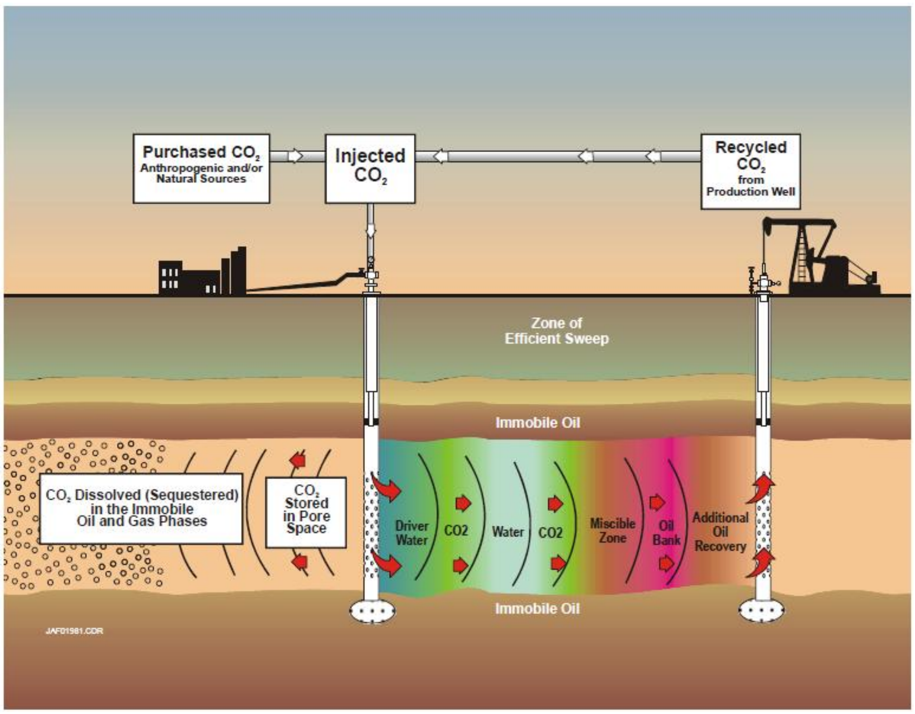
CO_2-EOR Background

The sections below describe enhanced oil recovery using CO_2 (CO_2-EOR), provide a snapshot of the current status of CO_2-EOR, and highlight the potential for greatly expanded CO_2-EOR production.

CO_2-EOR Description

CO_2 enhanced oil recovery (CO_2-EOR) refers to the injection of carbon dioxide (CO_2) into mature oil fields to recover more of the original oil in place than would be otherwise recoverable. Figure 1 illustrates how CO_2-EOR works.

Figure 1: Schematic Showing CO_2-EOR Process[1]



The National Energy Technology Laboratory (NETL) describes CO_2-EOR as follows.[2]

> When an oil reservoir is first produced, the pressure that exists in the subsurface provides the energy for moving the oil . . . that is in the rock to the surface. After a while, the pressure dissipates, and pumps must be used to remove additional volumes of oil. Depending on the characteristics of the rock and the oil, a considerable amount of the original oil in place may be left behind as residual oil. When . . . injected CO_2 and residual oil are miscible [i.e., when they mix] . . . this enables the CO_2 to displace the oil from the rock pores, pushing it towards a

[1] Advanced Resources International and Melzer Consulting, *Optimization of CO_2 Storage in CO_2 Enhanced Oil Recovery Projects*, prepared for UK Department of Energy & Climate Change, November 2010. See http://bit.ly/la8tuq.
[2] National Energy Technology Laboratory (NETL), *Carbon Dioxide Enhanced Oil Recovery*. See http://1.usa.gov/kV5NeZ.

producing well just as a cleaning solvent would remove oil from your tools. As CO_2 dissolves in the oil it swells the oil and reduces its viscosity; [these effects also] improve the efficiency of the displacement process.

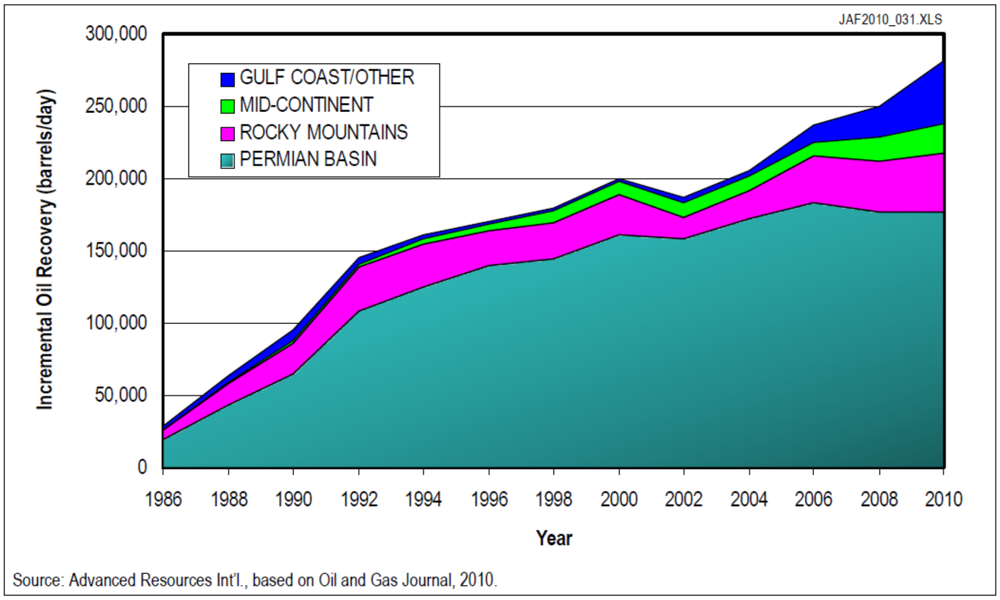
[Typically], a pipeline delivers the CO_2 [from natural or anthropogenic sources] to the [oil] field at a pressure and density high enough for the project needs . . . . . This CO_2 is directed to injection wells strategically placed . . . based on computer simulations. Any CO_2 [extracted with the oil] is separated . . . and recompressed for reinjection along with additional volumes of newly-purchased CO_2.

CO_2-EOR Status

Commercial CO_2-EOR in the United States first started in 1972 in West Texas using CO_2 captured at natural gas processing plants.[3] Subsequently, CO_2-EOR has grown to provide about 280,000 barrels of oil per day in the United States, equal to 6 percent of U.S. crude oil production. While most CO_2-EOR production is still in the Permian Basin in West Texas, CO_2-EOR has expanded to numerous other regions of the country (see Figure 2).

