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Storing CO_2 with Enhanced Oil Recovery

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Abstract

CO_2 enhanced oil recovery (CO_2-EOR) offers the potential for storing significant volumes of carbon dioxide emissions while increasing domestic oil production. This presentation, based on a recently completed study for DOE/NETL, examines the domestic oil resource amenable to CO_2-EOR, the size of the related market for CO_2, and the benefits to the power sector from CO_2 sales to the EOR industry. The study finds that, depending on future oil prices and the costs for purchasing CO_2 from power plants and other industrial sources, from 39 to 48 billion barrels of oil could be economically recoverable with CO_2-EOR. In addition, the size of the market for CO_2 offered by the EOR industry is on the order of 7,500 million metric tons between now and 2030. With advances in CO_2-EOR and storage technology, the economically recoverable oil resource would increase to 54 to 70 billion barrels.

The market for CO_2 from the EOR industry is examined in depth from the coal-fueled power plant industry's standpoint. The sale of CO_2 emissions captured from new coal-fueled power plants could provide significant revenue offsets to the cost of installing carbon capture technology. It is estimated these revenue offsets along with a value for carbon abatement could enable 40% (48 out of 121 GW) of the new coal-fueled power capacity expected to be built between now and 2030 to install CCS. With advances in CO_2-EOR and storage technology the number of power plants with CCS could increase to 50 to 70 GWs. This would provide significant assistance toward addressing CO_2 emissions from this sector, helping drive down the costs of installing CCS technology.

Keywords: CO_2-EOR; carbon capture and storage; enhanced oil recovery; coal power plants; CO_2 emissions

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1. Introduction

CO_2 enhanced oil recovery (CO_2-EOR) offers the potential for storing significant volumes of carbon dioxide emissions while increasing domestic oil production. Four notable benefits would accrue from integrating CO_2 storage and enhanced oil recovery:

- First, CO_2-EOR provides a large, "value added" market for sale of CO_2 emissions captured from new coal-fueled power plants. The size of this market is on the order of 7,500 million metric tons between now and 2030. Sales of captured CO_2 emissions would help defray some of the costs of installing and operating carbon capture and storage (CCS) technology. These CO_2 sales would support "early market entry" of up to 49 (one GW size) installations of CCS technology in the coal-fueled power sector. With advances in CO_2-EOR and storage technology the market could increase to 10,850 million metric tons which would support up to 70 GW of CCS;
- Second, storing CO_2 with EOR helps bypass two of today's most serious barriers to using geological storage of CO_2 - - establishing mineral (pore space) rights and assigning long-term liability for the injected CO_2;
- Third, the oil produced with injection of captured CO_2 emissions is 70% "carbon-free", after accounting for the difference between the carbon content in the incremental oil produced by EOR and the volume of CO_2 stored in the reservoir . With "next generation" CO_2 storage technology and a value for storing CO_2, the oil produced by EOR could be 100+% "carbon free";
- Fourth, the 39 to 48 billion barrels of economically recoverable domestic oil economically recoverable from storing CO_2 with EOR would help displace imports, supporting a path toward energy independence. It could also help build pipeline infrastructure subsequently usable for storing CO_2 in saline formations.

Various analysts and studies have discussed the potential for storing CO_2 with enhanced oil recovery but have noted (incorrectly) that this option is quite small or is counter productive to reducing CO_2 emissions. For example, the "IPCC Special Report on Carbon Dioxide Capture and Storage", while recognizing that depleted oil fields could provide an attractive, early option for storing CO_2 (particularly with CO_2-EOR), concluded that oil fields would provide only a relatively small volume of CO_2 storage capacity.

The report finds that the opportunity for selling captured CO_2 emissions to the EOR industry and storing these emissions in oil reservoirs using CO_2-EOR is largely providing a market for productive use of CO_2 emissions from the nation's large and growing fleet of coal-fueled power plants.

