WHITE PAPER #2

CHALLENGES OF IMPLEMENTING LARGE-SCALE CO_2 ENHANCED OIL RECOVERY WITH CO_2 CAPTURE AND STORAGE

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This "White Paper", prepared for the "Symposium on the Role of Enhanced Oil Recovery in Accelerating the Deployment of Carbon Capture and Storage"[*], addresses five topics:

- Status of CO_2-EOR
- CO_2 Markets and Storage Capacity Offered by EOR
- Benefits of Productively Using CO_2 for EOR and Storage
- Feasibility of Large-Scale Implementation of CO_2-EOR/CCS
- Accelerating and Implementing Integrated CO_2-EOR/CCS Projects

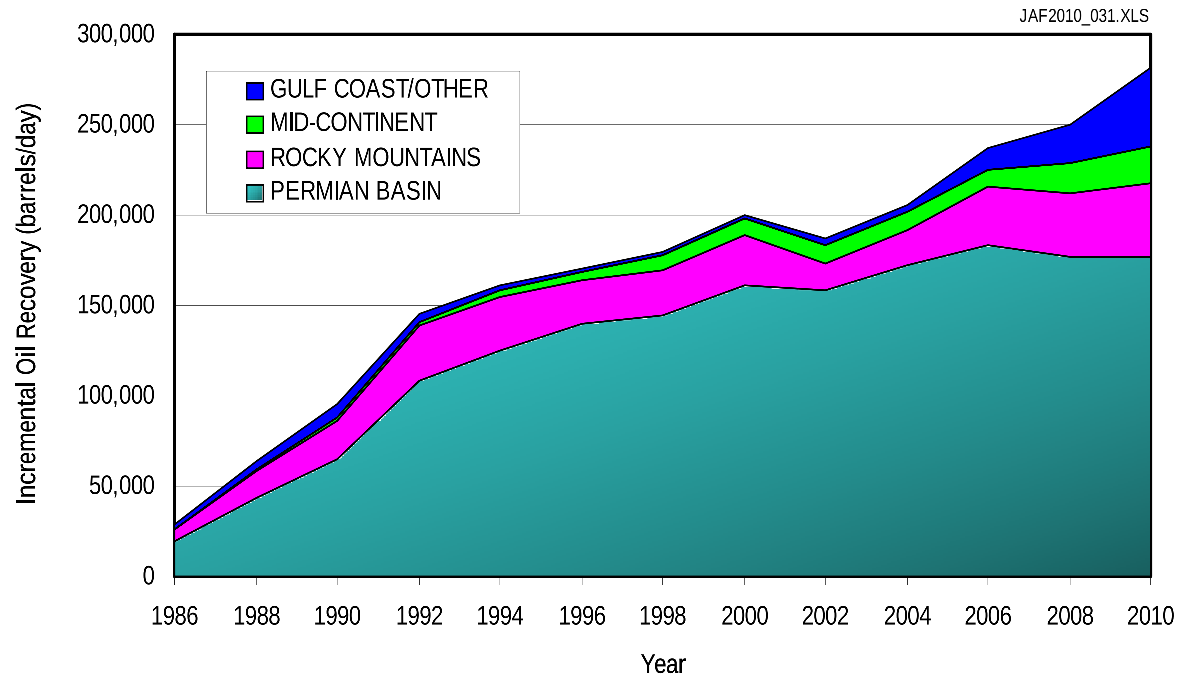
1. STATUS OF CO_2-EOR

In discussing and further examining the role of CO_2-based enhanced oil recovery (CO_2-EOR) for accelerating the deployment of CO_2 capture and storage (CCS), it is useful to recognize the following:

- CO_2-EOR currently provides about 280,000 barrels of oil per day in the U.S.,[1] equal to 6% of U.S. crude oil production. CO_2-EOR has been underway for several decades, starting initially in the Permian Basin and expanding today to numerous other regions of the country, **Figure 1**. The number one barrier to reaching higher levels of CO_2-EOR production is lack of access to adequate supplies of affordable CO_2.

[*] Hosted by MIT Energy Initiative and the Bureau of Economic Geology, University of Texas Austin Symposium, Cambridge, MA, July 23, 2010.
[1] Oil and Gas Journal EOR Survey, April 2010.

Figure 1. Growth of CO_2-EOR Production in the U.S.



Source: Advanced Resources Int'l., based on Oil and Gas Journal, 2010.

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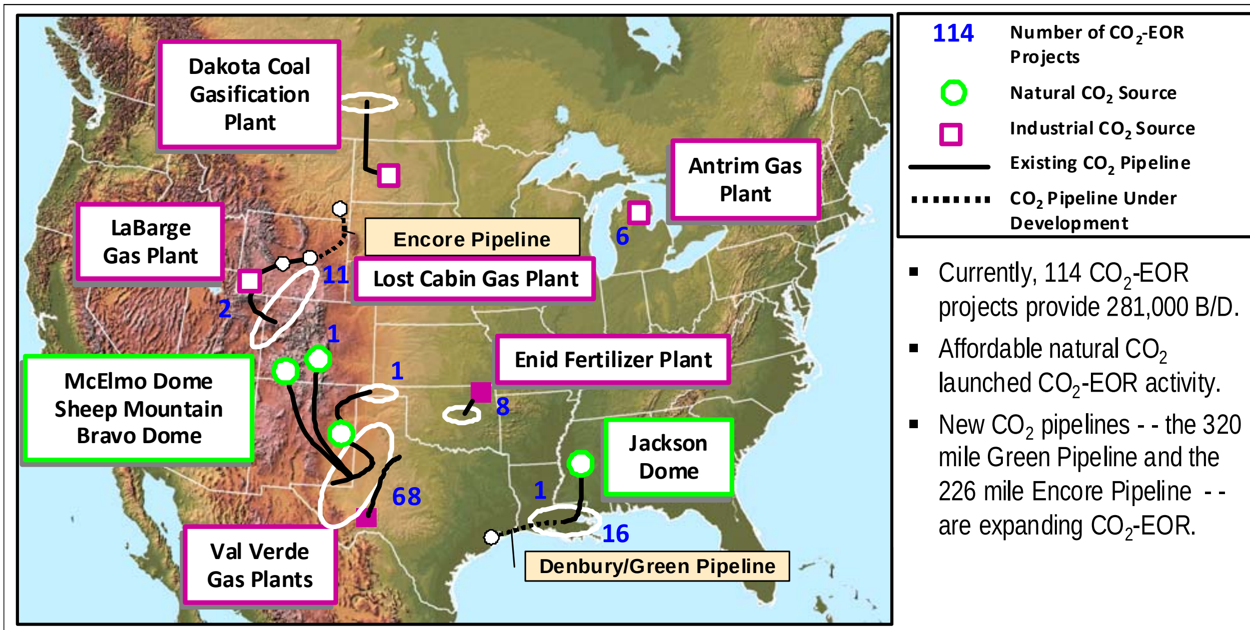
- New CO_2 pipelines and refurbished gas treating plants, such as Denbury's 320 mile Green Pipeline along the Gulf Coast, ExxonMobil's expansion of the Shute Creek (La Barge) gas processing plant, the new proposed 226 mile Encore Pipeline and refurbished Lost Cabin gas plant in the Rockies, and the new Century gas processing plant in West Texas, are all due on-line in late 2010 or early 2011. These new facilities will significantly expand the availability and use of CO_2 in domestic oil fields, leading to increased oil production from CO_2-EOR, **Figure 2**.[2]