[3] National Energy Technology Laboratory (NETL), *Carbon Dioxide Enhanced Oil Recovery*. See http://1.usa.gov/kV5NeZ. According to NETL: "[t]he ready availability of a low-cost source of CO_2 . . . drove the Permian Basin's EOR boom in the 1970s and 1980s. The first commercial flood occurred in Scurry County, Texas, in 1972, in what was known as the SACROC Unit (SACROC stands for Scurry Area Canyon Reef Operators Committee). For this project, the operator (Chevron) recovered CO_2 from natural gas processing plants in the southern part of the basin (that would have otherwise been vented) and transported the gas 220 miles for injection at SACROC. The technical success of this project, coupled with the high oil prices of the late 1970s and early 1980s, led to the construction of three major CO_2 pipelines connecting the Permian Basin oil fields with natural underground CO_2 sources located at the Sheep Mountain and McElmo Dome sites in Colorado and Bravo Dome in northeastern New Mexico. Construction of the pipelines spurred an acceleration of CO_2 injection activity in Permian Basin fields."

Figure 2: Growth of CO_2-EOR Production in the United States[4]



There are currently more than 100 CO_2-EOR projects nationwide that are supplied with CO_2 from both natural and anthropogenic sources (see Figure 3). In 2009, Advanced Resources International (ARI) reported that CO_2-EOR projects used 55 million metric tons of CO_2 per year.[5] Natural sources of CO_2 dominate the supply of CO_2 for CO_2-EOR, and most anthropogenic CO_2 supply comes from CO_2 captured at natural gas processing plants (see Figure 4). Table 1 shows the operators of CO_2-EOR projects, the magnitude of their CO_2-EOR production, and where they have operations.

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[4] Kuuskraa, Vello, *Challenges of Implementing Large-Scale CO_2 Enhanced Oil Recovery with CO_2 Capture and Storage*¸ 2010, White Paper prepared for the Symposium on the Role of Enhanced Oil Recovery in Accelerating the Deployment of Carbon Capture and Storage. See http://bit.ly/l3Rx5w.

[5] Kuuskraa, Vello, *Challenges of Implementing Large-Scale CO_2 Enhanced Oil Recovery with CO_2 Capture and Storage*¸ White Paper prepared for the 2010 Symposium on the Role of Enhanced Oil Recovery in Accelerating the Deployment of Carbon Capture and Storage. See http://bit.ly/l3Rx5w.

Figure 3: Current U.S. CO_2-EOR Activity[6]

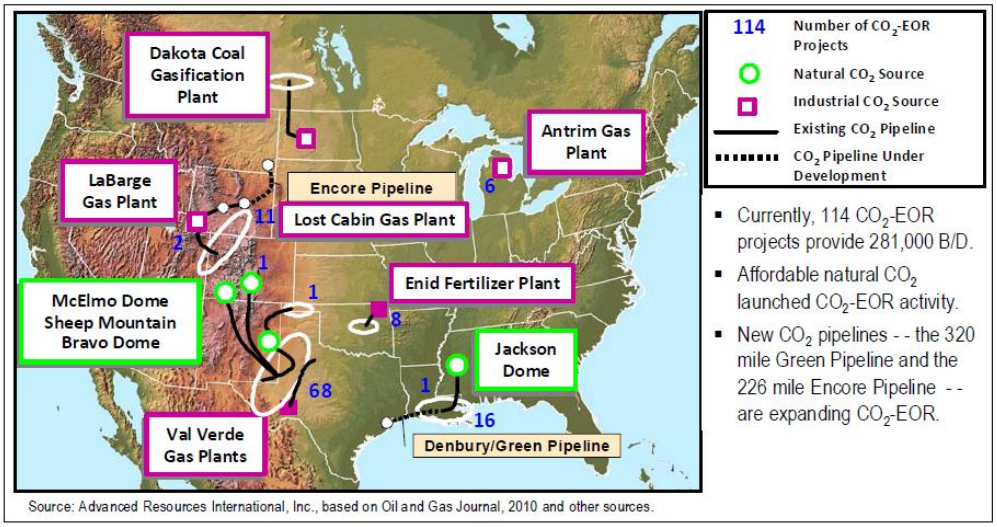
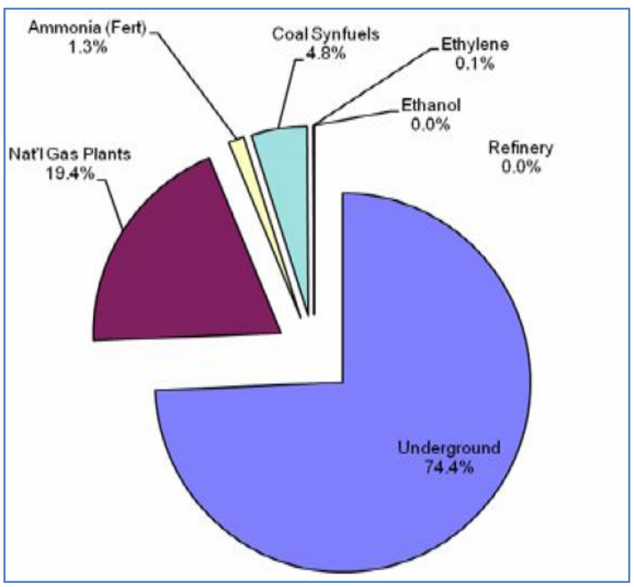


Figure 4: Estimated Daily North American CO_2 Source Deliveries for CO_2 EOR – December 2010[7]



[6] Advanced Resources International and Melzer Consulting, *Optimization of CO_2 Storage in CO_2 Enhanced Oil Recovery Projects*, prepared for UK Department of Energy & Climate Change, November 2010. See http://bit.ly/la8tuq.

[7] Hargrove, Melzer, and Whitman, "A Status Report on North American CO_2 EOR Production and CO_2 Supply," Presented at the 16th Annual CO_2 Flooding Conference, December 9-10, 2010, Midland, TX. See http://bit.ly/lY9gXy.