2. Evaluating the Market for Captured CO_2 Emissions Offered by EOR

The size and value of the market for captured CO_2 emissions offered by enhanced oil recovery rests on three pillars: (1) the size and nature of the domestic crude oil resource base, particularly the large portion of this resource base unrecoverable with existing primary and secondary oil recovery methods; (2) the ability of CO_2-EOR to recover a portion of this currently unrecoverable ("stranded") domestic oil, while efficiently storing CO_2; and (3) the impact of alternative oil prices and CO_2 costs on the volume of oil that could be economically produced.

2.1. The Domestic Oil Resource Base

The U.S. has a large, established oil resource base, on the order of 596 billion barrels originally in-place. About one-third of this resource base, nearly 196 billion barrels, has been recovered or placed into proved reserves with existing primary and secondary oil recovery technologies. This leaves behind a massive target of 400 billion barrels of "technically stranded" oil, Table 1.

Table 1. National In-Place, Conventionally Recoverable and "Stranded" Crude Oil Resources

Basin/Area	OOIP* (Billion Barrels)	Conventionally Recoverable (Billion Barrels)	ROIP** "Stranded" (Billion Barrels)
1. Alaska	67.3	22.3	45.0
2. California	83.3	26.0	57.3
3. Gulf Coast (AL, FL, MS, LA)	44.4	16.9	27.5
4. Mid-Continent (OK, AR, KS, NE)	89.6	24.0	65.6
5. Illinois/Michigan	17.8	6.3	11.5
6. Permian (W TX, NM)	95.4	33.7	61.7
7. Rockies (CO,UT,WY)	33.6	11.0	22.6
8. Texas, East/Central	109.0	35.4	73.6
9. Williston (MT, ND, SD)	13.2	3.8	9.4
10. Louisiana Offshore	28.1	12.4	15.7
11. Appalachia (WV, OH, KY, PA)	14.0	3.9	10.1
Total	595.7	195.7	400.0

*Original Oil in Place, in all reservoirs in basin/area; Calculated through internal ARI analysis and EIA production data.
** Remaining Oil in Place, in all reservoirs in basin/area. Source: Advanced Resources Int'l, 2008.

2.2. Technically Recoverable Oil Resources Using CO_2-EOR

Numerous scientific as well as practical reasons account for the large volume of "stranded" oil, unrecoverable with primary and secondary methods. These include: oil that is bypassed due to poor waterflood sweep efficiency; oil that is physically unconnected to a wellbore; and, most importantly, oil that is trapped by viscous, capillary and interfacial tension forces as residual oil in the pore space.

Injection of CO_2 helps lower the oil viscosity and trapping forces in the reservoir. Additional well drilling and pattern realignment for the EOR project helps contact bypassed and occluded oil. These actions enable a portion of this "stranded oil" to become mobile, connected to a wellbore and thus recoverable.

2.2.1. Current CO2-EOR Activity and Production

According to the latest tabulation of CO_2-EOR activity in the U.S., in the 2008 EOR Survey published by the Oil and Gas Journal, approximately 250,000 barrels per day of incremental domestic oil is being produced by 101 CO_2-EOR projects, distributed broadly across the U.S.

2.2.2. Evolution in CO_2 Flooding Practices

Considerable evolution has occurred in the design and implementation of CO_2-EOR technology since it was developed in the 1970's. Notable changes include: (1) use of much larger (up to 1 HCPV*) volumes of CO_2; (2) incorporation of tapered WAG (water alternating with gas) and other methods for mobility control; and (3) application of advanced well drilling and completion strategies to better contact previously bypassed oil. As a result of the changes mentioned above, the oil recovery efficiencies of today's better designed "state-of-the-art" CO_2-EOR projects have steadily improved.

