A Note on Sources of CO_2 Supply for Enhanced-Oil-Recovery Operations

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Summary

This paper presents compiled information on sources of carbon dioxide (CO_2) for enhanced-oil-recovery (EOR) operations in the United States. CO_2 supply in 2010 was 58 Mt. Production from natural sources accounted for 85% of the 2010 CO_2 supply, and estimates of reserves are large enough to support the level of growing CO_2-production rates for several decades. Natural-gas processing accounted for 13% of the 2010 supply and is dominated by ExxonMobil's facility in LaBarge, Wyoming. A significant number of CO_2-supply projects have become operational recently, are under construction, or are in the final stages of design and financing. The forecast rate of CO_2 supply in 2015 is 93 Mt/a of CO_2, a 60% increase over the 2010 level. Hydrocarbon-conversion facilities with CO_2 capture account for 36% of the projected growth between 2010 and 2015.

Background

In 2010, CO_2 EOR provided 280,000 B/D of crude oil, or 5% of domestic supply (Moritis 2010, Energy Information Administration 2011). Sources of CO_2 are organized into three categories.

1. Natural sources—naturally occurring underground accumulations, where the produced gas is primarily CO_2 (90% or higher).
2. Natural-gas processing—naturally occurring underground accumulations, where the produced gas contains significant amounts of methane.
3. Hydrocarbon conversion—industrial processes in which a hydrocarbon feedstock (coal or crude oil) is converted into a higher-value product or slate of products and exhaust CO_2 is captured.

Fig. 1 shows the supply from the three source types in 2000 and 2010, and a projection for supply in 2015 based on known projects that are newly deployed, under construction, or in final design.

Natural Sources

Table 1 presents summary data on nine major CO_2-bearing source fields in the United States. It is an update and expansion of an earlier, similar compilation of natural CO_2 sources (Stevens et. al. 2001). Five of the reservoirs are established and are supplying CO_2 to EOR floods, and four are in the initial, exploratory stages.

The production rates from Sheep Mountain and Bravo in 2010 are less than in 2000, but production from the other sources is steady or increasing. The rate of production from Jackson Dome increased 17-fold between 2000 and 2010 and is now approaching that of McElmo.

The future level of supply from natural sources of CO_2 is difficult to predict. The sum of the reserves estimates for the nine reservoirs is 2.2 billion t, equivalent to 45 years of supply at the current rate of production. However, one-quarter of the reserves estimates is from the four fields that are in the initial stages of development. All of the developmental fields (Kevin, St. John's, Escalante, and Gordon Creek) will require pipeline infrastructure to access EOR targets. Two formations, Bravo and St. John's, are shallow and will tend to have lower wellhead pressure and higher plant-gate-production cost than other natural sources. Counterbalancing these factors is the possibility of new discoveries or of upwardly revised reserves estimates at known reservoirs.

Natural-Gas Processing

Table 2 shows sources of CO_2 from natural-gas processing and sets forth a forecast for the CO_2-production rate in 2015. Production from natural-gas processing in 2010 was 7.5 Mt of CO_2, or 13% of total CO_2 supply. The expanded capture facility at LaBarge supplied approximately 5.8 Mt of CO_2 in 2010 and draws from an enormous reserve of 5.3 billion Mt of CO_2. Sandridge Energy Incorporated and Occidental Petroleum Corporation recently deployed the Century Plant in Pecos County, Texas (Occidental Petroleum Corporation 2011). When both trains at the Century Plant are operational, it will provide 8.7 Mt/a of captured CO_2. Denbury Resources is building a natural-gas-processing plant at Riley Ridge, north of Labarge in Wyoming. The Riley Ridge facility will add 2.5 Mta of CO_2 supply beginning in 2012 and may provide up to 12 Mt/a of CO_2 when fully deployed. Three of the facilities, LaBarge, Century, and Riley Ridge, process a gas stream that contains approximately 65% CO_2.