Table 1: CO_2-EOR Production by Operator[8]

Operator	Number of Fields	Incremental Production (bbl per day)	States with Operations
Occidental	22	90,211	NM , TX
Denbury Resources	14	32,980	LA , MS
Kinder Morgan	2	30,507	TX
Hess	2	25,250	TX
Chevron	7	24,221	CO , NM , TX
Merit Energy	4	13,640	OK , WY
ExxonMobil	2	11,700	TX , UT
Anadarko	3	9,000	WY
Whiting Petroleum	3	6,900	OK , TX
ConocoPhillips	2	5,450	NM , TX
Apache	2	5,000	TX
XTO Energy Inc.	3	2,670	TX
Chaparral Energy	6	2,515	OK , TX
Devon	1	2,425	WY
Core Energy	6	641	MI
Energen Resources	1	450	TX
Fasken	5	450	TX
Resolute Natural Resources	1	400	UT
Great Western Drilling	1	170	TX
Orla Petco	1	128	TX
Stanberry Oil	1	102	TX
Murfin Drilling	1	3	KS

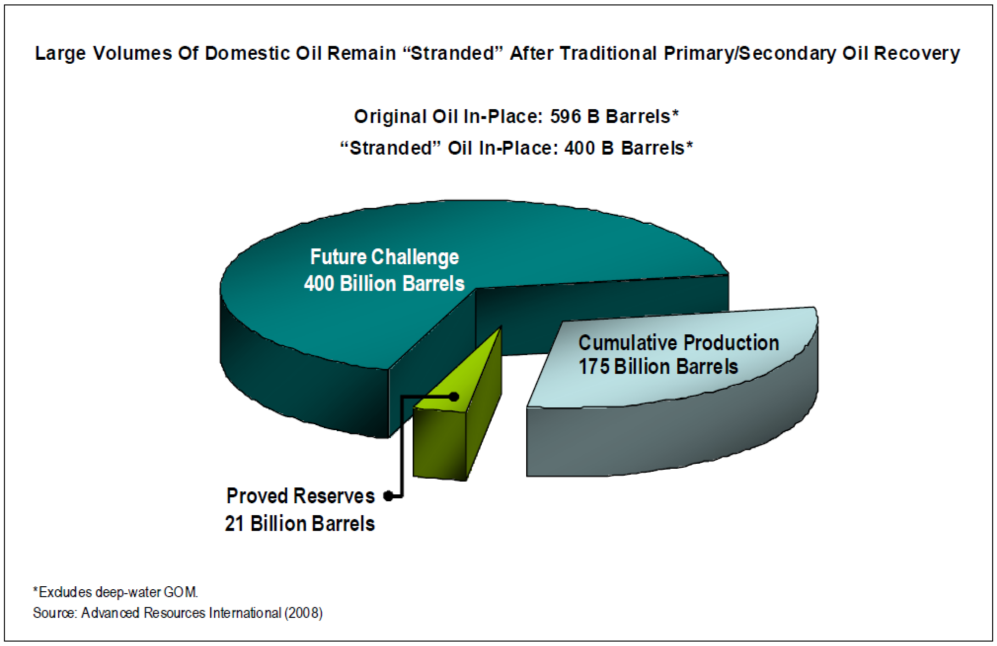
CO_2-EOR Outlook and Potential

The U.S. has a large oil resource base (nearly 600 billion barrels originally in-place). About one-third of this oil resource base has been recovered or placed into proved reserves with existing primary and secondary oil recovery technologies.[9] As such, 400 billion barrels of the U.S. oil resource base remain as "technically stranded" oil, some significant portion of which can be recovered via CO_2-EOR.

[8] Data from *Oil & Gas Journal* surveys as presented in Appendix B: U.S. Oilfields Using CO_2 Injection for Enhanced Oil Recovery of EPA's Greenhouse Gas Reporting Program *General Technical Support Document for Injection and Geologic Sequestration of Carbon Dioxide: Subparts RR and UU*, November 2010. See http://1.usa.gov/inUqXb.

[9] Proved reserves refer to "[e]stimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The location, quantity, and grade of the energy source are usually considered to be well established in such reserves." U.S. EIA Glossary.

Figure 5: U.S. Domestic Oil Resource Base[10]



Studies have arrived at different estimates of the amount of oil that is technically and economically recoverable via CO_2-EOR.[11] Estimates of the technically and economically recoverable oil will vary depending on such factors as:

- Oil reservoirs judged suitable for CO_2-EOR
- Oil prices
- Cost and availability of CO_2
- CO_2-EOR technology (e.g., "state-of-the-art" vs. "next generation")

Advanced Resources International (ARI) and the U.S. Energy Information Administration (EIA) have both recently estimated the amount of oil that is technically and economically recoverable via CO_2-EOR (Figure 6 and Figure 7 show the estimates from ARI and EIA, respectively).

[10] National Energy Technology Laboratory (NETL), *Storing CO_2 and Producing Domestic Crude Oil with Next Generation CO_2-EOR Technology*, prepared by Advanced Resources International, Inc., January 2009. See http://1.usa.gov/lEiYAp.

[11] Technically recoverable refers to oil that could be potentially produced using current technology and industry practices. Economically recoverable oil is technically recoverable oil that could be sold at a price that covers the costs of discovery, development, production and transportation to the market.

Figure 6: ARI's Estimates of Potential New U.S. Oil Supplies from CO_2-EOR[12]

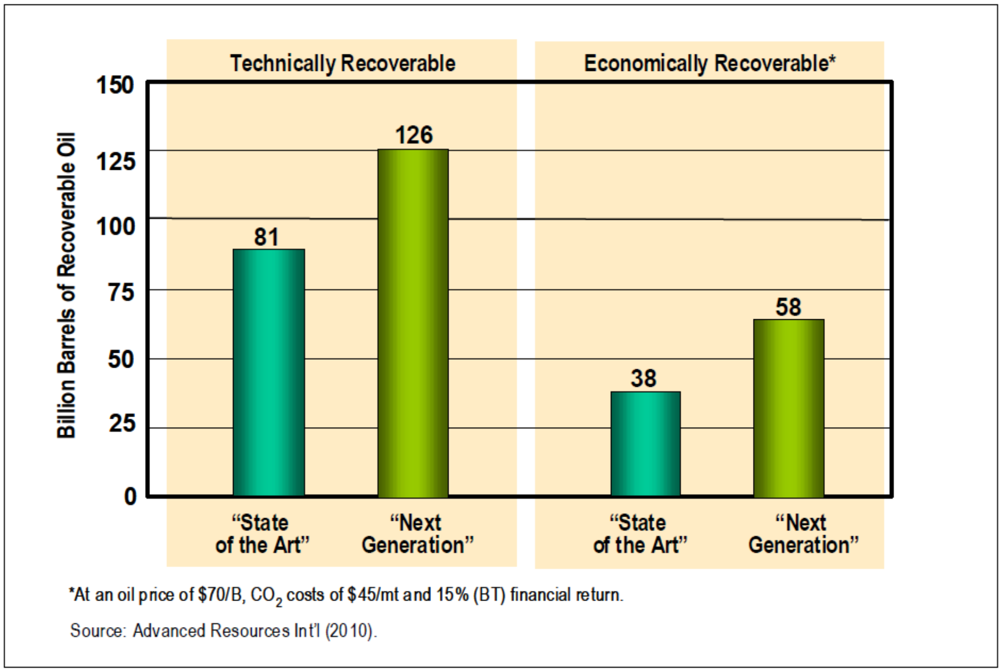
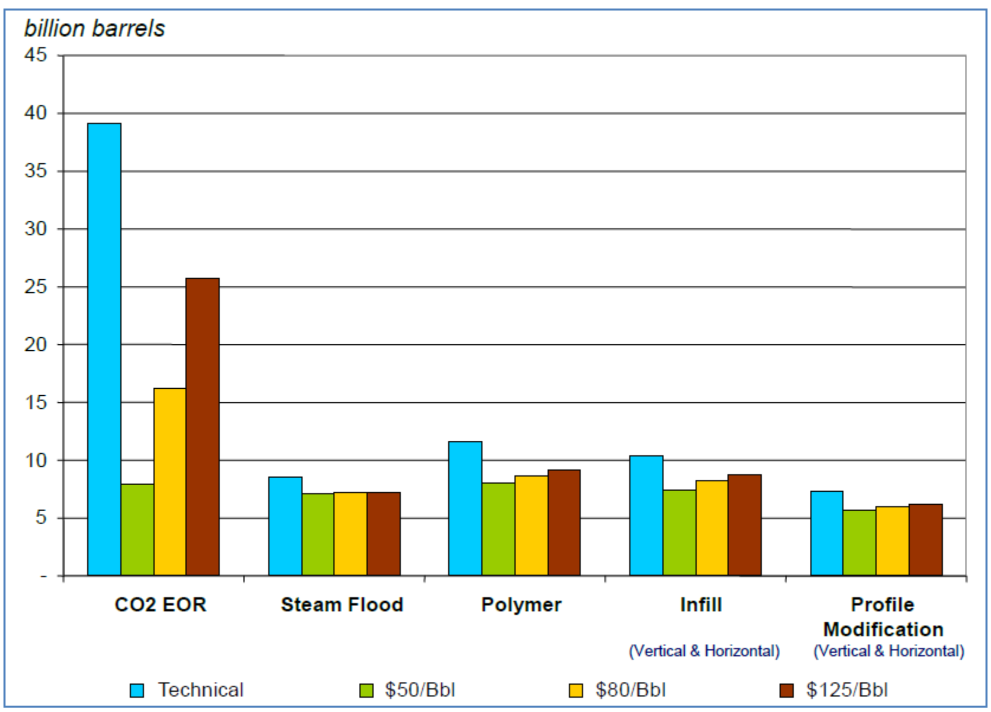


