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

Phil DiPietro and Peter Balash, National Energy Technology Laboratory

Joseph.dipietro@netl.doe.gov

412.386.5853

December 2011

Summary

This paper presents compiled information on sources of carbon dioxide (CO_2) for enhanced oil recovery (EOR) operations in the lower 48 states.CO_2supply in 2010 was 60 MMmtCO_2. Production from natural sources accounted for 84% of the 2010 CO_2 supply, and reserve estimates are large enough to support level or growing CO_2 production rates for several decades. Natural gas processing accounted for 14% of 2010 supply and is dominated by two large facilities, Labarge in Wyoming and Century in Texas. Ten hydrocarbon conversion facilities with CO_2 capture are newly deployed, under construction, or in final design and are expected to be online by 2015. They will provide an additional 25.5 MMmtCO_2/yr of supply.

Background

In 2010 CO_2 EOR provided 280,000 barrels per day of crude oil or 5% of domestic supply (Moritis 2010; EIA 2012). 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, crude oil) is converted into a higher value product or slate of products and exhaust CO_2 is captured.

Figure 1 shows the supply from the three source types in 2000 and 2010. Figure 1 also presents a projection for supply in 2015 based on known projects. Total CO_2 supply nearly doubled between 2000 and 2010; most of the increase came from natural sources. CO_2 supply will likely increase by another 70% over the next few years based on the Century and Riley Ridge natural gas processing plants and ten

hydrocarbon conversion projects with CO_2 capture 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 lower 48 states. It is an update and expansion of an earlier, similar compilation of natural CO_2 sources (Stevens et. al., 2001). Four of the reservoirs are established and are supplying CO_2 to EOR floods, and five are in the initial, exploratory stages.

The production rate from Sheep Mountain and Bravo in 2010 islessthan it was in 2000, but production from the other sources is steady or increasing. The rate of production from Jackson Dome increased twenty fold between 2000 and 2010 and is now approaching McElmo.

The future level of supply from natural sources of CO_2 is difficult to predict. The sum of the reserve estimates for the nine reservoirs is 2.1 billion metric tons, equivalent to 39 years of supply at the current rate of production. However, a third of the reserve estimates are from the five fields that are in the initial stages of development. And four 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 well head pressure and higher plant gate production cost than other natural sources. Counterbalancing these factors is the possibility of new discoveries or upwardly revised reserve estimates at known reservoirs.

Natural Gas Processing

Table 2 shows sources of CO_2 from natural gas processing and sets forth a forecast for CO_2 production rate in 2015. Production from natural gas processing in 2010 was 8.2 MMmtCO_2 or 14% of total CO_2 supply. The expanded capture facilityat Labarge supplied approximately 5.8 MMmtCO_2 in 2010 and draws from an enormous reserve of 2.9 Bmt CO_2. Sandridge Energy and Occidenal Petroleum recently deployed the Century Plant in Pecos County Texas (Occidental Petroleum 2011). When both trains at the Century Plant are operational, it will provide 8.7 MMmt per year of captured CO_2. Denbury Resources is building a natural gas processing plant at Riley Ridge, just north of Labarge in Wyoming. The Riley Ridge facility will add 2.5 MMmt CO_2/yr of supply beginning in 2012 and may provide up to 12 MMmt CO_2/yr when fully deployed. Thethree facilities, LaBarge, Century, and Riley Ridge, account for 88% of the CO_2 supply estimate for 2015 from this category of sources. All three facilities process a gas stream that contains roughly 65% CO_2.

Figure 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 (#2) and the Century natural gas processing plant (#10) are in ideal locations relative to oil-bearing formations. Doe Canyon (#5), St John's (#6), and Escalante (#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 and the Riley Ridge deployment 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 nine projects either under construction or in design. If the ten projects are deployed as planned they will provide 21.5 million metric tons per year of captured CO_2, an amount equivalent to 36% of the 2010 supply.Two marquee project are not included in Table 3: the Dakota Gasification facility supplies CO_2 to a flood in Canada (scope is the United States) and the HECA project in California is not scheduled to supply CO2 until 2017 or 2018 (beyond the 2015 forecast).

