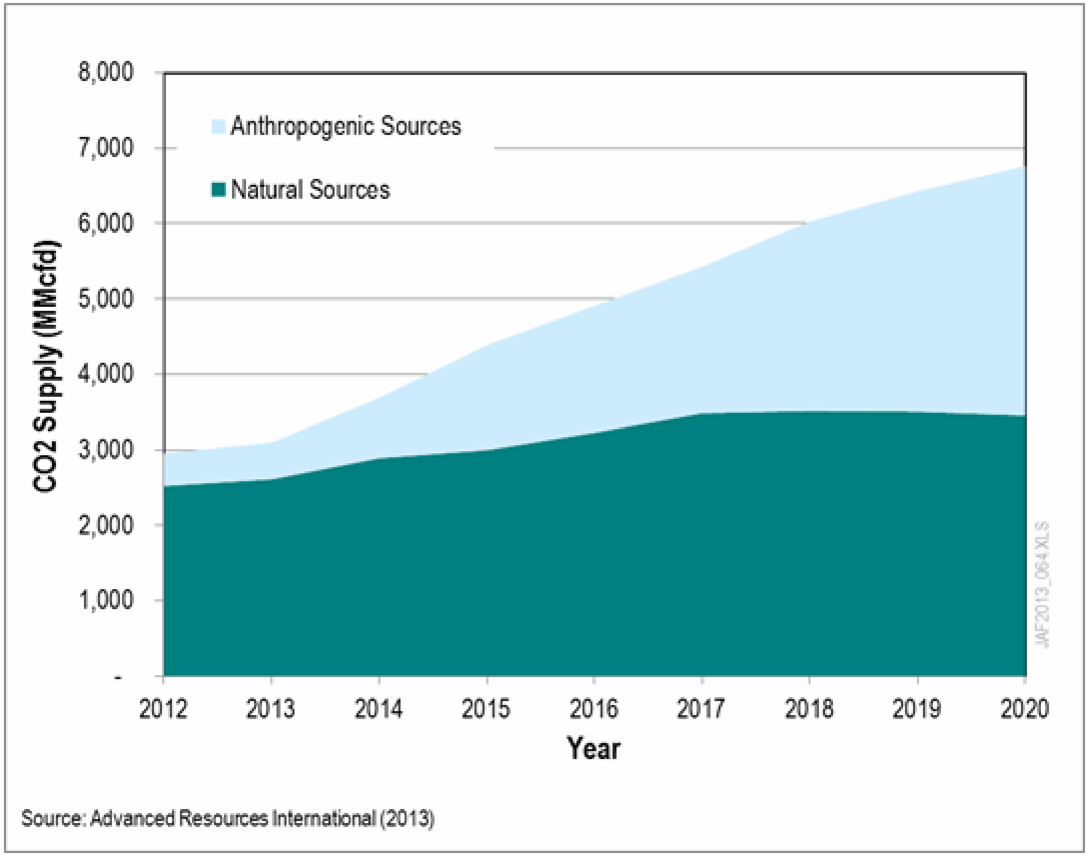
1. Oil Production (2020)	
CO_2-EOR Projects	129
Oil Production (MB/D)	653
2. CO_2 Supplies (2020)	
Number of Sources	31
Natural	*6*
Anthropogenic	*25*
CO_2 Supply (MMcfd)	6,910
Natural	*3,450*
Anthropogenic	*3,460*

129	Number of CO_2-EOR Projects
●	Natural CO_2 Source
■	Industrial CO_2 Source
―	CO_2 Pipeline
▪▪▪▪▪▪▪	CO_2 Proposed Pipeline

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2012 and other sources.

Rapidly Increasing Utilization and Storage of Anthropogenic CO_2 with EOR

CO_2 Supply by Source Type (MMcfd)



Source: Advanced Resources International (2013)

As part of a recent study for U.S. DOE/NETL, Advanced Resources tabulated the announced new sources of CO_2 supply scheduled to come on-line by 2020.