Figure 7: EIA's Technical and Economic Production for EOR and Advanced Secondary Recovery (ASR)[13]



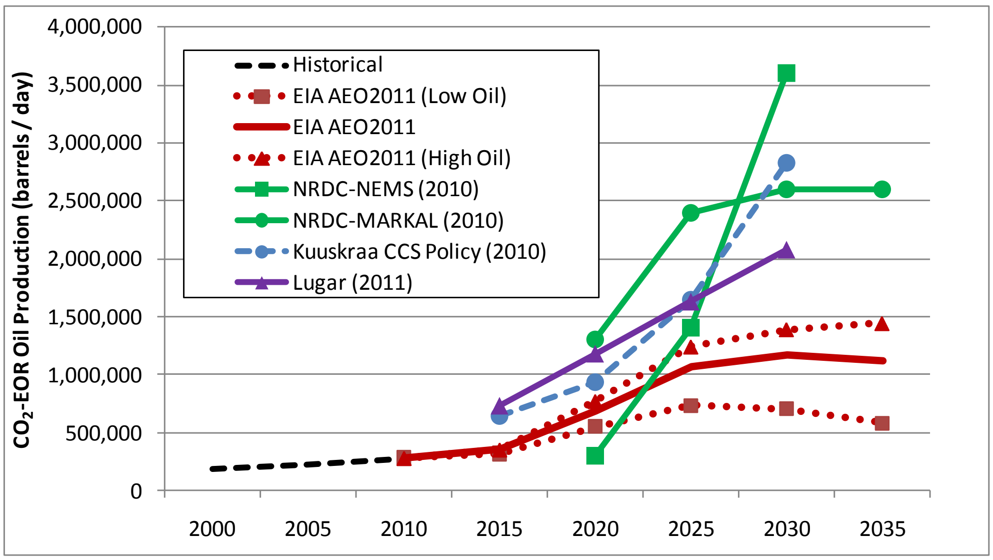
[12] Advanced Resources International and Melzer Consulting, *Optimization of CO_2 Storage in CO_2 Enhanced Oil Recovery Projects*, prepared for UK Department of Energy & Climate Change, November 2010. See http://bit.ly/la8tuq.

[13] Wagener and Mohan, "Onshore Lower 48 Oil & Gas Supply Submodule (OLOGSS)," Workshop Presentation, 27 April 2011, available at http://bit.ly/psQnbn.

Several analyses have sought to project future CO_2-EOR production under both "business-as-usual" policies and under new policies to incentivize CO_2 capture and/or CO_2-EOR. Figure 8 illustrates such recent projections and highlights the finding that new policies to promote CO_2 capture and CO_2-EOR can lead to very large increases in CO_2-EOR production.

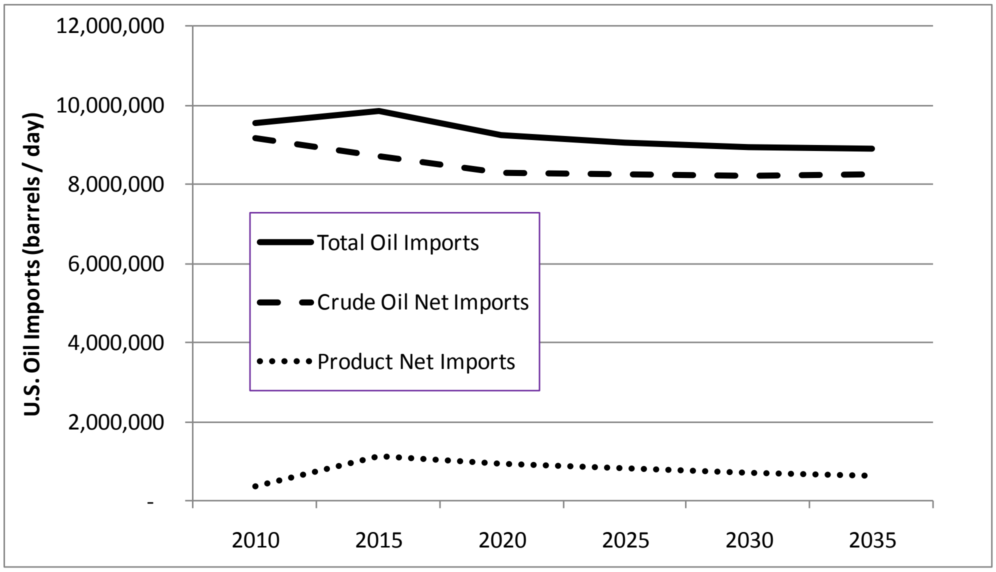
To provide a sense of the magnitude of the potential energy security benefit from greater domestic CO_2-EOR oil production, Figure 9 shows the projected level of U.S. oil imports under the most recent "business as usual" projections from the U.S. Energy Information Administration. The analyses summarized in Figure 8 suggest that CO_2-EOR production could increase substantially and displace a large fraction of U.S. oil imports.