- Natural CO_2 fields currently are the dominant source of CO_2 for the EOR market, providing 2.35 Bcfd (equal to 45 million metric tons per year). However, anthropogenic sources account for steadily increasing volumes,

[2] Various industry presentations and publications.

currently providing 0.53 Bcfd (10 million metric tons per year) of CO_2 for enhanced oil recovery, **Table 1**.[3]

Figure 2. Current U.S. CO_2-EOR Activity



Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2010 and other sources.

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Table 1. Significant Volumes of Anthropogenic CO_2 Are Already Being Injected for EOR

Location of EOR / CO_2 Storage	CO_2 Sources by Type and Location	CO_2 Supply (MMcfd)	
		Natural	Anthropogenic
W. Texas-New Mexico-Oklahoma	Natural CO_2 (Colorado-New Mexico) Gas Processing Plants (W. Texas)	1,670	105
Colorado-Wyoming	Gas Processing Plant (Wyoming)	-	230
Mississippi/Louisiana	Natural CO_2 (Mississippi)	680	-
Michigan	Ammonia Plant (Michigan)	-	15
Oklahoma	Fertilizer Plant (Oklahoma)	-	30
Saskatchewan	Coal Gasification Plant (North Dakota)	-	150
TOTAL (MMcfd)		2,350	530
TOTAL (million mt)		45	10

* Source: Advanced Resources International, 2009.
**MMcfd of CO_2 can be converted to million metric tons per year by first multiplying by 365 (days per year) and then dividing by 18.9 Mcf per metric ton.

[3] Advanced Resources International internal data base, 2010.

- The largest single source of anthropogenic CO_2 used for EOR is the capture of 230 MMcfd (4+ MMmt/yr) of CO_2 from the gas processing plant at La Barge in western Wyoming. This is followed by the "poster child" for integrating large-scale CO_2-EOR with CCS - - the capture of 150 MMcfd (~3MMmt/yr) of CO_2 from the Northern Great Plains Gasification plant in Beulah, North Dakota and its transport, via a 200 mile cross-border CO_2 pipeline, to the two EOR projects at the Weyburn oil field in Saskatchewan, Canada.

- Capture of CO_2 from a series of proposed coal-to-liquids (CTL), integrated gas combined cycle (IGCC) and other carbon conversion projects would add significant volumes of anthropogenic CO_2 for use by CO_2-EOR. Three example projects from a much larger group are listed below:[4]

  - Hydrogen Energy's (BP/Rio Tinto) pet-coke gasification plant in Kern County, California plans to deliver 2 MMt/yr for CO_2-EOR at Elk Hills oil field, **Figure 3**.

  - Southern Company's Kemper County IGCC plant plans to provide 1.1 to 1.5 MMt/yr to Denbury Resources for CO_2-EOR in oil fields in Louisiana and Mississippi.

  - Summit Energy's Texas Clean Energy IGCC project plans to sell 3 MMt/yr for CO_2-EOR in West Texas, **Figure 4**.

- In addition, Denbury Resources has identified 17 MMmt/yr of anthropogenic CO_2 potentially available for EOR in the Rockies, **Table 2**. It has also entered into contingent purchase contracts for 18 MMmt/yr of anthropogenic CO_2 in the Midwest and for 14 MMmt/yr of anthropogenic CO_2 in the Gulf Coast.[5]

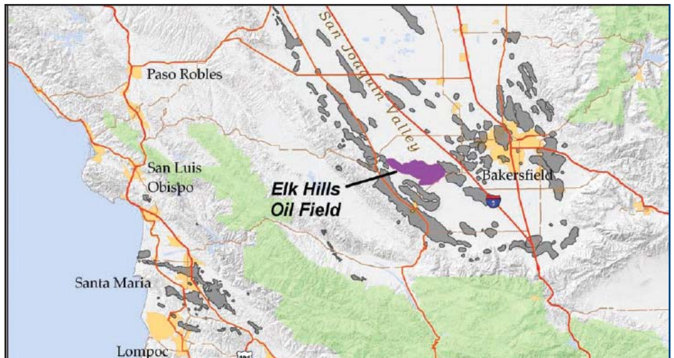
[4] Various industry presentations and publications.
[5] Denbury Resources corporate presentation, June 2010.

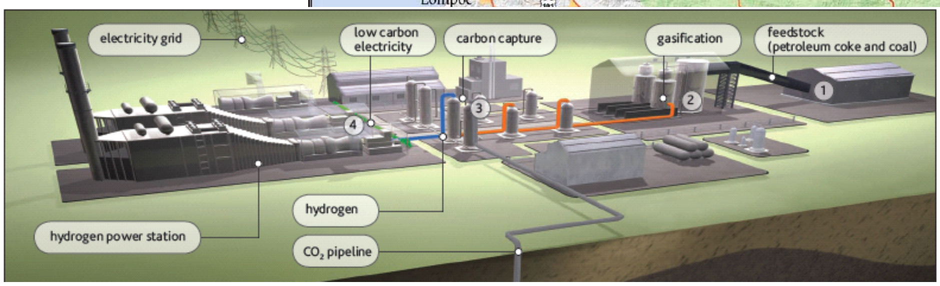
Figure 3. Advanced Power Plants and Use of EOR for CO_2 Storage

Hydrogen Energy's (Rio Tinto/BP) Pet-coke Gasification Plant

- 250MW gasification of pet-coke
- Capture 90% of CO_2; over 2 million tons of CO_2 per year
- Oxy will take CO_2 for EOR at Elk Hills oil field
- Operational by 2015

Elk Hills Oil Field near Bakersfield, CA





Source: Hydrogen Energy

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Figure 4. Advanced Power Plants Using EOR for Storage

Southern Company's Kemper County IGCC Plant

- 582 MW IGCC fueled by Mississippi lignite
- Capture 65% of CO_2
- Negotiating to sell 1.1 to 1.5 million tons of CO_2 per year for EOR
- Cost $2.4 B; operational by 2014

*Source: Mississippi Power, Denbury Resources

Summit's Texas Clean Energy IGCC Project

- 400 MW IGCC with 90% capture
- Located near Odessa in Permian Basin
- Sell 3 million tons of CO_2 per year to EOR market
- Expected cost $1.75 B; $350 MM award under CCPI Round 3.

