AN UPDATED ASSESSMENT OF THE CO_2 ENHANCED OIL RECOVERY POTENTIAL IN THE VICINITY OF THE WASTE ISOLATION PILOT PLANT

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AN UPDATED ASSESSMENT OF THE CO_2 ENHANCED OIL RECOVERY POTENTIAL IN THE VICINITY OF THE WASTE ISOLATION PILOT PLANT

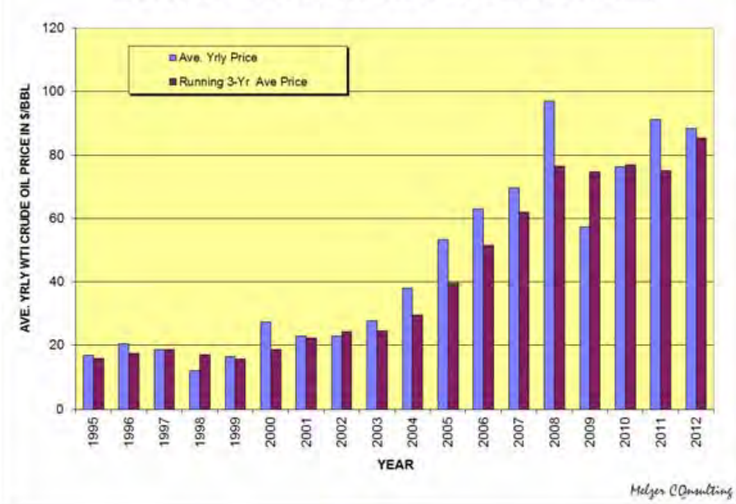
Melzer Consulting, June 2013

OVERVIEW

The Permian Basin region of southwestern U.S. has had a long and heralded history as one of the premier oil and gas provinces in the world. The oil production peaked in the early 1970's at about 2 million barrels of oil per day. Thus, over the last three to four decades, it has been viewed as a mature basin with its most productive years in the past. But during the interim years of declining oil production, it was the home to pioneering waterflood projects and innovated commercial CO_2 flooding (also known as CO_2 enhanced oil recovery{EOR}). The consensus of opinion in the industry was that those technologies were viewed as only cause for flattening the decline curve and extending the productive life of the Basin and its oilfields. It was in this declining perspective that the Waste Isolation Pilot Plant (WIPP) site was first certified in 1998 (Ref 1). Subsequent to the initial certification, the Compliance Recertification Applications of 2004 (Ref 2) and 2009 (Ref 3) included assessments of CO_2 EOR (Ref 4 and Ref 5) in 2003 and 2008 as they pertained to the local area around the WIPP site. An assessment of water flooding for EOR near the WIPP site was also included in the Compliance Recertification Application of 2009 (Ref 6).

Worldwide crude oil supplies, although declining in the Permian Basin, were in relative abundance and surplus in the 1990's, holding oil prices in the $15-20/barrel range. Recognition of more limited supplies since 2005 plus a very robust worldwide growth in oil (motor fuel) demand in China, India and now Brazil have changed the oil price landscape. The effect of this growth has struck a tighter balance between oil supply and demand and given rise to increases in oil prices well over the prices seen at the time of the initial certification of the WIPP site. Figure 1 tracks the oil prices since 1995 as measured by the West Texas Intermediate oil price index which remains a relatively good worldwide index of oil prices since oil is truly a globally transported and traded commodity. One can note from the figure that the steep incline of prices around $15-$20/barrel since the initial certification date has given way to a new tier of pricing around $80/barrel since 2008.

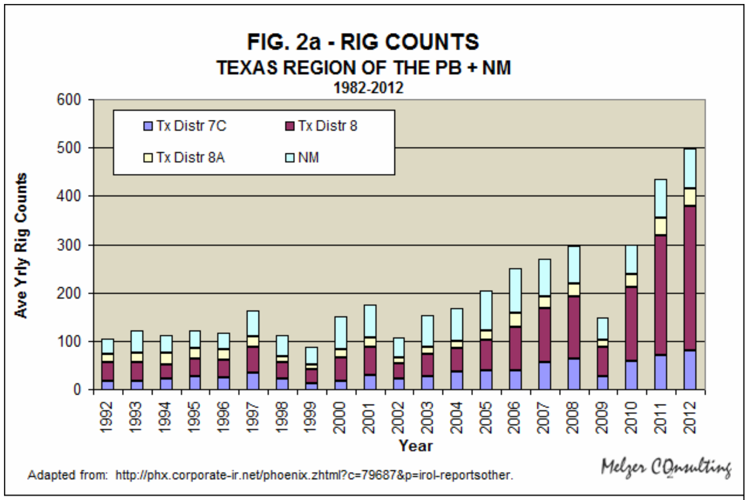
FIG. 1 - YEARLY AVERAGES OF WTI CRUDE OIL PRICES - 1995-2012