Figure 3 is the map shown in Figure 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.

Figure 1. Sources of CO_2 Supply for Enhanced Recovery Operations in the United States

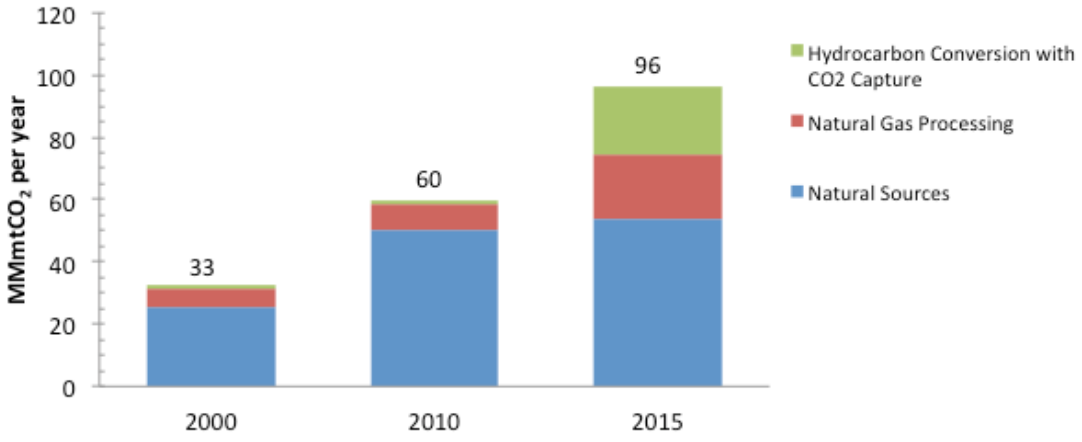


Table 1. Natural Sources of CO_2 in the United States

	General Reservoir Characteristics								Reserves and Production Information					
									Standard Cubic Foot Basis				Metric Ton Basis	
	Formation name	State	Discover year	Depth of producing zone, ft	CO_2 purity vol %	Other species	Operator	Original CO_2 in Place (TCF)	Current CO_2 Reserves (TCF)	Production Rate, MMscfD		Cum. CO_2 prodn thru 2010 (TCF)	Current CO_2 Reserves (MMmt)	Production Rate, MMmt/yr in 2010
										2000	2010			
In Production	**McElmo Dome**	CO	1944	8,000	98%	N_2	Kinder Morgan, ExxonMobil	30	10	840	1,150	7.2	530	22
	Jackson Dome	MS	~1960	16,000	70-99%	H_2S	Denbury		10	55	930	1.8	530	18
	Bravo Dome	NM	1916	2,300	99%	N_2	KM, Occidental, Amerada H.	30	8	350	290	2.9	420	5.8
	Sheep Mountain	CO	1971	3,500-6,000	97%	N_2, CH_4	Occidental	15	Nearly depleted	70	35	1.3	0	0.7
Under Development	**Doe Canyon Deep**	CO		9,000			Kinder Morgan	1.5	0.75*	0	100	0.09	40	1.9
	St. John's	NM	1994	1,600	95%	He 0.75%	Kinder Morgan	16	8.2	0	100	0.09	430	1.9
	Kevin Dome	MO	~1960	4,000	93%	N_2, CH_4, He	Vecta Oil & Gas	6	0.7	0	0	0	37	0
	Gordon Creek	UT	1947	11,000-13,000	99%+	N_2, CH_4	Thunderbird Energy	1.4	~ 1	0	0	0	53	0
	Escalante Anticline	UT	1960		93-99%				1.5	0	0	0	80	0
								Total	**40**	**1,300**	**2,600**	**13**	**2,100**	**50**