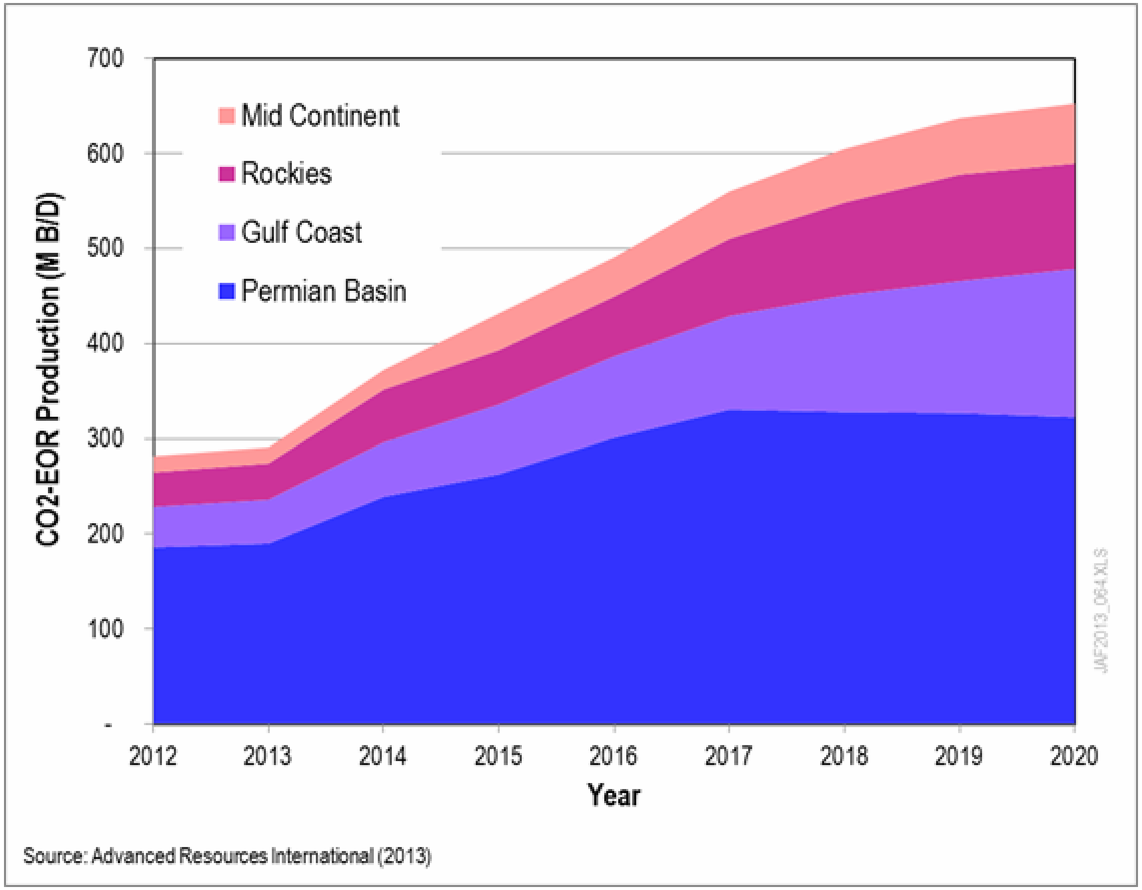
- Expansion of natural sources (St. Johns, Doe Canyon, Jackson Dome, etc.)
- Installation of CO_2 capture on industrial plants (Air Products hydrogen, Coffeyville fertilizer, Lost Cabin gas processing, Kemper Co. IGCC, etc.)

As such, we envision significant growth in CO_2 supplies for EOR:

- 4.4 Bcfd by 2015
- 6.8 Bcfd by 2020

Near-Term Outlook for Oil Production from CO_2-EOR

CO_2–EOR Production by Region (MB/D)



Source: Advanced Resources International (2013)

Increased CO_2 supplies are enabling industry to launch new CO_2-EOR projects and expand existing CO_2 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_2 floods will drive significant growth in near-term CO_2-EOR based oil production:

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

The Billion Metric Ton Anthropogenic CO_2 Utilization and Storage "Prize"

The availability and utilization of new/expanded industrial sources of CO_2 by the EOR industry would provide:

- Storage of at least a billion metric tons of anthropogenic CO_2 by year 2030 (from existing and announced projects only).
- This is a conservative estimate as it does not include the numerous new announced petrochemical plants not yet linked to CO_2-EOR.

The "billion metric tons" of anthropogenic CO_2 utilized (stored) by 2030 is only a small fraction (±10%) of the economically viable long-term, Lower-48 onshore EOR demand for CO_2.

New CO_2-EOR Opportunities and Challenges

In addition to Lower-48 onshore "conventional" oil fields, numerous other reservoir settings and "unconventional" resources have demand for CO_2:

- CO_2-EOR for Offshore Gulf of Mexico and Alaska
- CO_2-EOR for Residual Oil Zones and Shale Oil

These other reservoir settings and resources offer opportunities for significantly increasing oil recovery and CO_2 utilization.