Source: Siemens Energy

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Table 2. Rockies New Anthropogenic CO_2 Sources

	Location	MMcfd	Million mt/yr	Comments
Natural Gas Treating Plants				
1. Exxon La Barge	SW Wyoming	100	1.9	Plant expansion
2. COP Lost Cabin	Central Wyoming	50	1.0	Under contract
3. Riley Ridge	SW Wyoming	-	-	Under discussion
	Subtotal		2.9	
Proposed Coal to Gas/ Liquids Plants				
1. DKRW/Medicine Bow	SE Wyoming	150	2.9	DOE Loan Guarantee
2. Refined Energy	SE Idaho	80-175	2.3	Diesel/Fertilizer
3. Gas Tech	NE Wyoming	115	2.2	UCG
4. Many Stars	C. Montana	250	4.8	Start in 2012
5. South Heart	SW N. Dakota	100	1.9	Coal to H_2
	Subtotal		14.1	
	TOTAL		17.0	

2. CO_2 MARKETS AND STORAGE CAPACITY OFFERED BY EOR

Clearly, many of the proposed new IGCC and coal to gas/liquids plants look to CO_2-EOR as their CO_2 storage option. Because of this, some power companies have expressed concerns that these initial plants will "use up" all of the available EOR market and CO_2 storage capacity, leaving little for subsequent use. As such, a key question is - - *just how much CO_2 could be stored with CO_2 enhanced oil recovery?*

Storage of CO_2 with enhanced oil recovery is claimed, by some, to be a small, niche opportunity. Many of these claims are based upon anecdotal evidence, outdated characterization of CO_2-EOR performance and past perceptions of the small oil recovery potential offered by CO_2-EOR. A rigorous assessment of the CO_2 storage and oil recovery potential offered by domestic oilfields is summarized in this "White Paper" and is available in the recent DOE/NETL publication - - *"Storing CO_2 and Producing Domestic Crude Oil with Next Generation CO_2-EOR Technology"*, April 2010.[6]

[6] U.S. Department of Energy, National Energy Technology Laboratory, "Storing CO_2 and Producing Domestic Crude Oil with Next Generation CO_2-EOR Technology: An Update", prepared by Advanced Resources International, Publication Number: DOE/NETL-2010/1417, April 2010.

A. CO_2 Storage in the Traditional ("Main") Pay Zone of Oil Fields. The assessment of CO_2 storage capacity set forth in the above NETL report is based on a data base of over 6,000 domestic oil reservoirs, accounting for three-quarters of U.S. oil resources. The study identifies over 1,700 large oil reservoirs with 305 billion barrels of remaining oil in-place (345 billion barrels of remaining oil in-place when extrapolated to national totals) as favorable for CO_2-EOR. These large oil reservoirs were modeled for CO_2–based enhanced oil recovery using ARI's adaptation of the streamline reservoir simulator *PROPHET2*. The amount of CO_2 storage capacity offered by oil fields favorable for CO_2-EOR was then further evaluated as a function of technology and economics:

- The study examined two technology scenarios: "State of the Art" and "Next Generation".
- The study established two recoverable categories: "Technical Potential" (without consideration of prices and costs) and "Economic Potential" (the volume of CO_2 the oil industry could buy at a specified oil price and CO_2 cost).

As shown in **Figure 5**, the volume of technically recoverable oil using CO_2-EOR ranges from 81 to 126 billion barrels, depending on technology; the volume of economically recoverable oil (at an oil price of $70/B, CO_2 costs of $45/Mt and a 15% before tax financial return) ranges from 38 to 58 billion barrels, depending on technology (State of the Art" or "Next Generation").

The associated volumes of CO_2 required to be purchased and subsequently stored to recover the above volumes of oil range from 10 to 28 billion metric tons, depending on technology and economics, as shown on **Table 3**.

Figure 5. New Domestic Oil Supplies From CO_2-EOR

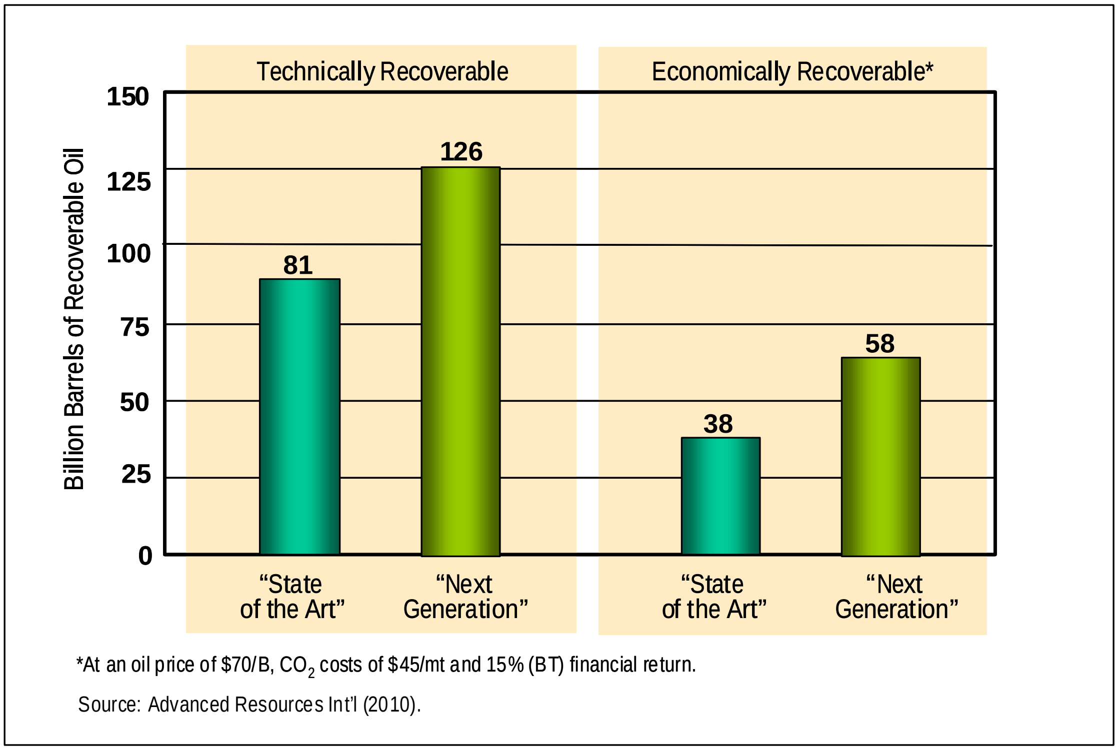

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Table 3. Volume of CO_2 Storage with CO_2-EOR in Main Pay Zone