Fig. 2 is a map of the CO_2 sources contained in Tables 1 and 2. Two sources of recent growth in CO_2 supply, the Jackson Dome (No. 2) and the Century natural-gas-processing plant (No. 11), are in ideal locations relative to oil-bearing formations. Doe Canyon (No. 5), St John's (No. 6), and Escalante (No. 8) are in the same general region as Sheep Mountain and Bravo and could plausibly make up for decline in production rates from those two fields. The LaBarge expansion, the Riley Ridge deployment, and the refurbishment project at Lost Cabin indicate growth in CO_2 EOR production from the Rocky Mountain region.

Hydrocarbon Conversion

The third category of CO_2 supply is hydrocarbon-conversion facilities with CO_2 capture. **Table 3** shows that after a 30-year hiatus with no new facilities, there are eight projects either recently deployed, under construction, or in design. The Dakota Gasification Facility is not included because it supplies a CO_2 EOR operation in Canada. A number of other projects in early stages of planning and design are not included in Table 3 because they are expected to come on line after 2015. These include a coal-to-liquids facility in Wyoming, a synthetic natural gas plant in Illinois, and an ammonia/urea facility in California (Bleizeffer 2012; Borklund 2011; Tomer et al. 2010).

Fig. 3 is the map shown in Fig. 2 with the hydrocarbon-conversion sources added. The hydrocarbon-conversion sources tend to be located near established underground sources, apparently taking advantage of existing pipeline infrastructure.

The data show significant growth in CO_2 supply over the past 10 years and most likely in the near future. The 2015 forecast shows an increasing role for anthropogenic sources of CO_2.

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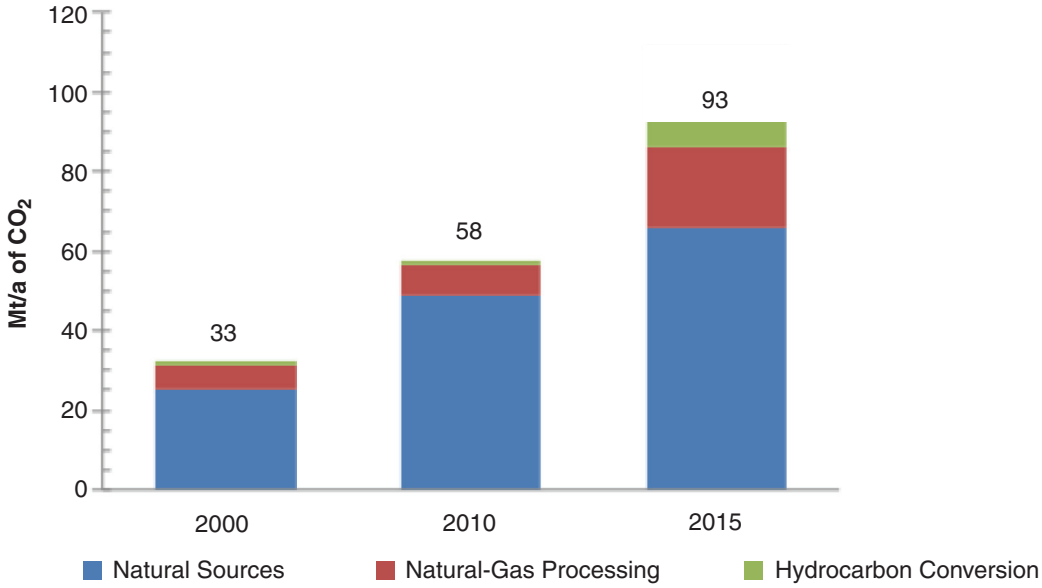

Fig. 1—Sources of CO_2 supply for EOR operations in the United States.