Conversion factors: 53 million metric tons CO_2 per trillion cubic feet, 51.69 MMscfd/$MtCO_2$/yr (15°C and 14.5 psi)

* estimated at 50% of CO_2 in place

Information sources (Bradley 2010;Broadhead 1998;Denbury Resources 2011;Gloyn 1997;Hargrove 2010;Kinder Morgan 2011; Lasker 2011;*Oil & Gas J.* 2001;Roth

1983;Schwochow 1983;Thunderbird Energy 2011, Vecta Energy Corporation 2011;and Zimmerman 1979

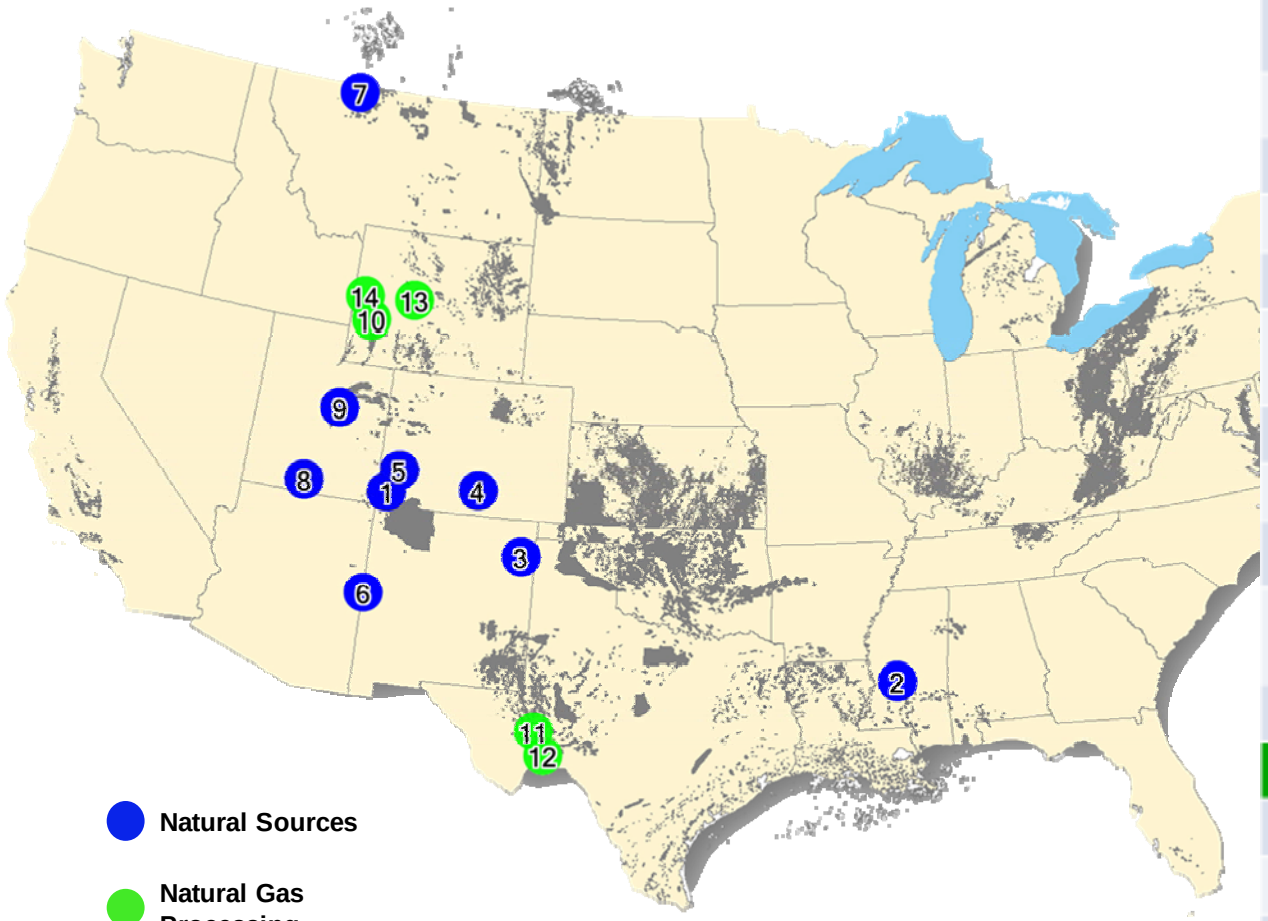
Table 2. Natural Gas Processing Facilities with CO_2 Capture