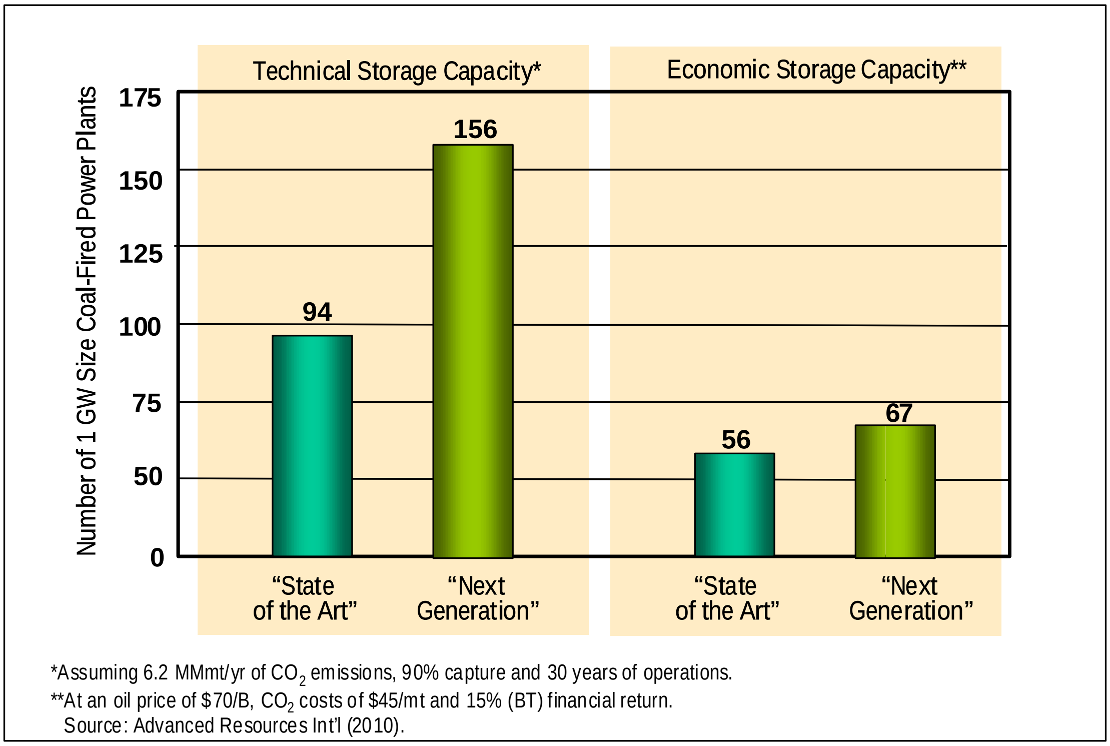
Technology Scenario	Billion Metric Tons of CO_2	
	Technical Potential	Economic Potential*
"Next Generation"	28.4	11.5**
• Permian Basin	6.4	2.8
• Other Basins	22.0	8.7

*At an oil price of $70/B, CO_2 costs of $45/mt and 15% (BT) financial return.
**A portion of this storage capacity (~ 2 billion mt) could be consumed by natural CO_2 sources.

Figure 6 provides an alternative way to characterize the CO_2 storage capacity offered by CO_2-EOR, defined in terms of the number of one-GW size power plants that could rely on CO_2-EOR for storing their captured CO_2. The figure shows that CO_2-EOR offers sufficient technical storage capacity for all of the CO_2 captured from 94 to 156 one-GW size coal-fired power plants for 30 years of operation. The volume of economic

CO_2 storage capacity offered by CO_2-EOR, at the oil price and CO_2 costs presented above, is smaller but still substantial, ranging from 56 to 67 one-GW size coal-fired power plants.

Figure 6. Volumes of CO_2 Storage Capacity Available from CO_2-EOR



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B. CO_2 Storage in the Residual Oil Zone of Oil Fields. Beyond the CO_2 storage capacity offered by the traditional, main pay portion of depleted oil fields, a second potentially much larger, CO_2 storage option is offered by residual oil zones (ROZ) - - saline formations containing residual oil. These regionally extensive (and previously unrecognized) resources are contained in high quality reservoir intervals located below the main pay zone of many oil fields as well as in hydrodynamic ROZ fairways surrounding large oil fields.

While the full volume of CO_2 storage capacity offered by residual oil zones is still to be defined, the ground breaking conceptual framework for this option has been established by Melzer.[7] A more recent DOE/NETL study estimates that the hydrodynamic ROZ fairways in the Permian Basin could add 12 to 18 billion metric tons of CO_2 storage capacity, **Figure 7** and **Table 4**.[8] In comparison, the "traditional" CO_2 storage capacity offered by CO_2-EOR in the Permian Basin is 6.4 billion metric tons, based on the previously cited DOE/NETL report. Additional oil fields with residual oil zones have been identified in other basins, such as the Big Horn and Williston, but are not further discussed in this "White Paper".

Table 4. Volume of CO_2 Storage with CO_2-EOR in Residual Oil Zones (Permian Basin)