2.2.3. Technically Recoverable Resources

The reservoir-by-reservoir assessment of the 1,111 large oil reservoirs contained in the ARI database amenable to CO_2-EOR shows that a significant volume, 64 billion barrels, of domestic oil may be recoverable with state-of-the-art application of CO_2-EOR. Extrapolating the data base to national-level results indicates that 87.1 billion barrels

(84.8 after subtracting the 2.3 that has already been produced and proven) of domestic oil may become recoverable by applying “state-of-the-art” CO_2-EOR, Table 2.

Table 2. Technically Recoverable Resources from Applying “State-of-the-Art” CO_2-EOR: National Totals

	Technically Recoverable (Billion Barrels)	Existing CO_2-EOR Production/Reserves	Incremental Technically Recoverable (Billion Barrels)
1. Alaska	12.4	-	12.4
2. California	6.3	-	6.3
3. Gulf Coast (AL, FL, MS, LA)	7	-	7
4. Mid-Continent (OK, AR, KS, NE)	10.7	-0.1	10.6
5. Illinois/Michigan	1.2	-	1.2
6. Permian (W TX, NM)	17.8	-1.9	15.9
7. Rockies (CO,UT,WY)	4.2	-0.3	3.9
8. Texas, East/Central	17.6	-	17.6
9. Williston (MT, ND, SD)	2.5	-	2.5
10. Louisiana Offshore	5.8	-	5.8
11. Appalachia (WV, OH, KY, PA)	1.6	-	1.6
Total	87.1	-2.3	84.8

3. Economically Recoverable Resources

3.1. Economically Recoverable Resources: Base Case Scenario

Out of 85 billion barrels technically recoverable using CO_2-EOR technology, 45 billion barrels of incremental oil are economically recoverable in our base case scenario, Table 3. The Base Case evaluates the CO_2-EOR potential using an oil price of $70 per barrel (constant, real) and a CO_2 cost of $45 per metric ton ($2.38 per Mcf) (delivered at pressures around 2,200 psi to the field, constant and real), Table 4. The 40 billion barrels that are not economic to recover in this scenario are contained in reservoirs that cannot provide a sufficient rate of return, 15%, in this scenario, on a CO_2-EOR project’s capital costs.

Table 3. Economically Recoverable Resources from Applying "State-of-the-Art" CO_2-EOR: National Totals at Base Case Economics*

Basin/Area	Incremental Technically Recoverable (Billion Barrels)	Incremental Economically Recoverable* (Billion Barrels)
1. Alaska	12.4	9.5
2. California	6.3	5.4
3. Gulf Coast (AL, FL, MS, LA)	7.0	2.2
4. Mid-Continent (OK, AR, KS, NE)	10.6	5.6
5. Illinois/Michigan	1.2	0.5
6. Permian (W TX, NM)	15.9	7.1
7. Rockies (CO,UT,WY)	3.9	1.9
8. Texas, East/Central	17.6	8.3
9. Williston (MT, ND, SD)	2.5	0.5
10. Louisiana Offshore	5.8	3.9
11. Appalachia (WV, OH, KY, PA)	1.6	0.1
Total	84.8	45.0

*Base Case Economics use an oil price of $70 per barrel (constant, real) and a CO_2 cost of $45 per metric ton ($2.38/Mcf), delivered at pressure to the field.

Table 4. Economically Recoverable Resources from Applying "State-of-the-Art" CO_2-EOR: National Totals at Base Case and Alternative Oil Prices/CO_2 Costs

Oil Prices	CO2 Costs			
($ per Bbl)	($ per metric ton)			
	$35	$45*	$55	$60
Lower Prices				
$50	39.1 BBbls			
Base Case				
$70		45.0 BBbls		
Higher Prices				
$90			47.9 BBbls	
$100				48.3 BBbls

*A CO_2 cost of $45 per metric ton (mt) is equal to $2.38 per Mcf. 15% IRR project hurtle rate

4. The Market for Storing CO2 with EOR

Our analysis shows that significant volumes of CO_2 (ranging from 10 to 13 billion metric tons depending on oil price) can be stored with enhanced oil recovery. In general, about 5 to 6 Mcf (0.26 to 0.32 metric tons (mt)) of purchased CO_2 per barrel of oil is injected and stored as part of CO_2-EOR. This is augmented with 5 to 10 Mcf (0.26 mt to 0.52 mt) of recycled CO_2 during the latter stages of a CO_2-EOR process. With incentives for storing CO_2 emissions and "next generation" CO_2 storage technology, considerably larger volumes of CO_2 could be stored.