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TABLE 1—NATURAL SOURCES OF CO_2 IN THE UNITED STATES

	Formation Name	State	Discover Year	Depth of Producing Zone, ft	CO_2 Purity vol %	Other Species	Operator	Original CO_2 in Place, Tcf	Cum. CO_2 Prodn Thru 2010, Tcf	Current CO_2 Reserve, Tcf	Production Rate, MMscf/D 2000	2010	2015	Metric Ton Basis: Current CO_2 Reserves (Mt)	Production Rate, Mt/a in 2015
In Production	McElmo Dome	CO	1944	8,000	98%	N_2	Kinder Morgan, ExxonMobil	30	7.2	10	840	1,150	1,230	530	24
	Jackson Dome	MS	~1960	16,000	70-99%	H_2S	Denbury		1.8	11	55	930	1,300	594	25
	Bravo Dome	NM	1916	2,300	99%	N_2	KM, Occidental, Amerada H.	30	2.9	8	350	290	260	424	5.0
	Sheep Mountain	CO	1971	3,500–6,000	97%	N_2, CH_4	Occidental	15	1.3	Nearly depleted	70	50	30	0	0.6
	Doe Canyon Deep	CO		9,000			Kinder Morgan	1.5	0.09	0.75		110	170	40	3.3
Under Development	St. John's	NM	1994	1,600	95%	He 0.75%	Kinder Morgan	16		8.2				435	
	Kevin Dome	MO	~1960	4,000	93%	N_2, CH_4, He	Vecta Oil & Gas	6		0.7				37	
	Escalante Anticline	UT	1960		93–99%					1.0				53	
	Gordon Creek	UT	1947	11,000-13,000	99%+	N_2, CH_4	Thunderbird Energy	1.4		1.5				80	
							Totals		13	41	1,315	2,530	2,990	2192	58

Conversion factors: 53 million metric tons CO_2 per trillion ft^3, 51.69 MMscfd/Mt CO_2/a (15°C and 14.5 psi)

Information sources: Allis et. al. (2001); Broadhead (1998); Denbury Resources (2011); Allison et al. (1997); Hargrove et al. (2010); Kinder Morgan (2011); Lasker (2011); Moritis (2001); Roth (1983); Schwochow (1983); Thunderbird Energy (2012), Vecta Energy Corporation (2011); and Zimmerman (1979).

TABLE 2—NATURAL-GAS-PROCESSING FACILITIES WITH CO_2 CAPTURE

General Facility Information					CO_2 Production Rates					
Facility Name (Owner)	Owner	Capture Location	Year Online	CO_2 Conc. in Source Gas	Standard Cubic Feet Basis				Metric Ton Basis	
					CO_2 Reserve Estimate, Tcf	Production Rate (MMscf/D)			CO_2 Reserve Estimate, Mt CO_2	Production Rate in 2015, Mt CO_2/a
						2000	2010	2015		
LaBarge	Exxon Mobil	WY	1963	65%	100	233	300*	360	5300	7.0
Century Plant	Oxy/ Sandridge	Pecos County, TX	2011	65%	3.5	0	0	450	186	8.7
Terrell, Grey Ranch, Mitchell, and Puckett	Sandridge Energy Inc.	Terrell and Pecos Counties, TX	1998			75	75	75		1.5
Lost Cabin	Conoco Phillips	Fremont County, WY	1995	20%			0	50		1.0
Riley Ridge	Denbury	WY	2012	65%	2.4	0	0	130**	130	2.5
Turtle Lake	DTE Energy	Ostego, MI					11	11		0.2
				Total	105.9	308	386	1,076	5613	20.8

Conversion factors: 53 million metric tons CO_2 per trillion ft^3, 51.69 MMscfd/Mt CO_2/a (15°C and 14.5 psi)

* Expansion implemented during 2010, full capture capacity not realized

**Full project plans for the Riley Ridge facility are for 580–630 MMscf/D of CO_2 production, not predicted to be completed by 2015.

Information sources: Blue Source (2011); Campbell (1978), Collings (2008); Denbury Resources (2011); Dooley et al. (2009); Lemmons (2010); Lohnes (2007); McEwan (2008); Melzer (2009); Moritis (2009); Occidental Petroleum Corporation (2010, 2011); Parker et al. (2009); Sandridge Energy Inc. (2008).