However, they also present major technical challenges that need to be addressed, if we are to realize these opportunities.

Offshore CO_2-EOR Offers Significant Benefits

Use of CO_2-EOR in GOM OCS would provide numerous benefits:*

- Increased domestic oil production;
- Market for CO_2 emissions captured from Gulf Coast power and industrial plants;
- Access and secure locations for storing CO_2, away from populated areas;
- Clear surface and mineral rights for storage sites;
- Reduced risks to underground sources of drinking water;
- Utilization of existing corridors and oil and gas infrastructure; and
- Potentially more favorable regulations and incentives.

*J.T. Litynski et al., (2011); citing extensively Schrag, D., Storage of Carbon Dioxide in Offshore Sediments. Science 325, 1658, DOE: 10.1126/science.1175770, 2009.

Offshore Gulf of Mexico

Recently completed work by Advanced Resources for U.S. DOE/NETL shows that significant volumes of oil are "stranded" in maturing shallow and deep water oil fields in the Gulf of Mexico.

In addition, a host of newly discovered, large deep water oil fields are coming on-line, steadily increasing the size of the offshore oil resource base.

CO_2-EOR Technology Status	**Economic* Oil Recovery/CO_2 Demand - - Offshore Gulf of Mexico**		
	Economic Fields**	**Crude Oil**	**CO_2 Demand**
	(No. of Fields)	(Billion Barrels)	(Gt)
Current Technology	18	0.8	0.3
"Next Generation" Technology***	81	14.9	3.9

*At $90/B oil price, $50/mt CO_2 price, and 20% (BT) ROR.

**The offshore oil fields hold multiple oil reservoirs.

***Discussion of "next generation" offshore CO_2-EOR technologies is available in the Advanced Resources October, 2013 report prepared for U.S. DOE/NETL entitled "CO_2-EOR Offshore Resource Assessment" (due for publication).

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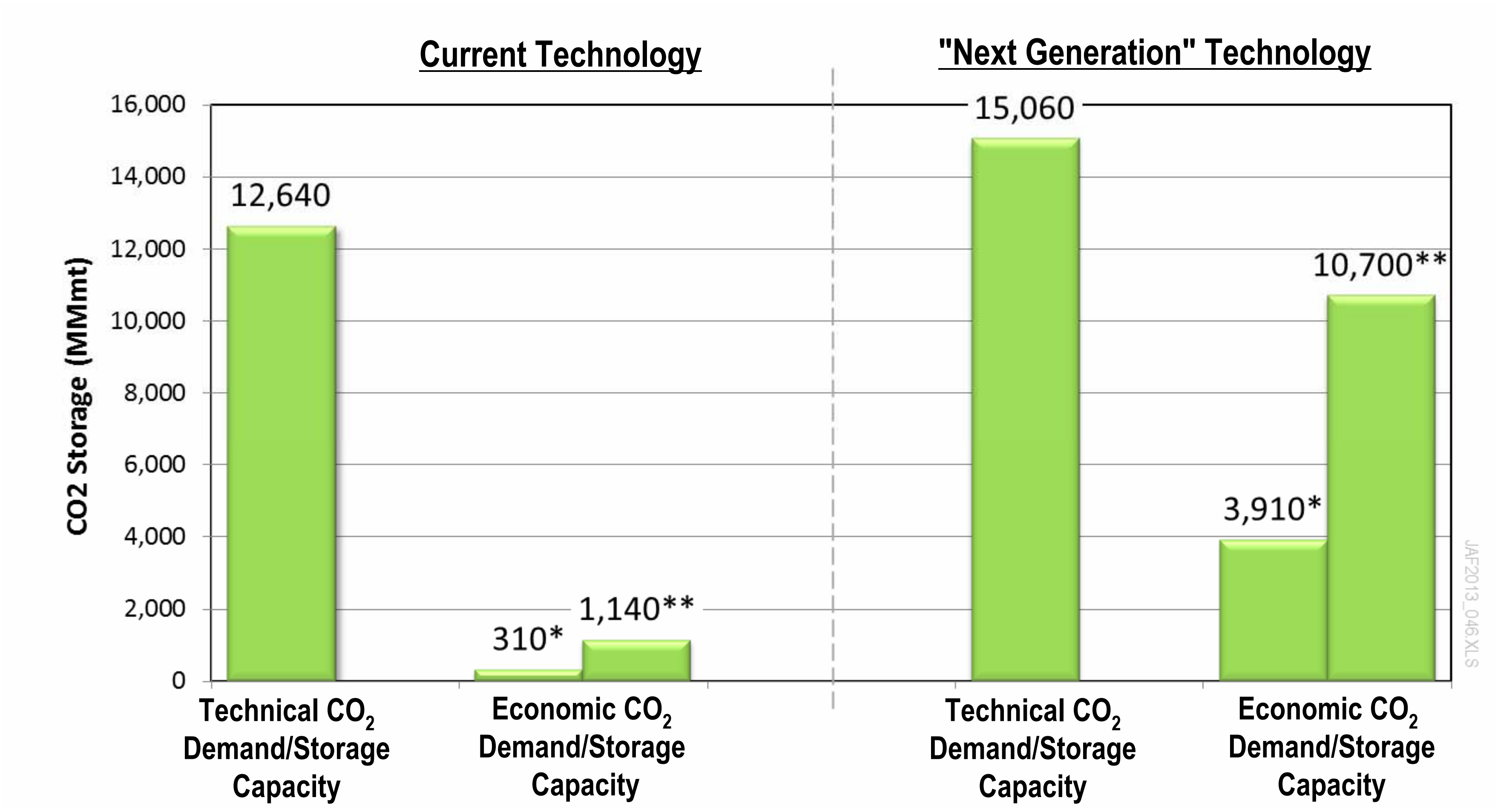
Higher Oil Prices Would Significantly Expand Offshore Gulf of Mexico’s CO_2 Utilization/Storage Potential