4.1. Producing "Carbon Free" Domestic Oil

A typical barrel of crude oil contains 0.42 metric tons (mt) of releasable CO_2 (assuming that 3% of the produced and refined oil barrel remains as asphalt or coke). As such, netting the injection and storage of 0.26 to 0.32 mt of CO_2 emissions against the 0.42 mt of CO_2 in the produced oil, makes the domestic oil produced by CO_2-EOR about 70% (62% to 76%) "carbon free".

4.2. Market Demand for CO_2: Power Plant Perspective

The overall demand for CO_2 by the CO_2-EOR industry can be met by three potential sources of CO_2 supply, namely:

- Natural CO_2 supplies already found and defined in geological structures;
- Industrial, high concentration sources of CO_2 (e.g. refineries and fertilizer plants) that are currently being captured and used by the CO_2-EOR industry; and
- The large volumes of low concentration power plant and industrial emissions of CO_2 that needs to be captured and stored to mitigate CO_2 emissions.

Excluding Alaska, which is not projected to build new coal-fueled power plants to any great extent, the demand for CO_2 in the lower-48 states offered by the EOR industry is 9,694 million metric tons (183.4 Tcf)

Table 5 sets forth the net remaining demand for CO_2 by the EOR industry of 7,470 million metric tons for the lower-48 states, after subtracting the 2,224 million metric tons (42.2 Tcf) of CO_2 available, in the next 30 years, from natural CO_2 deposits and high concentration industrial CO_2 sources (e.g., natural gas processing plants, fertilizer plants) already being captured and used for enhanced oil recovery.

The overall conclusion from the analysis is that CO_2-EOR may provide a 7,500 million metric ton market for captured CO2 emissions by the coal-fueled power generation industry, Table 5. While the actual revenues afforded by this market will be established, in the main, by one-on-one negotiations between individual power companies and oil field operators, the potential size of this market could be large.

Using an oil price of $70 per barrel (Base Case), assuming a delivered CO_2 cost of $45 per metric ton, and subtracting $10 per metric ton for transportation and handling, the revenue potential offered by the CO_2-EOR market could reach $260 billion.

Table 5. Economically Feasible Market Demand for CO_2 by EOR: NEMS/EMM Power Generation Regions*

NEMS EMM Region	Purchased CO_2 Requirements (Tcf)	Natural CO_2** (Tcf)	Industrial CO_2** (MMcfd)	(Tcf)	Unmet (Net) Demand for CO_2 (Tcf)	(Million mt)
Region 1 - ECAR	1.1	-	15	***	1.1	58
Region 2 – ERCOT	72.2	25	110	1.2	46.0	2,436
Region 3 – PJM (MAAC)	0.1	-	-	-	0.1	4
Region 4 – MAIN	1.9	-	-	-	1.9	100
Region 5 – MAPP	2.1	-	-	-	2.1	109
Region 6 – NY ISO	-	-	-	-	-	-
Region 7 – NW ISO	-	-	-	-	-	-
Region 8 – Florida	0.2	-	-	-	0.2	9
Region 9 – SERC	40.0	8	-	-	32.0	1,695
Region 10 – SWPP	29.7	5	35	0.4	24.3	1,286
Region 11 – WECC/NWPP	7.8	-	175	1.9	5.9	311
Region 12 – WECC/RMPP	2.3	-	65	0.7	1.6	83
Region 13 – WECC/CA	26.0	-	-	-	26.0	1,377
Region 14 - Alaska	39.6	5	-	-	34.6	1,831
TOTAL U.S.	223.0	43	400	4.2	175.8	9,301
TOTAL Lower-48	183.4	38	400	4.2	141.2	7,470