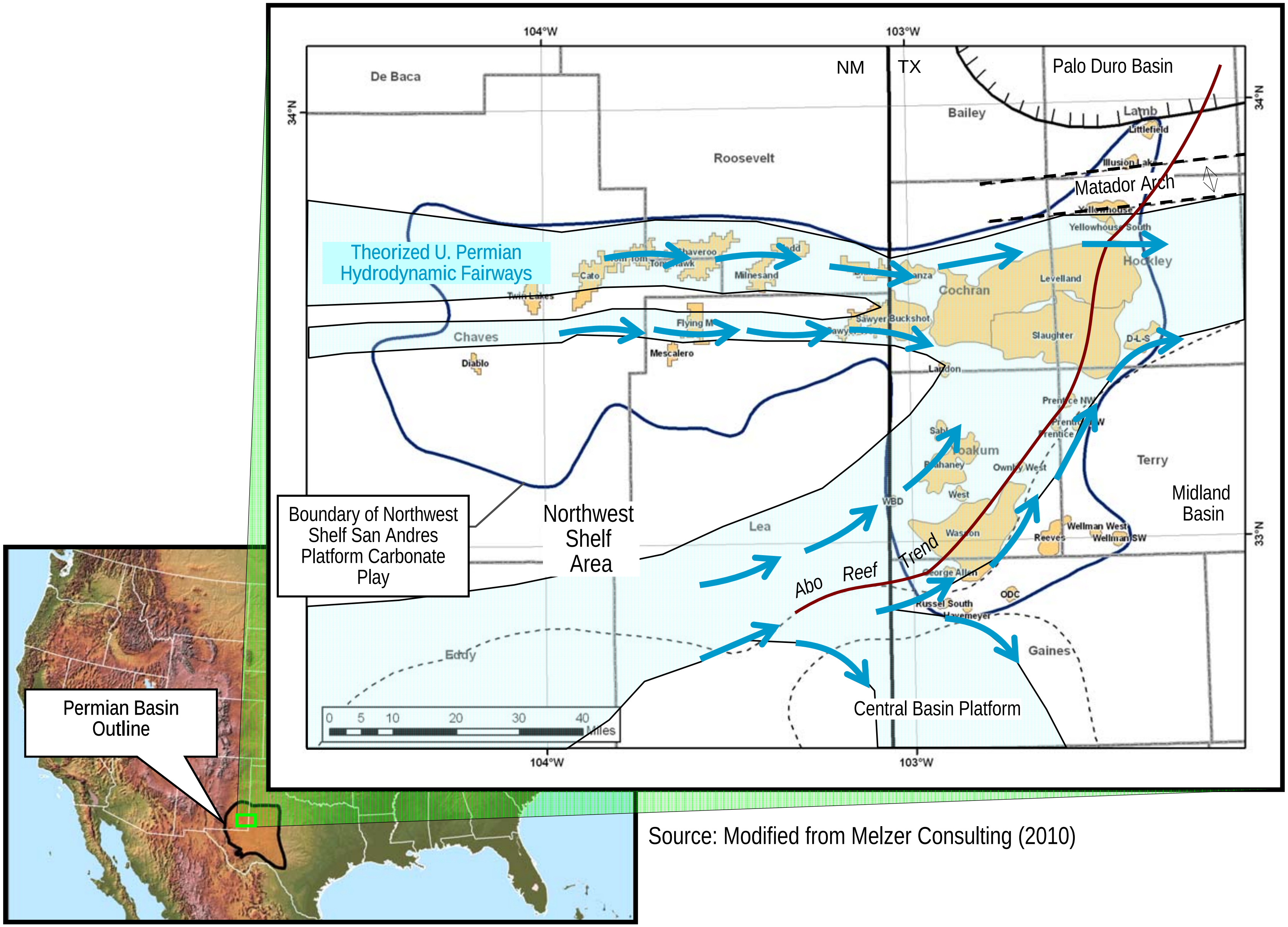
	Estimated ROZ OOIP* (billion barrels)	Calculated ROZ OIP (billion barrels)	Technically Recoverable w/CO_2-EOR		CO_2 Storage Capacity (Billion mt)
			(billion barrels)	% OOIP	
PERMIAN BASIN					
• Discrete Oil Fields (56 fields in 5 plays)	65	31	12	18%	4 to 6
• Hydrodynamic Fairways	210	100	36	17%	12 to 18

*Assuming 52% hydrodynamic flushing of the original oil in-place (OOIP) in the ROZ interval.
Source: Advanced Resources International, 2010.

A number of CO_2-EOR projects are underway in the ROZ that help demonstrate the technical and economic feasibility of producing this resource while storing CO_2. These include significant ROZ projects by Hess at Seminole, by Oxy at Wasson, by Chevron at Vacuum and by Legado at Goldsmith.

[7] "Stranded Oil in the Residual Oil Zone", prepared by Steven L. Melzer, Melzer Consulting for Advanced Resources International and the U.S. Department of Energy, Office of Fossil Energy - Office of Oil and Natural Gas, February 2006.
[8] "White Paper: Establishing the Viability of Storing CO_2 in Deep Saline Formations Containing Residual Oil", prepared by Advanced Resources International, Inc. and Melzer Consulting for the U.S. Department of Energy, National Energy Technology Laboratory, September 8, 2009.

Figure 7. Development of ROZ Fairway w/CO_2-EOR Would Greatly Expand CO_2 Storage Capacity in the Permian Basin.



Source: Modified from Melzer Consulting (2010)

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3. BENEFITS OF PRODUCTIVE USE OF CO_2 FOR EOR AND STORAGE

Numerous benefits stem from productively using captured CO_2 emissions for EOR. The most compelling of these benefits include:

- The sale of captured CO_2 would provide a revenue stream to the capturer of the CO_2 as well as to other entities involved in the value chain of productive use of CO_2.
- The use of an oil field for CO_2 storage would significantly help confine the areal extent of the CO_2 plume, reducing the risks of CO_2 leakage and public opposition to CCS.
- Selection of EOR as the CO_2 storage option would enable major CCS projects to be implemented while the still "thorny issues" surrounding using saline formations for storing CO_2 (e.g., pore space rights, regulatory approval, public acceptance) are resolved.
- The productive use of captured CO_2 emissions from implementation of CCS at coal plants could provide 3 million barrels per day of domestic oil production by 2030, greatly improving domestic energy security.

These four benefits of integrating CO_2-EOR with CO_2 capture and storage are further developed below.

A. Revenue Streams from Sale of CO_2 and Production of Oil. A most important benefit from integrating CO_2-EOR and CO_2 storage is that productive use of CO_2 for oil recovery, as opposed to its non-productive disposal in saline formations, would provide a series of revenue streams:

- One of these revenue streams (or cost avoidance) would accrue to the capturer of the CO_2, helping lower the overall cost of conducting CCS.

- A second revenue stream would accrue to state (and local) governments (or the National treasury if the EOR project is on Federal lands) from royalties, plus severance and ad valorem taxes. These revenues, in states such as Texas and Wyoming, are a primary source of funds for school systems and other public services.

- A third revenue stream would accrue to a variety of individuals and entities from royalty payments, equipment sales, jobs and profits stemming from a successful CO_2-EOR project.

B. Confining the CO_2 Plume. Because of buoyancy of the CO_2 and the unconfined nature of saline formations, a CO_2 project is able to productively utilize only 1% to 4% of the geologically available storage capacity offered by saline formations.[9] As a result, the areal extent of the CO_2 plume in a saline formation associated with CO_2 capture from a large one GW power plant can be extensive.

- For example, the CO_2 plume from a one GW coal-fired power plant (with 168 million metric tons of captured CO_2 emissions; 5.6 million metric tons of annually captured and stored CO_2, operated for 30 years) would underlie an area of 200 square miles, assuming a deep saline formation with 200 feet of net pay, 20% porosity, and the upside 4% productive use of available storage capacity.