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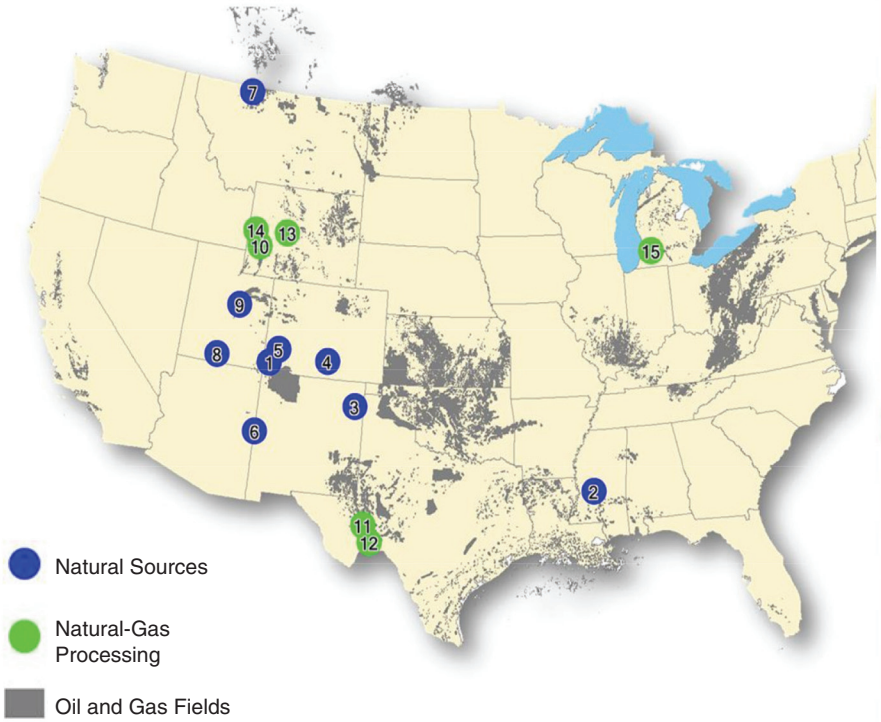

Unmixed Accumulations		Reserves Tcf	2010 Prodtn., MMscf/D
1	McElmo	10	1,150
2	Jackson	11	930
3	Bravo	8.0	290
4	Sheep		50
5	Doe Canyon	0.8	110
6	St. John's	8.2	0
7	Kevin	0.7	0
8	Escalante	1.0	0
9	Gordon Cr.	1.0	0
	Subtotal	41	2,530
Natural-Gas Processing			
10	LaBarge	100	300
11	Century	3.5	0
12	TGRMP		75
13	Lost Cabin		0
14	Riley Ridge	2.4	0
15	Turtle Lake		11
	Subtotal	106	386
Total		**147**	**2,916**

Fig. 2—CO_2 from natural sources and natural-gas processing.

TABLE 3—HYDROCARBON-CONVERSION FACILITIES WITH CO_2 CAPTURE

Facility Characteristics					CO_2 Capture Rates			
					Standard ft^3 (MMscf/D)			Metric Tons (Mt CO_2/a)
Primary Product	Owner	Capture Location	Status	Year Online	2000	2010	2015	2015
Fertilizer	Agrium, Inc.	Borger, TX	Operation	1980	26	26	26	0.5
Fertilizer	Koch Nitrogen	Enid, Oklahoma	Operation	1982	35	35	35	0.68
Ethanol	Conestoga	Liberal KS	Operation	2010		4	15	0.29
Ethanol	Bonanza Energy	Garden City, KS	Operation	2011			8	0.15
Fertilizer	CVR Energy	Coffeyville, KS	Construction	2013			40	0.8
Hydrogen	Air Products*	Port Arthur, TX	Construction	2013			52	1.0
Power	Mississippi Power*	Kemper County, MS	Planning	2014			141	2.7
Power/Urea	Summit Texas Clean Energy*	Ector County, TX	Construction	2014			117	2.3*
Methanol	Leucadia Energy*	Lake Charles, LA	Planning	2014			208	4.0
Power	NRG*	Thompson, TX	Planning	2015			72	1.4
				Total	61	65	714	13.8

Conversion factor: 51.69 MMscfd/Mt CO_2/a (15°C and 14.5 psi)

*Some portion of the captured CO_2 is utilized to manufacture urea. Shown is the amount supplied to EOR.