Figure 8: Projections for CO_2-EOR Oil Production[14]



[14] Historical data are from the *Oil & Gas Journal* CO_2-EOR survey (2010). "EIA AEO2011" refers to the *Annual Energy Outlook 2011*. EIA data presented are from the Reference Case and High and Low Oil Price cases and are from Wagener and Mohan, "Onshore Lower 48 Oil & Gas Supply Submodule (OLOGSS)," Workshop Presentation, 27 April 2011. See http://bit.ly/psQnbn. The Natural Resources Defense Council (NRDC) projections are from NRDC's NEMS and MARKAL modeling of CO_2-EOR production using CO_2 captured as a result of the policies in the American Clean Energy and Security Act of 2009. See Advanced Resources International, Inc., (ARI), *U.S. Oil Production Potential from Accelerated Deployment of Carbon Capture and Storage,* March 2010, prepared for NRDC, available at http://bit.ly/k83vO2. "Kuuskraa CCS Policy" refers to the projections for a policy that uses federal tax revenues associated with incremental CO_2-EOR production to provide financial incentives for CO_2 capture projects. See ARI, *Challenges of Implementing Large-Scale CO_2 Enhanced Oil Recovery with CO_2 Capture and Storage*, White Paper for MIT Symposium, July 2010, available at http://bit.ly/izq5yd. "Lugar" refers to the incremental CO_2-EOR production projected under Senator Lugar's Practical Energy Plan of 2011 by ClimateWorks (see http://bit.ly/oZqix6).

Figure 9: Projected U.S. Oil Imports (EIA's AEO2011)[15]



Multiple analyses have estimated the cost of supplying anthropogenic CO_2 from various sources for EOR operations. Table 2 shows one recent estimate (from the U.S. Energy Information Administration) of CO_2 supply costs and the potential magnitude of annual CO_2 supply for EOR from various anthropogenic CO_2 sources. Note that Table 2 is meant to illustrate the relative potential cost and availability of CO_2 from anthropogenic sources rather than to provide definite estimates. One can see from Table 2 that the estimated costs of CO_2 varies widely across different types of anthropogenic CO_2 sources as does the potential magnitude of CO_2 supply from such sources.

Table 2: EIA Estimates of Cost and Magnitude of Anthropogenic CO_2 Sources (AEO2011)[16]

CO_2 Source	Maximum CO_2 Volumes (million tons)	Average Carbon Capture & Transportation Cost ($/ton)
Natural Gas Processing	11	27
Coal-to-Liquids	77	27
Refineries	17	29
Ammonia Plants	5	31
Ethanol Plants	18	33
Hydrogen Plants	0.2	37
Cement Plants	22	70
Fossil Fuel Power Plants	1,209	100

[15] EIA's *Annual Energy Outlook 2011* Reference Case.
[16] Wagener and Mohan, "Onshore Lower 48 Oil & Gas Supply Submodule (OLOGSS)," Workshop Presentation, 27 April 2011. See http://bit.ly/psQnbn. The estimates of maximum CO_2 volumes in Table 2 include assumptions about which CO_2 sources might be suitable for capturing CO_2 and supplying it for EOR.

<u>Key Excerpts from Relevant Analyses</u>

ARI, *U.S. Oil Production Potential from Accelerated Deployment of Carbon Capture and Storage,* March 2010

Of the estimated 596 billion barrels of U.S. oil endowment (expressed as original volumes of oil in place, or OOIP), about two-thirds (395 billion barrels) is favorable for CO_2-EOR. Application of "best practices" CO_2-EOR would enable over 72 billion barrels to be technically recoverable in the Lower 48. At oil prices of $70 per barrel and CO_2 costs of $15 per tonne, over 38 billion barrels would be economically recoverable. This is in addition to the estimated 2.3 billion barrels already being developed with CO_2-EOR in the U.S.

The use of "next generation" technology would add to these totals. Specifically, the application of this technology would provide over 106 billion barrels of technically recoverable domestic oil in the lower 48 (nearly 50% more than can be accomplished with current best practices for CO_2-EOR). About 70% of this technical potential exists in just four regions (California, Mid-Continent, Permian Basin, and East/Central Texas). Of this technically recoverable resource, over 57 billion barrels would be economically recoverable at these oil prices and CO_2 costs. (For purposes of this assessment, the CO_2-EOR potential in Alaska was not included.)

Within each region of the country, the majority of the economic CO_2-EOR potential generally exists in a relatively small share of the economic prospects. The importance of the characterization of this distribution is that, in the initial stages of growth of the CO_2-EOR/CCS market, these largest CO_2-EOR prospects will serve as the "anchors" for the establishment of CO_2 transport and storage infrastructure in the various basin regions. Once infrastructure is established around these "anchor" prospects, the development of the smaller prospects can subsequently occur more economically, adding both to the oil production and economic storage potential achieved within the region.

However, it is important to recognize that for a single large coal-fired electric power production facility, producing 5 to 8 million tonnes of CO_2 per year for as long as 50 years, a single CO_2-EOR prospect will generally not be sufficiently large to store all of the CO_2 emissions from the plant. However, a hydrocarbon basin, in general, will be able to accommodate, in aggregate, the output of a number of plants. Thus, given the nature of the field size distribution in a basin described above, in most cases, several CO_2 -EOR prospects will often need to be pooled together to accommodate the produced CO_2.

[A] number of high purity CO_2 sources -- ammonia/fertilizer plants, ethanol and ethylene oxide plants, hydrogen plants, and natural gas processing plants -- which have lower capture costs than power plants and, consequently, could adopt CCS before such technologies begin to deploy broadly within the electric power sector. These high concentration CO_2 sources are some of the most likely earlier sources for expanded application for CO_2-EOR, even in the absence of enabling legislation like [the American Clean Energy and Security Act of 2009, or the Waxman-Markey bill]. More than 500 of these types of industrial sources of CO_2 emissions exist in the U.S. Depending upon the portion of refinery emissions included, these sources can produce from 170 to 370 million tonnes of CO_2 per year, with perhaps a best estimate, including only CO_2 emissions from H2 production at oil refineries, of about 200 million tonnes of CO_2 per year.

In addition, energy intensive industries such as steel and cement production have significant potential for carbon capture, which could add an additional 90 million tonnes of CO_2 per year. Some of these industrial applications of carbon capture are capital intensive and would require state and federal incentives to be economic, even with potential revenue from selling captured CO_2 to EOR operations.