- In contrast, it is feasible to productively utilize much more (up to 40%) of the geologically available storage capacity in an oil field under a CO_2 flood, assuming the CO_2 flood is properly designed and operated to incorporate CO_2 storage. (In gravity stable, "next generation" CO_2 floods, it may be possible to productively utilize 60% to 70% of the geologically available storage capacity.) As such, use of an oil field would concentrate the CO_2 shape and limit the area of the CO_2 plume by ten-fold, reducing an otherwise 200 square mile CO_2 plume to 20 square miles. By

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[9] U.S. Department of Energy, National Energy Technology Laboratory, "Carbon Sequestration Atlas of the United States and Canada", Appendix A: Methodology for Development of Carbon Sequestration Capacity Estimates – Appendix 2, March 2007.

productively utilizing the structurally confined saline aquifer and any residual oil zone below the main pay zone of the oil field, the areal extent of the CO_2 plume could be further reduced by two-fold or more.

C. Accelerating the Application of CO_2 Storage. The integration of CO_2-EOR and CCS would greatly help accelerate the regulatory acceptance and implementation of CO_2 storage:

- Oil fields provide CO_2 storage options that can be permitted under existing (or slightly modified) regulatory guidelines, thereby avoiding the large delays inherent when waiting on new regulations and permitting for large-scale storage of CO_2 in saline formations.

- The pore space, mineral rights and long-term liability issues of oil fields are already well established and thus would not be impediments to a CO_2 storage project.

- Oil fields generally have existing subsurface data and often possess usable infrastructure such as injection wells and gathering systems, enabling more accurate assessment of CO_2 storage capacity and substantial cost savings.

- Oil fields have a proven reservoir caprock (seal) and structural closure, providing reliable vertical and lateral confinement for the injected volumes of CO_2.

Beyond these benefits, a number of other conditions favor the use of oil fields for injecting and storing CO_2. First, oil fields are located in areas with an accepted history of subsurface field activities contributing to public acceptance for storing CO_2. Second, oil fields provide an existing "brown field" storage site versus having to establish a new "green field" site when preparing a saline formation for CO_2 storage. Finally, the early reliance on EOR for storing CO_2 would help build the regional pipeline infrastructure for future CO_2 storage projects in saline formations.

D. Improving Energy Security by Using CO_2-EOR to Increase Domestic Oil Production. The recent report, prepared for the Natural Resources Defense Council by Advanced Resources International, entitled "U.S. Oil Production Potential from Accelerated Deployment of Carbon Capture and Storage",[10] states that combining CCS with enhanced oil recovery could boost U.S. oil production to 3 million barrels per day by year 2030, assuming that the vast majority of the CO_2 captured from the CCS projects deployed is used for CO_2-EOR. (A portion of this CO_2-EOR production, about 0.6 million barrels per day, would be from continued use of CO_2 from natural sources and gas processing plants.) This would significantly reduce imports of crude oil and reduce annual CO_2 emissions by 500 million metric tons by 2030.

The report draws on past extensive work on the topic of CO_2-EOR sponsored by the U.S. DOE/National Energy Technology Laboratory and assumes that: (1) Federal legislation designed to capture power plant CO_2 emissions (the America Clean Energy and Security Act, H.R. 2454) is adopted; (2) that all of the captured CO_2 is preferentially used for EOR; and (3) that oil prices are $70 per barrel. While clearly not all of the captured CO_2 would be used for EOR, due to a variety of constraints, the report does highlight that policies that encourage the productive use of captured CO_2 emissions could have a significant impact on increasing domestic oil production and improving domestic energy security.

This large volume of CO_2 enhanced domestic oil production would also improve the U.S. trade balance by $700 billion, increase state and Federal revenues by $200 billion and add tens of thousands of jobs between now and year 2030.

[10] Advanced Resources International, Inc., "U.S. Oil Production Potential from Accelerated Deployment of Carbon Capture and Storage", prepared for the Natural Resources Defense Council, March 2010.

4. FEASIBILITY OF LARGE-SCALE IMPLEMENTATION OF CO_2-EOR/CCS

A key implementation challenge for using CO_2-EOR to accelerate CCS is matching CO_2 sources from power and industrial plants with large oil fields favorable for enhanced oil recovery.

Certain regions, such as the Electricity Reliability Council of Texas (ERCOT), already contain large oil fields favorable for CO_2. As such, with about 100 billion kilowatt hours of coal-fired generation and about 100 million metric tons of annual CO_2 emissions from coal-fired power (equal to 3 billion metric tons in 30 years), entities within the ERCOT area should be able to relatively easily implement CO_2-EOR and CO_2 storage, assuming proper economic incentives and/or regulations are in place.[11]

Other electricity generation regions are not so fortunate. The CO_2 captured from these regions would need to be transported to markets using long distance, large capacity pipelines.

The largest coal-fired electricity region in the U.S. is the Ohio River Valley represented by the East Central Area Reliability Coordination Agreement (ECAR). This region annually delivers about 500 billion kilowatt hours from coal-fired generation and annually emits about 500 million metric tons of CO_2 (equal to 15 billion metric tons in 30 years). If CO_2-EOR is to have a significant role in accelerating the deployment of CCS in the power sector, there is a need to show that the large CO_2 emissions in the ECAR region can be matched with and used by favorable oil fields[11].

After retirement of older, inefficient coal plants and implementation of CCS in the remainder of the coal-fired power plant fleet in ECAR, approximately 9 billion metric tons of CO_2 (at a rate of 300 million metric tons per year for 30 years) would need to find a “happy home” in oil fields favorable for EOR. With only a very modest EOR-based CO_2 storage capacity of 0.6 billion metric tons offered by the nearby small oil fields in the Illinois Basin, if the captured CO_2 is to be productively used for CO_2-EOR, it

[11] Annual Energy Outlook 2010; U.S. Energy Information Administration

would need to be transported to the giant oil fields of Texas, Oklahoma and the Gulf Coast.