Source: Advanced Resources October 2013 report prepared for U.S. DOE NETL entitled “CO_2-EOR Offshore Resource Assessment” (due for publication).

* @ \$90/B Oil Price and \$50/mt CO_2 Cost; ** @ \$135/B Oil Price and \$70/mt CO_2 Cost.

Alaska

With the approval of LNG exports from Alaska, significant volumes of by-product CO_2 supplies will become available from the Prudhoe Bay oil field’s gas cap. As such, the potential for applying CO_2 enhanced oil recovery in Alaska’s oil field would become viable.

Our recent study shows that Alaska’s oil fields offer attractive CO_2-EOR and CO_2 utilization potential.

CO_2-EOR Technology Status	**Economic* Oil Recovery/CO_2 Demand - - Alaska**		
	Economic Fields	**Crude Oil**	**CO_2 Demand**
	(No. of Fields)	(Billion Barrels)	(Gt)
Current Technology	14	5.1	3.1
“Next Generation” Technology	23	10.9	4.4

*At $90/B oil price, $40/mt CO_2 price, and 20% (BT) ROR.

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The Residual Oil Zone

In a series of reports and presentations, Steve Melzer convincingly articulates the origins and presence of oil in residual oil zones:*

- Below existing oil fields in ROZ intervals,
- Beyond existing oil fields in numerous ROZ “fairways”.

My task today is to take the next step in assessing the ROZ resource by addressing two questions:

- *How much of the ROZ resource below existing oil fields is recoverable?*
- *What do we know about the size of the ROZ “fairway” resource?*

*SP2 102964, “The Origin and Resource Potential of Residual Oil Zones”, L.S. Melzer, G.J. Koperna, and V.A. Kuuskraa, 2006.

Technically Recoverable ROZ Resources Below Existing Oil Fields

Advanced Resources estimates that 16 billion barrels of the 42 billion barrel ROZ resource below 88 large existing oil fields is technically recoverable, creating a market for about 7 Gt of CO_2.

Basin	Technically Recoverable ROZ Oil/CO_2 Demand - - Below Existing Oil Fields			
	Assessed Fields	ROZ OIP	Technically Recoverable*	
			Crude Oil	CO_2 Demand
	(No. of Fields)	(Billion Barrels)	(Billion Barrels)	(Gt)
Permian[1]	55	30.7	11.9	~5
Big Horn[2]	13	4.4	1.1	0.5
Williston[3]	20	6.8	3.3	1.5

*With current CO_2-EOR technology.

Sources:

1.“Technical Oil Recovery Potential From Residual Oil Zones: Permian Basin” report prepared by Advanced Resources International for U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, February 2006.

2.“Technical Oil Recovery Potential From Residual Oil Zones: Big Horn Basin” report prepared by Advanced Resources International for U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, February 2006.

3.“Technical Oil Recovery Potential From Residual Oil Zones: Williston Basin” report prepared by Advanced Resources International for U.S. Department of Energy, Office of Fossil Energy, Office of Oil and Natural Gas, February 2006.