[C]urrent sources of CO_2 for CO_2-EOR (both natural and anthropogenic) support production of over 250,000 barrels of oil per day. These sources, along with the planned expansions of CO_2 supply and transport capacity also discussed above, could support additional CO_2-EOR production for some time. Conservatively, assuming that about 300,000 barrels per day can be produced using CO_2 from these (predominately) natural sources, and that CO_2-EOR production ramps up uniformly over 18 years (from 2012 to 2030), 6 to 7 billion barrels of incremental oil could be produced using captured CO_2 from industrial sources, assuming all of this CO_2 is utilized for CO_2-EOR. This ranges from 16% to 18% of the economic Lower-48 oil production potential assuming "best practices" CO_2-EOR technology. This would result in 1.6 to 1.8 billion tonnes of stored CO_2 from "high value" industrial sources by 2030. Therefore, substantial CO_2-EOR oil production potential (along with the associated CO_2 storage potential) remains that could be the target for CO_2 captured via the application of CCS technologies for power plants.

[I]n general, a "typical" project would require 2 to 3 years for conversion of an oil field under waterflood to one ready for CO_2 flooding (including well drilling and workover and the construction of CO_2 processing, recycling, compression, and distribution facilities). Once flooding begins, the early years (the first 5 to 10 years) are dominated by the use of CO_2 acquired from external supplies, after which an increasing proportion of the CO_2 injected is that which is recycled as it is produced in association with the oil.

Region	Incremental Technically Recoverable Oil* (Billion Barrels)		Incremental Economically Recoverable Oil** (Billion Barrels)	
	"Best Practices"	"Next Generation"	"Best Practices"	"Next Generation"
California	6.3	10.0	5.5	7.8
Gulf Coast (AL, FL, MS, LA)	7.0	7.4	2.3	2.3
Mid-Continent (OK, AR, KS, NE)	10.6	17.0	5.6	8.7
Illinois/Michigan	1.2	3.2	0.5	1.7
Permian (W TX, NM)	15.9	28.0	9.4	15.0
Rockies (CO,UT,WY)	3.9	7.1	2.2	4.3
Texas, East/Central	17.6	20.0	8.4	12.1
Williston (MT, ND, SD)	2.5	5.2	0.5	0.5
Appalachia (WV, OH, KY, PA)	1.6	2.6	0.1	0.1
Louisiana Offshore	5.8	5.8	3.9	3.9
Lower 48	**72.4**	**106.3**	**38.5**	**56.5**
Alaska	12.4	12.4	9.5	9.5
TOTAL	**84.8**	**118.7**	**48.0**	**66.0**

*Incremental technically recoverable oil resources after subtracting 2.3 billion barrels already being developed with CO_2-EOR.

**Assumes an oil price of $70 per barrel (constant, real) and a CO_2 cost of $15 per metric ton ($0.79/Mcf), delivered at pressure to the field; and a 25% investment hurdle rate of return

Region	Gross Market for CO_2 (million metric tons)		CO_2 Already Scheduled to be Injected (million metric tons)	Net New Market for CO_2 (million metric tons)	
	"Best Practices"	"Next Generation"		"Best Practices"	"Next Generation"
California	1,410	1,459	-	1,410	1,459
Gulf Coast (AL, FL, MS, LA)	721	721	250	471	471
Mid-Continent (OK, AR, KS, NE)	1,439	1,778	20	1,419	1,758
Illinois/Michigan	122	365	-	122	365
Permian (W TX, NM)	2,877	3,648	570	2,307	3,078
Rockies (CO,UT,WY)	568	809	74	494	735
Texas, East/Central	1,997	2,182	-	1,997	2,182
Williston (MT, ND, SD)	125	92	-	125	92
Appalachia (WV, OH, KY, PA)	41	18	-	41	18
Louisiana Offshore	1,386	1,386	-	1,386	1,386
Lower 48	**10,687**	**12,456**	**914**	**9,773**	**11,542**
Alaska	2,094	2,094	-	2,094	2,094
TOTAL	**12,781**	**14,550**	**914**	**11,867**	**13,636**

*Assumes oil price of $70 per barrel; CO_2 cost of $15 per metric ton; and a 25% investment hurdle rate of return

CO_2-EOR Field Cumulative Probability Distribution					
Region	Field Size Cutoff for 70% of Economic Potential (MMBbls)	Fields > Field Size Cutoff		Fields < Field Size Cutoff	
		#	% of Total	#	% of Total
California	830	17	23%	58	77%
Gulf Coast (AL, FL, MS, LA)	149	26	34%	50	66%
Mid Continent (OK, AR, KS, NE)	289	21	29%	51	71%
Illinois/Michigan	77	9	20%	35	80%
Permian (W TX, NM)	625	25	27%	67	73%
Rockies (CO, UT, WY)	135	21	30%	49	70%
Texas (East/Central)	305	21	17%	104	83%
Williston (MT, ND, SD)	96	9	41%	13	59%
Appalachia (WV, OH, KY)	150	2	33%	4	67%
Average	295	151	26%	431	74%

Source: U.S. Department of Energy/National Energy Technology Laboratory

Table 5. Comparison of Forecasts of CCS Deployment and Associated Benefits due to ACES

	2020	2025	2030	Estimated Cum by 2030	2035	2040	2045	2050	Estimated Cum by 2050
Coal with CCS Deployment - Capacity (GW)									(GW)
NRDC - MARKAL	16.9	36.9	39.8		87	138	154	201	**201**
NRDC - NEMS	13.6	45.6	108.8						
EIA - NEMS	13.1	31.4	68.9						
Coal with CCS Deployment - CO_2 Stored (million tonnes)				(Gt)					(Gt)
NRDC - MARKAL	124	226	243	**2.4**	521	809	902	1,170	**96**
NRDC - NEMS	78	224	530	**1.6**					
EIA - NEMS	85	190	409	**1.5**					
Incremental Oil Prod. from CO_2 Stored with CCS from Power Plants (MMBpd)*				(Billion Barrels)					(Billion Barrels)
NRDC - MARKAL***	1.3	2.4	2.6	**9**	2.6	2.6	3.9	4.8	**37**
NRDC - NEMS	0.3	1.4	3.6	**6**					
EIA - NEMS	0.4	1.3	3.0	**6**					

* Assumes all CO_2 from CCS is stored in oil fields with EOR potential at a rate of 0.26 tonnes of stored CO_2 per barrel of oil.
** Assumes a price for captured CO_2 of $15/ton, which increases economic potential to between 38 billion barrels using "best practices" and 59 billion barrels using "next generation" technologies at oil prices ranging from $70 and $100 per barrel."

Key Assumptions:

In this report, [the authors] assumed that such "best practices" were applied at a minimum to all prospective CO_2-EOR projects. Specifically, "best practices" in this assessment, assumes "State-of-the-Art" technology characteristics used in previous DOE/NETL studies. These represent the practices used by the most sophisticated operators today, which are much improved over the CO_2-EOR practices traditionally used by many operators.