Information sources: Ahmad (2010); Bleizeffer (2012); Chaparral Energy (2011); Borklund (2011); Global CCS Institute (2011); Kirksey (2011); Mississippi Power (2011); Ciferno et al. (2010); Tomer et al. (2010); and Moritis (2008).

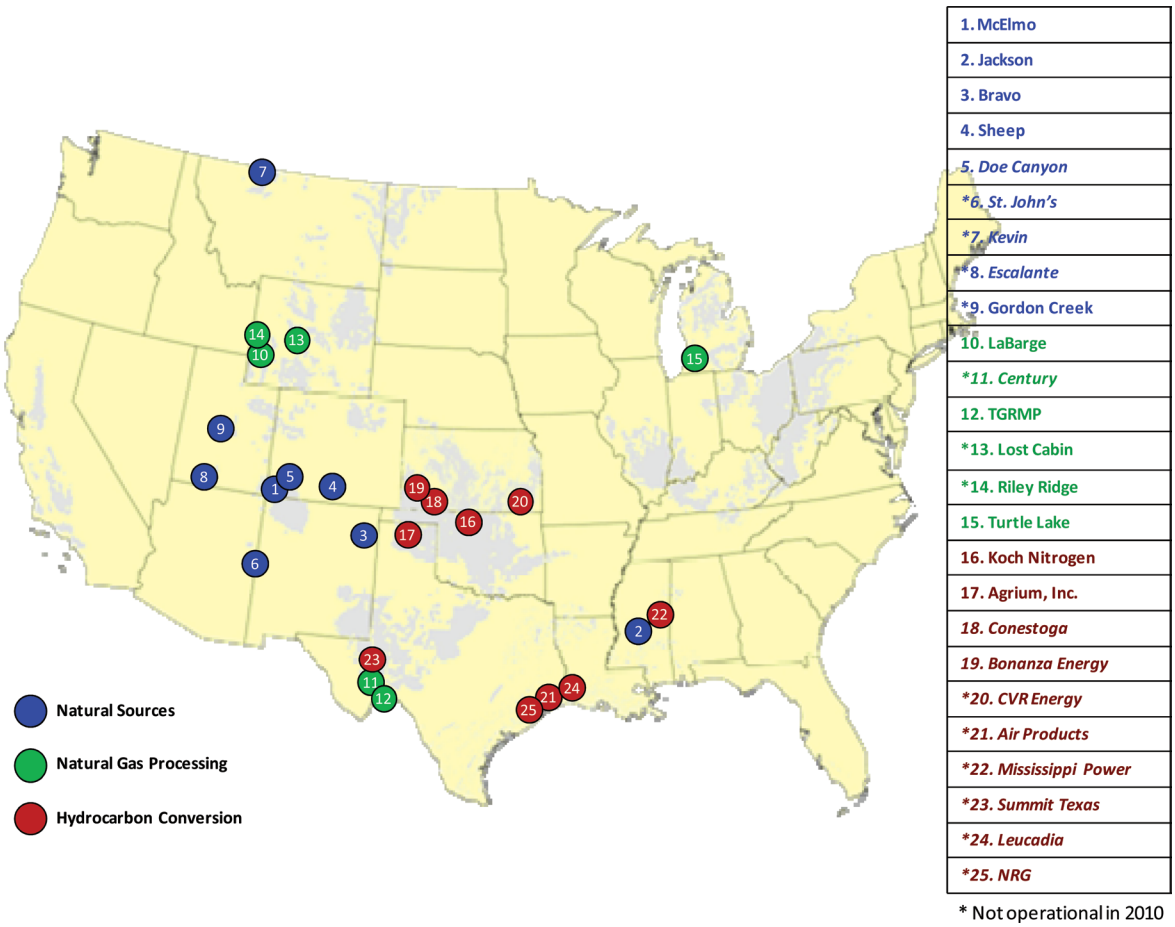

Fig. 3—Sources of CO_2 for domestic EOR floods.

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