Residual Oil Zone "Fairways"

Research Sponsored by
The Research Partnership to Secure Energy for America

The ROZ "Fairway Prize"

The Permian Basin ROZ "Fairway" map was prepared by Steve Melzer.

Our "quick look" indicates that ROZ "fairways" cover an area at least three times larger than the area covered by the 55 Permian Basin oil fields with below main pay zone ROZ resources.

However, additional work is required to establish the size, recoverability, economic feasibility and CO_2 requirements of producing ROZ "Fairway" resources with EOR.

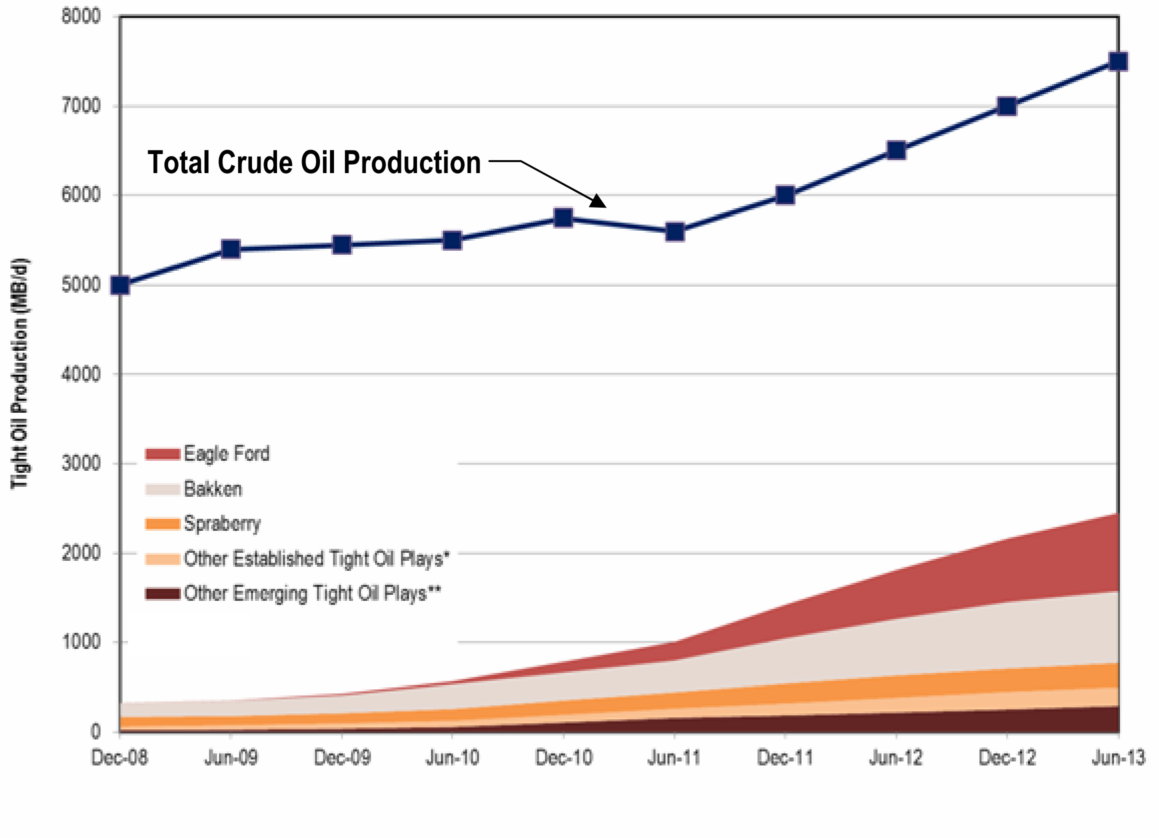
The "Tight Oil" Resource

The recent and rapid development of "tight oil" (liquids rich tight sand and shale formations) has enabled the U.S. to set modern day production records for crude oil production.

- The resource plays include the Bakken, Eagle Ford and Wolfcamp shales and the Sprayberry and Granite Wash tight sands.
- However, the oil recovery efficiencies of "tight oil" resource plays are low - - ranging generally from 3% to 7% of OOIP.

Advanced Resources estimates an in-place "tight oil" resource on the order of 1,000 billion barrels, with 48 billion barrels technically recoverable (from 45 distinct "tight oil" resource plays) using today's technology and development practices.