The injection of much larger volumes of CO_2 (1.0 HCPV), rather than the smaller (0.4 HCPV) volumes used in the past.

While average rates of return for the oil industry tend to average much lower, in practice, a 25% ROR hurdle rate was assumed in this assessment to represent the increased risks associated with the application of CO_2-EOR, especially for those operators not familiar with the technology.

Based on this characterization of economic potential for CO_2-EOR, it takes, on average, approximately 0.28 tonnes of CO_2 per incremental barrel produced for CO_2-EOR under the "best practices" scenario, and 0.22 tonnes of CO_2 per incremental barrel produced under the "next generation" technologies case.

As there is insufficient characterization of this residual oil zone (ROZ), the stranded oil potential for recovery was not included in our modeling of technical and economic CO_2-EOR potential and would be an additional opportunity for expanded CO_2-EOR production as CO_2 supplies develop and saturate EOR markets.[17]

EIA, AEO2011[18]

[17] Residual Oil Zones (ROZs) are underground reservoirs consisting of a brine or saline solution that is partially saturated with oil.
[18] The information presented herein concerning EIA's AEO2011 CO_2-EOR modeling results and assumptions comes from both the AEO2011 full report and Wagener and Mohan, "Onshore Lower 48 Oil & Gas Supply Submodule (OLOGSS)," Workshop Presentation, 27 April 2011, available at http://www.eia.gov/oiaf/emdworkshop/pdf/ologss_wkshop.pdf.

In 2009, CO_2-EOR operators injected nearly 50 million metric tons of CO_2 into operating domestic oil wells, most of which was obtained from natural sources. However, the limited supply of natural CO_2 has provided enough incentive for a few facilities to capture anthropogenic CO_2. This activity has also financed the construction of several pipelines to transport CO_2 to oil fields. There is potential for more early adopters of CCS to continue receiving payments from CO_2-EOR operators, but the quantity of CO_2 that potentially could be used for EOR is small in comparison with the 2.2 billion metric tons emitted in the U.S. power sector in 2009.

In the Reference case, CO_2-EOR plays an increasing role in U.S. petroleum production. Figure 10 shows the increasingly important role that EOR and advanced secondary recovery (ASR) play in U.S. onshore oil production, and Figure 11 depicts how CO_2-EOR dominates projected EOR/ASR production. Early in the projection period, most CO_2 is obtained from natural sources. As demand for CO_2 increases beyond the capacity of natural sources, industrial emitters with relatively pure streams of CO_2 begin to capture and sell the CO_2 to EOR operators (see Figure 12). No anthropogenic CO_2 is captured from power plants beyond the 2 gigawatts of advanced coal with sequestration that is assumed to be supported by Federal incentives, because the cost is too high for oil producers to implicitly fund the construction of a CCS-capable power plant. CO_2-EOR supports more than 1.1 million barrels per day of domestic oil production in 2035 in the Reference case, nearly 4 times the CO_2-EOR production level in 2009. CO_2-EOR provides 19 percent of total U.S. crude oil production in 2035.

Figure 10: U.S. Onshore Crude Oil Production, AEO2011 Reference Case

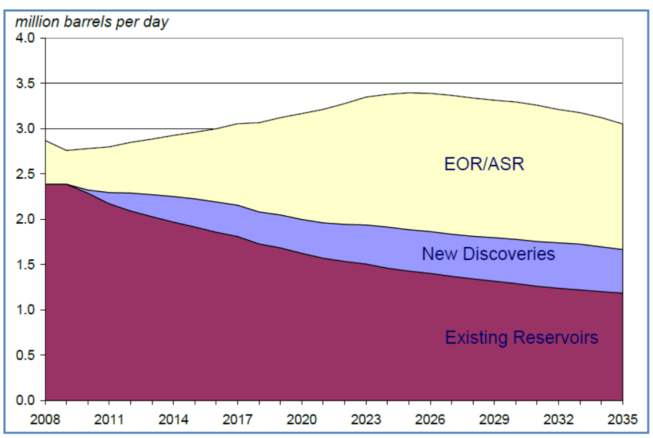


Figure 11: Components of EOR/ASR Production in AEO2011 Reference Case

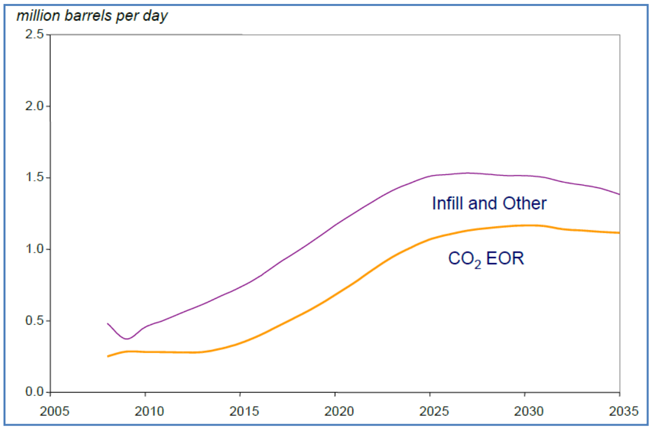
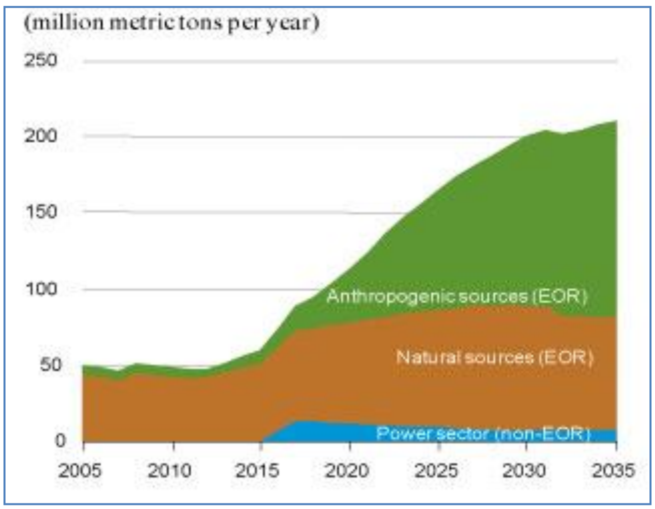


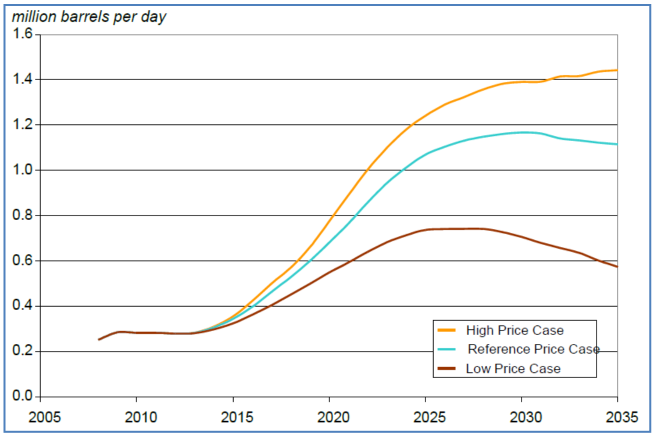
Figure 12: CO_2 Injection Volumes in the AEO2011 Reference Case