General Facility Information					CO_2 Production Rates					
					Standard Cubic Feet Basis				Metric Ton Basis	
Facility name (owner)	Owner	Capture Location	Year online	CO_2 conc. in source gas	CO_2 reserve estimate, TCF	Production Rate (MMscf/d)			CO_2 reserve estimate, $MMmtCO_2$	Production rate in 2015, $MtCO_2$/yr
						2000	2010	2015		
LaBarge	Exxon Mobil	WY	1963	65%	55	233	300*	360	2,900	7.0
Century Plant	Oxy/ Sandridge	Pecos County, TX	2011	65%		0	0	450		8.7
Terrell, Grey Ranch, Mitchell, and Puckett	Sandridge Energy Inc.	Terrell and Pecos Counties, TX	1998			75	75	75		1.5
Turtle Creek		Ostego, MI					40	40		0.4
Lost Cabin	Conoco Phillips	Fremont County, WY					50	50		1.0
Riley Ridge	Denbury	WY	2012	65%	2.4	0	0	130**	130	2.5
				Total	**57.4**	**308**	**465**	**1,105**	**3,030**	**21**

Conversion factors: 53 million metric tons CO_2 per trillion cubic feet, 51.69 $MMscfd/MtCO_2/yr$ (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 2011, Dooley 2009; Melzer 2009; Moritis 2009; Occidental Petroleum 2011; Parker 2009; Sandridge E&P 2008)

Figure 2. CO_2 from Natural Sources and Natural Gas Processing



		Reserve TCF	2010 Prodtn, MMscf/d
Unmixed Accumulations			
1	McElmo	10	1,150
2	Jackson	10	930
3	Bravo	8.0	290
4	Sheep		35
5	DOE Canyon	0.8	100
6	St. John's	8.2	100
7	Kevin	0.7	0
8	Escalante	1.5	0
9	Gordon Creek	1.0	0
	Subtotal	40.2	2,605
Natural Gas Processing			
10	LaBarge	55	300
11	Century		0
12	TGRMP		75
13	Lost Cabin		50
14	Riley Ridge	2.4	0
	Turtle creek		40
	Subtotal	57.4	465
Total		**97.6**	**3,070**

Table 3. Hydrocarbon Conversion Facilities with CO_2 Capture

Facility Characteristics					CO_2 Capture Rates			
Primary Product	Owner	Capture Location	DOE cost share*	Year online	Standard Cubic Feet (MMscf/d)			Metric Tons ($MMmtCO_2$/yr)
					2000	2010	2015	2015
Fertilizer	Agrium, Inc.	Borger, TX	No	1980	26	26	26	0.5
Fertilizer	Koch Nitrogen	Enid, Oklahoma	No	1982	35	35	35	0.68
Ethanol	Bonanza Energy	Garden City, KS	No	2011			8	0.15
Fertilizer	CVR Energy	Coffeyville, KS	No	2013			40	0.8
Hydrogen	Air Products*	Port Arthur, TX	Yes	2013			52	1.0
Power	Mississippi Power*	Kemper County, MS	Yes	2014			141	2.7
Power /Urea	Summit Texas Clean Energy*	Ector County, TX	Yes	2014			123	2.4**
Ammonia	Green Rock Energy, L.L.C.	Donaldsville, LA (Faustina)	No	2014			208	4.0
Methanol	Leucadia Energy*	Lake Charles, LA	Yes	2015			208	4.0
Power	NRG*	Thompson, TX	Yes	2015			72	1.4
Liquid fuel	DKRW Advanced Fuels LLC	Medicine Bow, WY	No	2015			200	3.9
				Total	**61**	**61**	**1,112**	**21.5**