*Base Case: $70/Bbl oil and $45/mt CO_2

**Assumed available to be produced and productively used by the CO_2-EOR industry in the next 30 years.

***Less than 0.01 Tcf and thus not included in totals.

5. Using Sale of Captured CO_2 Emission for "Early Market Entry" of CCS Technology

A common feature of EIA carbon management studies is that, in general, CCS is not considered, as of yet, a key part of the solution. The reason, according to EIA's EMM cost model, is that using CCS with coal- or gas-fired power is not economically competitive with other options for generating power with low CO_2 emissions.

However, revenues from selling captured CO_2 emissions into the CO_2-EOR market can change the competitive outlook. For example, as shown in Table 6 and Figure 1, the sale of captured CO_2 emissions at $25 to $35 per metric ton can reduce the costs of power generation with CCS by $17 to $24 per MWh, significantly offsetting the costs of installing CCS with new coal-fueled power plants.

Table 6. Relationship of CO_2 Sales Price to Cost Offsets in the Coal-Fueled Power Sector (Year 2020)

Sale of CO_2	Sale of CO_2
@ \$25/mt CO_2	@ \$35/mt CO_2
*7,920 btu/kWh x	7,920 btu/kWh x
94 MMmt CO_2/QBtu x	94 MMmt CO_2/QBtu x
90% Capture	90% Capture
Cost Offset: \$16.80/MWh	Cost Offset: \$23.50/MWh

*Advanced Integrated Gasification Combined Cycle (IGCC) plant.

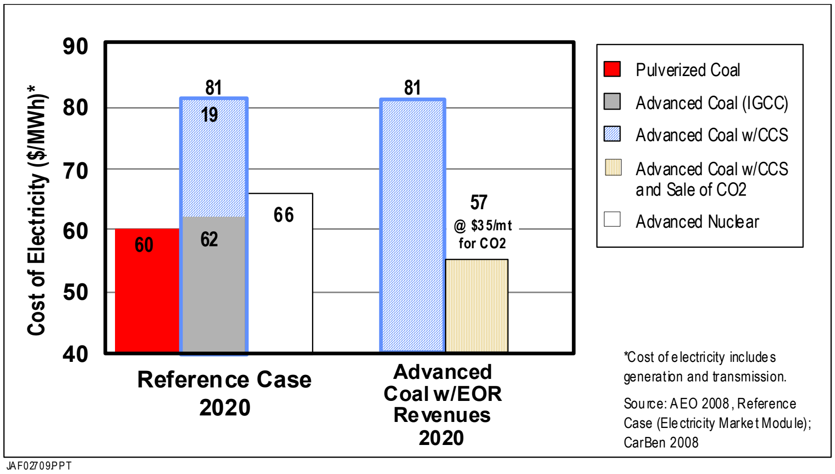

Figure 1. Sale of Captured CO_2 Emissions Can Help Make Coal Plants w/CCS Competitive

The CarBen and EIA EMM models project that 29 new coal-fueled power plants would be placed into operation between 2013 and 2020 in the lower-48. Assuming that half of these power plants are favorably located with respect to oil fields attractive for CO_2-EOR and are able to sell CO_2 at \$35/mt at the plant gate, the integration of CO_2 storage and EOR plus a value for abating CO_2 emissions would support the construction of 15 new advanced coal w/CCS power plants, each with 1 GW of capacity. (A 1 GW advanced coal-fueled power plant built by 2020 is estimated to be able to sell about 5.1 million metric tons of captured CO_2 emissions per year; 15 plants would be able to provide 2,300 million metric tons in 30 years). Sales of captured CO_2 emissions by power plants built after 2020 would support the 33 additional installations of CCS by 2030 for a total of 48 GWs of capacity with CCS.