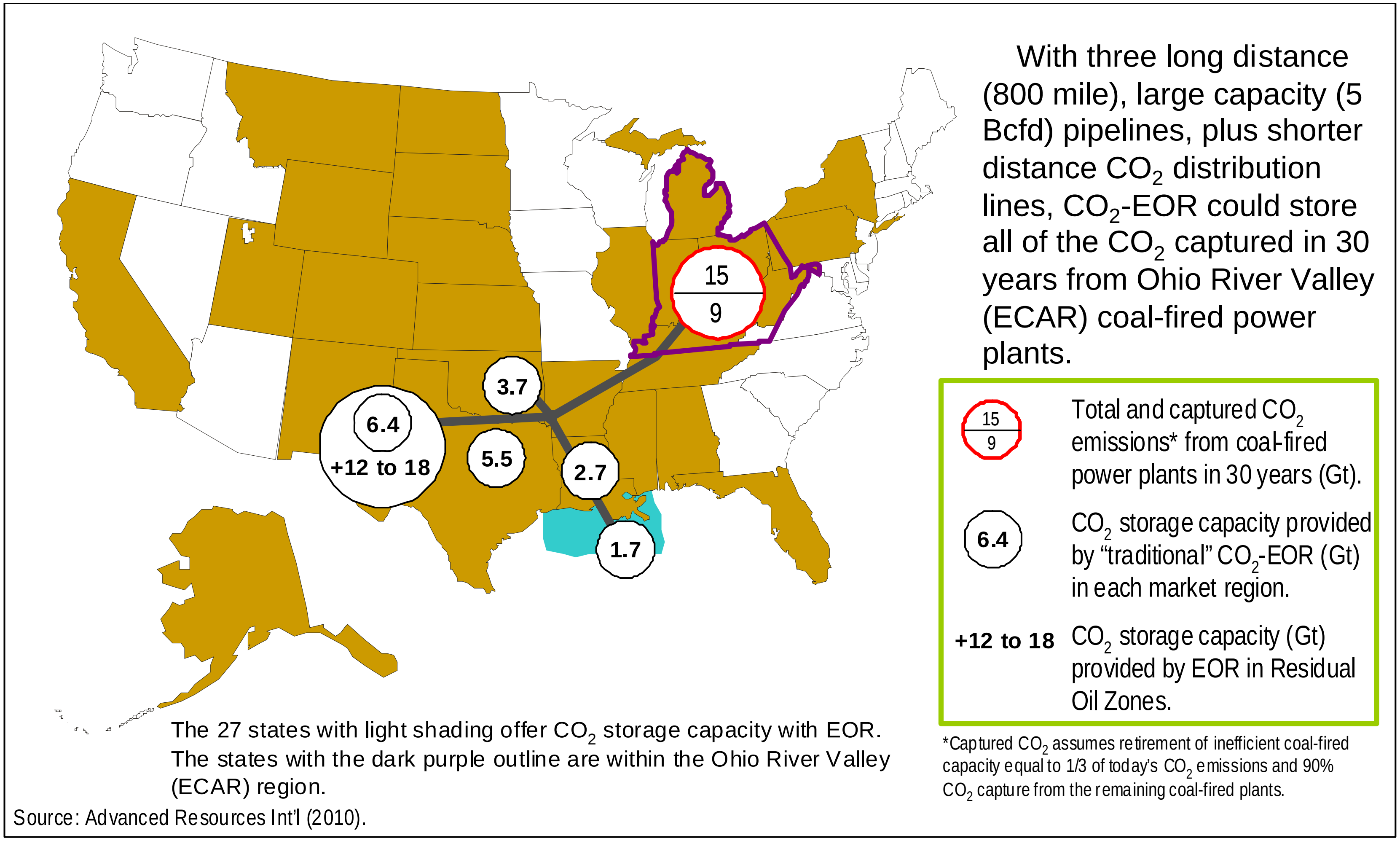
Figure 8 illustrates the feasibility of linking the captured CO_2 emissions from the ECAR Region (Michigan, Indiana, Ohio, Kentucky, West Virginia and the western portions of Pennsylvania and Virginia) with the vast EOR opportunities in Texas, New Mexico, the Mid-continent, and Louisiana.

- The traditional EOR markets, offering about 20 billion metric tons of traditional CO_2-EOR storage capacity, and increasing to 32 to 38 billion metric tons with the inclusion of the hydrodynamic residual oil zone fairways (ROZ) in the Permian Basin, could take all of this CO_2, plus more.

- A series of three 800 mile, large diameter (42 inch) pipelines, each with 5 Bcfd (100 million metric tons per year) of capacity would transport CO_2 from the Ohio/Indiana border to north-east Texas. (Because of the higher compressibility of CO_2, the diameter of the CO_2 pipeline would be smaller than an equivalent volume natural gas pipeline.) From there, a series of shorter distance CO_2 lines would distribute the CO_2 to EOR markets in Oklahoma, Louisiana, East/Central Texas and to the Permian Basin of West Texas/East New Mexico. Similar size natural gas pipelines and distribution systems are in common use. A similar CO_2 pipeline system, linking Ohio Valley CO_2 sources with Texas and Gulf Coast oil fields, is being studied by Denbury Resources.[12]

[12] Denbury Resources Corporate Presentation, June 2010.

Figure 8. Integrating CO_2 Capture from the Ohio River Valley with CO_2 Storage Using CO_2-EOR in Texas, Louisiana and Oklahoma



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5. ACCELERATING AND IMPLEMENTING INTEGRATED CO_2-EOR/CCS PROJECTS

Two sets of actions will be essential for accelerating the implementation of integrated CO_2-EOR/CCS:

- The first set of actions involves the development of public policies and the structuring of incentives that would first help "jump-start" CCS demonstrations and then would provide significant funds to accelerate its commercial-scale deployment.

- The second set of actions for implementing CO_2-EOR/CCS involves the establishment of contractual and business arrangements between the owner of the captured CO_2 (e.g., the power plant), the transporter of the CO_2 and the oil field operator interested in purchasing and using the CO_2 for enhanced oil recovery.

A. Developing Public Policies and Incentives

In the absence of requirements to capture CO_2 or a sufficiently high price on carbon emissions, the capture of CO_2 from a traditional coal-fired power plant will be uneconomic. As such, significant new financial incentives and funding support will be needed to "jump-start" CCS and accelerate its commercial-scale deployment.

1. "Jump-Starting" CCS Demonstrations. Most of all, it is important to get started. Federal and private funding is helping launch a handful of CCS demonstrations, including:

- The privately-funded (EPRI, Southern Company, MHI) small, 25 MW equivalent, post-combustion CO_2 capture plant at Plant Barry, Alabama, due on-line in early 2011.

- The AEP and Alstom 30 MW (thermal) chilled ammonia post-combustion CO_2 capture plant installed at AEP's Mountaineer Plant in West Virginia; to

- be followed by a larger 200 MW CO_2 capture plant at Northeastern Station, Oklahoma.

- The publically supported full-scale IGCC demonstration plants by Southern Company in Mississippi and by Summit Energy in West Texas, due on-line in 2014.

However, a significantly larger set of full-scale CO_2 capture demonstrations will be essential for “getting started” with CCS and particularly for introducing lower cost “second generation” CO_2 capture technologies.