Conversion factor: 51.69 MMscfd/$MtCO_2$/yr (15°C and 14.5 psi)

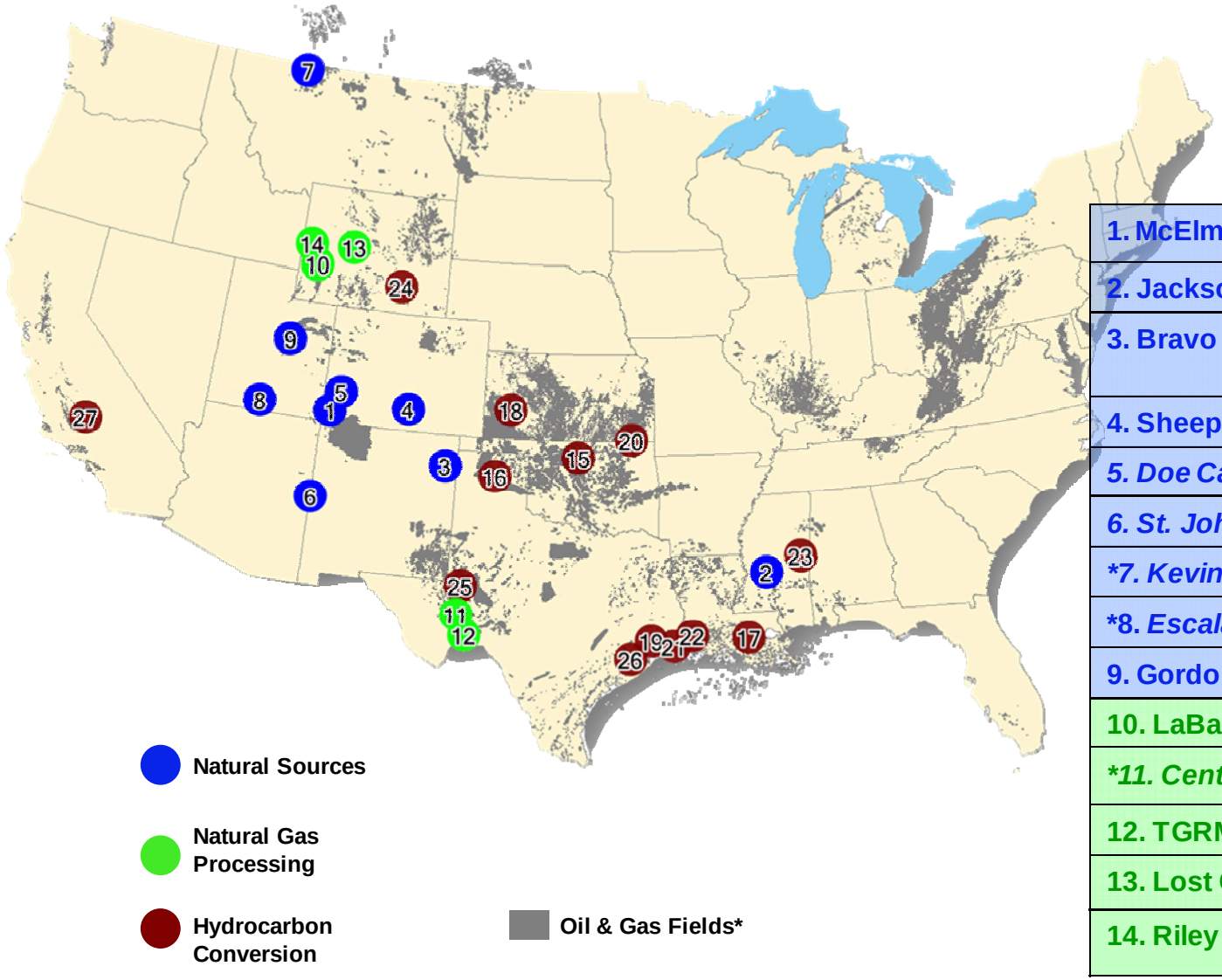
* Projects receiving cost share financial assistance from the U.S .DOE