Oil prices represent a key uncertainty for future CO_2-EOR projects, because they are the most significant factor in determining the economic feasibility of projects. Other major uncertainties are the amount of CO_2 available to oil producers and the CO_2 emissions cost required to give emitters enough incentive to capture it. In 2035, more than 125 million metric tons CO_2 per year is captured from anthropogenic sources outside the power sector—equivalent to more than 10 percent of the 1,147 million metric tons of direct CO_2 emissions from the industrial sector in 2035. Because not all industrial emissions are sufficiently pure to be captured cheaply, the Reference case results for CO_2-EOR imply that a large proportion of all CO_2 emissions from ethanol fermentation, CTL and BTL plants, hydrogen production in refineries, ammonia plants, and natural gas processing plants will be captured for sale.

The most significant difference between the Reference case and the High and Low Oil Price cases is the change in use of CO_2-EOR in response to the changes in oil price assumptions (see Figure 13). From 2015 to 2035, when compared with the Reference case, crude oil production using CO_2-EOR is 17 percent higher on average in the High Oil Price case. [The High Oil Price case shows a bigger increase in CO_2-EOR than does the GHG Price Economy-wide case.]

Figure 13: Projected CO_2-EOR Production in AEO2011, 3 Cases



EIA's assumptions for AEO2011 drive the findings above. Figure 14 shows EIA's assumptions about the technical and economic CO_2-EOR production. Table 3 and Figure 15 show the active, planned, and candidate CO_2-EOR oil fields in EIA's model. Table 4 shows the assumptions EIA makes about the supply of industrial CO_2 (available CO_2 and cost from different sources). EIA has not yet published its assumptions to the AEO2011, but the assumptions for the AEO2010 noted that:[19]

> Technology and market constraints prevent the total volumes of CO_2 from becoming immediately available. The development of the CO_2 market is divided into 3 periods: 1) technology R&D, 2) infrastructure construction, and 3) market acceptance. The capture technology is under development during the R&D phase, and no CO_2 is available at that time. During the infrastructure development, the required capture equipment, pipelines, and compressors are being constructed, and no CO_2 is available. During the market acceptance phase, the capture technology is being widely implemented and volumes of CO_2 first become available.

[19] See http://www.eia.gov/oiaf/aeo/assumption/oil_gas.html.

Figure 14: EIA's Technical and Economic Production for EOR/ASR

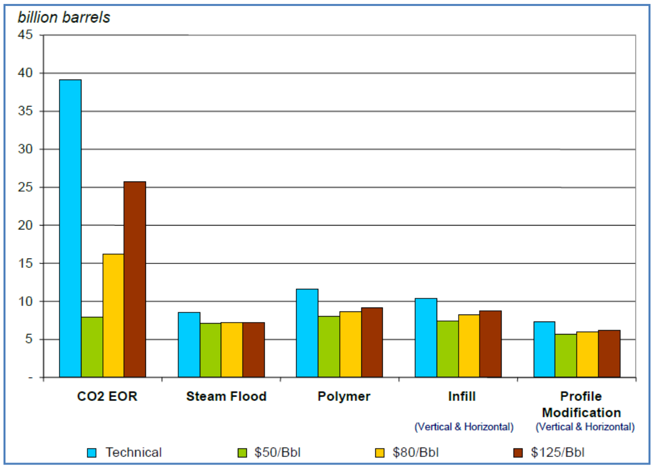


Table 3: AEO2011 Active, Planned, and Candidate CO_2-EOR Oil Fields

Category	Field Count
Active	113
Planned	12
Candidates	2,235

Figure 15: AEO2011 CO_2-EOR Candidate Oil Fields

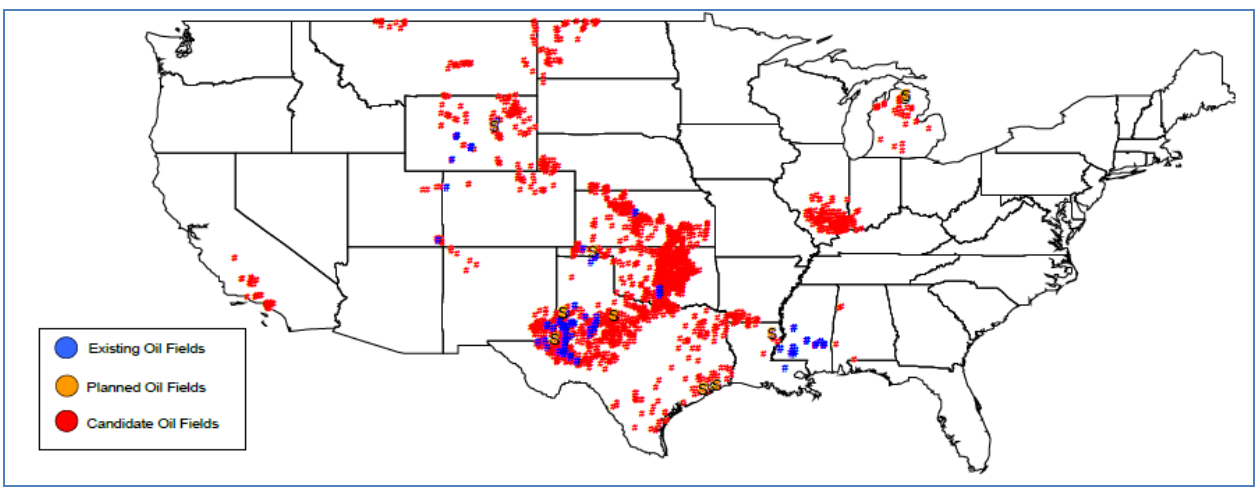


Table 4: AEO2011 CO_2 Supply Assumptions

Source Type	Infrastructure Development (years)	Market Acceptance (years)	Ultimate Market Acceptance	Maximum CO_2 Volumes (million tons)	Average Carbon Capture & Transportation (within Region) Cost ($/ton)
Ammonia Plants	2	10	100%	4.5	31
Natural Gas Processing	2	10	100%	10.9	27
Ethanol Plants	4	10	100%	18.4	33
Hydrogen Plants	4	10	100%	0.2	37
Refineries	4	10	100%	16.7	29
Cement Plants	7	10	100%	21.6	70
Fossil Fuel Plants	12	10	100%	1,209.0	100
Coal-to-Liquids	Determined by the Petroleum Market Module			77.2	27