The Pew Center Coal Initiative white paper - - “A Program to Accelerate the Deployment of CO_2 Capture and Storage”[13] - - analyzed the rationale, objectives and cost of one CCS strategy for “getting started” in the coal-fired power industry. This strategy would provide funding for retrofitting existing plants with CCS and for incorporating CCS into new plants. The key features of the strategy involved:

- Launching 30 commercial-scale CO_2 capture demonstrations (400 to 500+ MW each) by providing reimbursement of approximately $1 billon per plant.

- Funding this strategy with a fee (wire charge) of $0.0015 (0.15¢ per kWh) on coal-fired power plants.

A companion Pew Center Coal Initiative white paper - - “A Trust Fund Approach to Accelerating Deployment of CCS: Options and Considerations”[14] - - examined alternative funding options for helping CCS “get started”.

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[13] Pew Center on Global Climate Change, “A Program to Accelerate the Deployment of CO_2 Capture and Storage”, Coal Initiative Reports, White Paper Series, October, 2007.
[14] Pew Center on Global Climate Change, “A Trust Fund Approach to Accelerating Deployment of CCS: Options and Considerations”, Coal Initiative Reports, White Paper Series, January, 2008.

2. Accelerating Commercial-Scale Deployment of CCS. Accelerating commercial-scale deployment of CCS in the coal-fired power sector will require substantially larger incentives and funding support than for “getting started”. One such strategy is to draw on the incremental tax revenues that would be generated from productively using the CO_2 captured from coal plants by CO_2-based enhanced oil recovery.

For example, one potential CCS acceleration strategy would direct the Treasury to establish a CCS fund to support CCS deployment by annually depositing 5% of the projected 20 year tax revenues from incremental CO_2-EOR production:

- The first 20 GWs of CCS would receive $2.5 billion per GW, with the next 52 GWs of CCS receiving $2 billion per GW.

- This would enable 13 GWs of coal-fired power to be implemented with CCS by 2020, increasing to 69 GW by 2030.

- Assuming 70% of the captured CO_2 emissions would be used for CO_2-EOR, using the oil price track from AEO 2010, and using a sales price for CO_2 of $15 per ton, significant volumes of oil would be produced with CO_2-EOR (see below). The incremental tax revenues from the oil produced by CO_2-EOR would fund the CCS acceleration strategy.

- Under these assumptions, domestic oil production from CO_2-EOR would reach 2.8 million barrels per day. Approximately 0.56 million barrels per day of this total would be from CO_2-EOR using natural or gas separation plant CO_2. Another 0.60 million barrels per day would be from CO_2-EOR using various sources of new anthropogenic CO_2 (e.g., refinery hydrogen plants) and launched in response to increasing oil prices (the EIA AEO 2010 oil price track exceeds $100 per barrel starting in 2020). The final incremental 1.67 million barrels of CO_2-EOR based oil production would be from the installation of CCS due to the above CCS acceleration strategy, **Table 5**.

- The annual reduction of CO_2 emissions, from the 69 GWs of coal-fired power installed with CO_2 capture and stored with CO_2-EOR (implemented in response to the CCS acceleration strategy), would be on the order of 400 million metric tons.

Table 5. Projected Volumes of Oil Production from CO_2-EOR

CO_2 Sources		CO_2-EOR Production (B/D)			
		2012	2020	2025	2030
Natural/Gas Plant CO_2*		470	620	590	560
Anthropogenic CO_2					
	• Price Driven	-	70	220	600
	• Policy Driven	-	250	840	1,670
	TOTAL	470	940	1,650	2,830

*Includes 45 MMcfd of CO_2 from ammonia and fertilizer plants

B. *Establishing the Contractual Agreements*

Unless the integrated CO_2-EOR/CCS project is located in or near the Permian Basin or in Wyoming, areas which have a reasonably well established set of rules and historic practices for marketing CO_2, the sale and storage of the captured CO_2 will be established by a negotiated, project-specific contract. Various parties may be involved in this negotiation - - the owner (seller) of the captured CO_2, the CO_2 transporter, and the purchaser (user) of the captured CO_2 (the EOR field operator). The CO_2 user may also provide transportation; a marketing firm may facilitate the process between the CO_2 owner and the CO_2 user.

A great variety of contractual and business arrangements will likely need to be defined for an integrated CO_2 storage/CCS project, depending on the business interests of the various parties. Three potential business and contract arrangements are discussed below.

A. Arms Length Entities. Under this arrangement, the owner of the captured CO_2 (e.g., the power plant) would sell its CO_2 (and potentially transfer its liability for storing the CO_2) to an oil field operator interested in productively using the CO_2 for enhancing oil recovery.

The oil field operator will contract with a CO_2 pipeline (or build the pipeline and gathering system) to transport the CO_2 to the oil field. The sales price for the CO_2 (at the plant gate) will be negotiated and established based on the relative market power of the parties and the competitive market price for CO_2 in the local area. The CO_2 sales price may be indexed to the oil price, providing some upside value to the CO_2 seller and some downside protection to the CO_2 buyer.

Minimum and maximum volumes, as well as take or pay arrangements, may be included in the contract terms. If there is a credit or value for capturing CO_2, this value may be shared, in some way, among the two parties, as set forth in the contract.

Under this arrangement, the oil field operator assumes the major risks and all of the costs of storing CO_2, including providing documentation of its safe and secure storage for obtaining the CO_2 credit.

The Northern Great Plains Gasification and Weyburn oil field project illustrates the “arms length entities” arrangement for initiating CO_2 sales to an enhanced oil recovery project.

B. Joint Venture Entities. Under this arrangement, the owner of the captured CO_2 and the oil field operator enter into a joint venture to share, in some way, in the success of the CO_2-EOR project. The owner of the CO_2 may contribute the CO_2 to the EOR project in return for a portion of the revenues or profits (and CO_2 storage credits). In this case, the two parties will share the risk, costs and profits, if any.

The initial CO_2 sales proposals between KinderMorgan and various oil field operators, when CO_2 supplies in West Texas were plentiful, illustrate the “joint venture entities" approach for initiating CO_2 sales to enhanced oil recovery projects. (Because of complexities, only a few such sales arrangements were completed.)

C. Single Integrated Party Entity. In some cases, the owner of the captured CO_2 from a gas processing plant or a refinery may also be an oil field operator looking to use CO_2-EOR. In this single party situation, while there may be internal transfer costs among the various business units of the company, the costs, risks and rewards accrue to the overall company.

Integrated major oil companies, with CO_2 from refineries and gas processing plants and favorable oilfields, would represent this situation.

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The White Paper argues that the CO_2 storage capacity offered by EOR is vast and that the productive use of CO_2 for EOR would significantly accelerate the application of CCS while improving domestic energy security. As such, policies, incentives and regulations that encourage the integrated application of CO_2-EOR and CCS would clearly be in the nation's interest.