** Some portion of the captured CO2 is utilized to manufacture urea. Shown is the amount supplied to EOR.

The power and urea project in Kern County, California is not included as the projected start up data, 2017/18 is beyond the 2015 forecast. The project is owned by SCS Energy / HECA and is designed to supply 2-3 $MMmtCO_2$/yr or CO_2 EOR at the Elk Hills field.

Information Sources: (Ahmed 2010; Chaparral Energy, 2011; Global CCS Institute 2011; Mississippi Power 2011; NETL 2010a; NETL 2010b; *Oil & Gas J*. 2008; *RTT News* 2011;

Figure 3. Sources of CO_2 for Domestic EOR Floods



1. McElmo	15. Koch Nitrogen
2. Jackson	16. Agrium, Inc.
3. Bravo	*17. Green Rock Energy
4. Sheep	*18. Bonanza Energy
5. Doe Canyon	*19. ZEEP/Eastman
6. St. John's	*20. CVR Energy
*7. Kevin	*21. Air Products
*8. Escalante	*22. Leucadia Energy
9. Gordon Creek	*23. Mississippi Power
10. LaBarge	*24. DKRW
*11. Century	*25. Summit Texas
12. TGRMP	*26. NRG
13. Lost Cabin	*27. HECA
14. Riley Ridge	

Ahmad, S. 2010. Ethanol Plant to Sequester CO_2 Emissions. *The Garden City Telegram* (13 March 2010)

Allis, R.,Chidsey T., Gwynn, W., Morgan, C., White, S., Adams, M., Moore, J., 2001. Natural CO_2 Reservoirs on the Colorado Plateau and Southern Rocky Mountains: Candidates for CO_2 Sequestration. *Proc.*First National Conference on Carbon Sequestration

Annual Energy Outlook 2011. 2011. Energy Information Administration, Table A11

Blue Source. 2011. http://www.ghgworks.com/4c-valverde.html

Bradley, T. 2010. CO_2. Oral presentation given at the KMP analyst conference, January 2010

Broadhead, R. 1998. Natural Accumulations of Carbon Dioxide in the New Mexico Region. *Lite Geology*, #20: 2-7

Campbell, J.A. 1978. Carbon Dioxide Resources of Utah, Report of investigation No. 125, Utah Geological and Mineral Survey, Table 2

Chaparral Energy. 2011. http://www.chaparralenergy.com/index.php?page=chaparral-energy-agrees-to-a-co2-purchase-and-sale-agreement-with-cvr-energy-for-capture-of-co2-for-enhanced-oil-recovery

Collings, R.C. 2008. Verification of Blue Source's Greenhouse Gas Emission Reductions for PetroSource's Terrell, Mitchell and Grey Ranch Compressor Station Geologic Carbon Sequestration Project. Ruby Canyon Engineering, Grand Junction, Colorado (February 2008)

Denbury Resources. 2011. http://www.denbury.com/index.php?id=16

Dooley, J.J., Davidson, C.L., and Dahowski, R.T. 2009. An Assessment of the Commercial Availability of Carbon Dioxide Capture and Storage Technologies as of June 2009. Contract DE-AC05-76RL01830, US DOE, Washington DC (June 2009) page 12

Future of EOR & IOR: New companies, infrastructure, projects reshape landscape for CO_2 EOR in US*Oil and Gas J.* (14 May 2001)

Global CCS Institute. 2011. Resources and Projects, http://www.globalccsinstitute.com/resources/projects/enid-fertilizer-plant

Gloyn, R.W. and Allison, M.L. 1997. A Preliminary Assessment of Energy and Mineral Resources within the Grand Staircase - Escalante National Monument.Utah Geological Survey, Circular 93