Rapid Growth of U.S. “Tight Oil” Production



Source: Advanced Resources Int'l., 2013 based on state and HPDI data; U.S. Energy Information Administration.
*Granite Wash, Bone Spring, Woodford, Niobrara. ** Miss. Lime, Barnett, Eaglebine, Wolfcamp/Cline, Cleveland-Tonkawa, Marmaton, etc.

“Tight Oil” Has Enabled U.S. Oil Production to Reach Modern Day Peak

Source	Annual U.S. Crude Oil and Liquids Fuel Supply	
	2012	2013
Crude Oil	(MM B/D)	(MM B/D)
▪ **Shale/Tight**	**1.8**	**2.5**
▪ **Conventional**	**4.7**	**5.0**
-- L-48 Onshore	2.9	3.2
-- Offshore	1.3	1.3
-- Alaska	0.5	0.5
Total	**6.5**	**7.5**

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Pursuing Improved Recovery Efficiencies from “Tight Oil”

One option for increasing oil recovery efficiency from “tight oil” resources would be to inject CO_2:

- Given its light oil and favorable depth, injection of CO_2 (as a miscible gas) would be favorable for many of the “tight oil” reservoirs. (Water injection into these oil wet, low permeability formations appear to be unfavorable.)
- Reservoir modeling by numerous investigators indicates that CO_2 flooding using Hz wells would significantly improve oil recovery at favorable CO_2 to oil ratios.

Reservoir Simulation of CO_2-EOR in Bakken Shale, North Dakota

A reservoir modeling study (Eclipse) by C. Dong (CSM)* was conducted in 2013 for a Masters Degree in Petroleum Engineering:

- Four section area of Bakken Shale in Sanish Field, North Dakota:
  - 42° API light oil
  - 10,000’ depth
- Primary recovery efficiency: 5.4% of 36 MM barrels of OOIP.
- EOR project consists of:
  - 3 existing 10,000’ Hz production wells
  - 4 new long Hz injection wells
- CO_2-EOR performance:
  - Increased oil recovery of ~10 MMB (24% of OOIP)
  - 1.1 PV of CO_2 injection (96 Bcf)

The study examined a variety of CO_2 injection schemes and well patterns.

*Cuiyu Dong “Modeling Gas Injection into Shale Oil Reservoirs of the Sanish Field, North Dakota.

Reservoir Simulation of CO_2-EOR in Bakken Shale, Montana

Reservoir modeling work (Eclipse) by B. Todd Hoffman (CSM)* in 2012 (as follow on to earlier work by Shoaib and Hoffman, 2009)**, evaluated the feasibility of injecting CO_2 to enhance oil recovery from “tight oil” reservoirs”

- Four section area of Bakken Shale in Elm Coulee Field, Montana:
    - 42^o API light oil
    - 7,500’ depth (sub-sea)
- Primary recovery efficiency: 6% of 20 MM barrels of OOIP.
- EOR project consists of:
    - 6 existing 5,000 Hz production wells
    - 4 new Hz CO_2 injection wells
- CO_2-EOR performance:
    - ~4 MM barrels (~20% of OOIP) of increased oil recovery
    - ~15 MMcfd (0.3 HCPV) of CO2 injection

Optimization of well patterns improves oil recovery and CO_2 injectivity.

*SPE 154329, “Comparison of Various Gases for Enhanced Recovery from Shale Oil Reserves”; April, 2012.
**SPE 123176, “CO2 Flooding the Elm Coulee Field”, April, 2009.

Size of the CO_2 Utilization/Storage “Prize”?

CO_2-EOR already offers a large market for utilization and storage of anthropogenic CO_2. Adding CO_2 demand for ROZ “Fairways” and “tight oil” would further increase the “size of the prize”.

Existing Markets	**Current CO2-EOR Technology**		**"Next Generation" CO2-EOR Technology**	
	Anthropogenic CO2 Demand (Gt)	GW Size Coal-Fired Plants** (#)	Anthropogenic CO2 Demand (Gt)	GW Size Coal-Fired Plants** (#)
Lower-48 Onshore*	4.8	40	12.5	104
Lower-48 Offshore	0.3	2	3.9	32
Alaska	3.1	26	4.4	37
Residual Oil Zone				
▪ **Below Oil Fields**	7.0	58	7.0	58
TOTAL	**15.2**	**126**	**27.8**	**231**

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*Excludes 2.7 Gt of natural CO2 supply.
**Assuming the 1,100 pounds per MWh standard for existing coal-fired power plants require capture of 120 MMmt of CO2 (over 40 years) per GW of capacity.
Note: Current coal-fired power generation capacity is about 300 GWs.

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