Hargrove, B., Melzer, and S.L., Whitman, L. 2010. A Status Report on North American CO_2 EOR Production and CO_2 Supply, presented at the 16th Annual CO_2 Flooding Conference, Midland, TX, 9-10 December

Kinder Morgan Energy Partners. 2011. http://www.kindermorgan.com/business/co2/supply.cfm

Lasker, B. 2011. Enhanced Oil Resources Inc. Investor Presentation. Oral presentation given at the IPAA OGIC conference, Hollywood Florida, 3 February 2011

Lemons, G., 2010. Lost Cabin Gas Plant Can Continue Venting CO_2. *KDLY/KOVE Freemont Broadcasting*(June 9, 2010)

McEwan, M. 2008. SandRidge, Oxy Team Up to Build CO_2 Extraction Plant. *Midland Reporter-Telegram* July 13, 2008

Melzer, S. L. 2009. A One-day Seminar on CO_2 Injection Methods and Operations: EOR and its Relevance to CO_2 Sequestration. Lecture, Pittsburgh, Pennsylvania, USA (April 2, 2009)

Mississippi Power. 2011. Denbury Enters Into Two Industrial CO_2 Purchase Contracts, http://www.mississippipower.com/kemper/news_denbury.asp

Moritis, G. 2009. Special Report: More CO_2-EOR projects likely as new CO_2 supply sources become available *Oil & Gas J.*, Dec 7, 2009.

Moritis, G. 2010. "Special Report: EOR/Heavy Oil Survey: CO_2 miscible, steam dominate enhanced oil recovery process," *Oil&Gas J.*, April 19, 2010

National Energy Technology Laboratory. 2010a. DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap,http://www.netl.doe.gov/technologies/carbon_seq/refshelf/CCSRoadmap.pdf, pages 14-15

National Energy Technology Laboratory. 2010b. Project Fact Sheet, http://www.netl.doe.gov/publications/factsheets/project/FE0003311.pdf

Occidental Petroleum Corporation. 2011. http://www.oxy.com/OurBusinesses/OilAndGas/Technology/FieldDev/Pages/FacilitiesConstruction.aspx

Parker, M. E., Northrop, S., Valencia, J.A., Foglesong, R.E., and Duncan, W.T. 2009. CO_2 Management at ExxonMobil's Labarge Field, Wyoming, USA *Proc.*International Petroleum Technology Conference 13258

Roth, G. 1983. Sheep Mountain and Dike Mountain Fields, Huerfano County, Colorao; Source of CO_2 for Enhanced Oil Recovery. *Oil and Gas Fields of the Four Corners Area*volume III 740-744

Gas Treating and CO_2 Delivery Agreement by and between Sandridge Exploration and Production and Oxy USA. 2008 Securities and Exchange Commission, EDGAR filing with the Securities and Exchange Commission, August 7, 2008

Schwochow S.D., 1983. USGS Mineral Resources Data System, McElmo Creek Area, deposit # 10014208, USGS

Stevens, S.H., Perce, J.M., Rigg, A. A. J., 2001. Natural Analogs for Geologic Storage of CO_2: An Integrated Research Program. *Proc.* First National Conference on Carbon Sequestration

Special Report: More US EOR projects start but EOR production continues decline. *Oil & Gas J*. (21 April 2008)

Vecta Energy Corporation. 2011. http://www.vectaenergy.ca/index.htm

Zero Emission Energy To Buy Eastman TX Energy Project In Beaumont*RTT News* (21 January 2011)

Zimmerman, F.W. 1979. Naturally Occurring Carbon Dioxide Sources in the United States – A Geologic Appraisal and Economic Sensitivity Study of Drilling and Producing Carbon Dioxide for Use in Enhanced Oil Recovery. Final Report, Contract No. EX-76-C-01-2025 US DOE, Washington DC (January 1979).