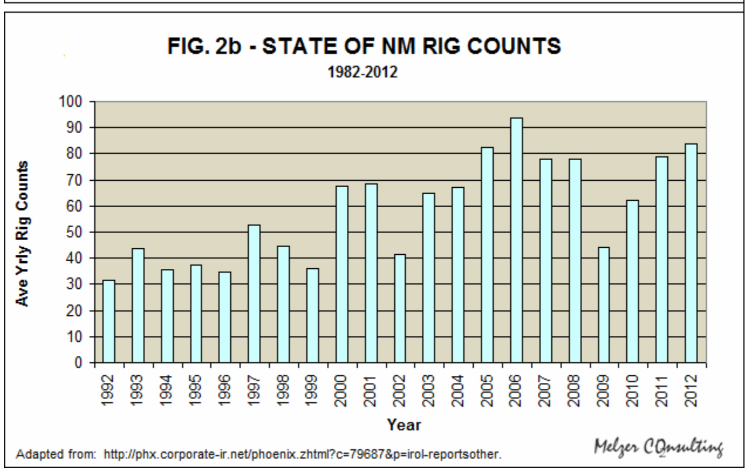


This tightening of the oil supply and demand marketplace and new level of oil pricing has reinvigorated interest in the Permian Basin's oil potential and contributed significantly to enhanced economics of new projects there including new waterflood projects, CO_2 flooding (the subject of this report) and, now, the emergence of unconventional oil exploration more commonly known as tight formations or shale reservoir exploitation. This enhanced activity has also created more production of water along with the oil and a need for more water disposal operations which is the subject of a sister report to this one.

FURTHER BACKGROUND AND CHANGED CONDITIONS

As Figure 1 tracked the changing worldwide oil prices as measured by the West Texas Intermediate oil price index, a useful second and more direct measure of activity is the drilling rig count. This is an index based upon the instantaneous count of active oil rigs drilling oil and gas wells and is a widely used measure of economic activity. Figure 2 charts the rig count for the four major sub-provinces of the Permian Basin and specifically includes the count in New Mexico, dominated by activity in the four county area of southeastern New Mexico. This count would therefore include the two counties around the WIPP site, Eddy and Lea Counties.





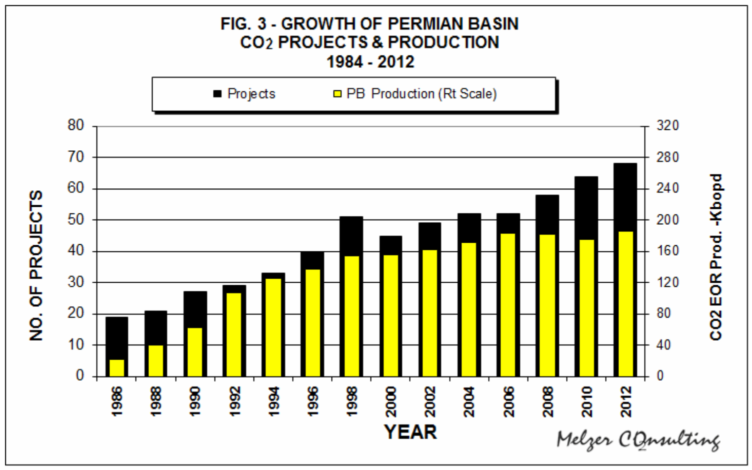
The high oil prices since 2007 have created opportunity and incentives for finding and producing oil where project economics were challenged in lesser price environments. New exploration plays such as the "Wolfberry" in West Texas (Ref 7) and the Bakken in North Dakota and Montana (Ref 8) have begun to reverse the reduction in oil rig counts over the previous decade as seen in Figure 2a.

In comparing Figures 1 and 2a, one can conclude that the two indices are clearly related and even the temporary dip in oil prices in 2009 was immediately reflected in the rig counts of 2009. What is not immediately apparent from either of the two charts is what kind of new activity is dominating but a hint can be taken when looking at Texas Railroad Commission District #8 where most of the growth in rig counts has occurred. This District, in and around Midland, Texas, has seen drilling concentrated in the aforementioned formation called the Wolfberry within the Midland Basin. Of particular significance to this report is the observation that New Mexico drilling has not witnessed such growth but has been relatively steady for approximately ten years (Figure 2b).

If one makes the connection of better economics for all facets of oil exploitation, the growth of CO_2 enhanced oil recovery (EOR) should also be occurring. Furthermore, with an increased worldwide focus on reducing CO_2 emissions and CO_2 EOR's ability to store large volumes of CO_2 in the subsurface, one could possibly set the stage for advantaged and, possibly, dramatic growth in CO_2 EOR. It is because of these fast changing dynamics that it is useful to conduct an updated assessment of the CO_2 EOR potential in the Permian Basin. More specifically, what do these changes hold in store for the immediate area around the WIPP site in southeastern New Mexico and for any possible new recertification activities?

PAST AND CURRENT CO_2 FLOODING STATUS

CO_2 flooding (EOR) has been recognized as a commercial oil recovery process for about thirty-five years. The first large scale demonstration projects were implemented in 1972 in west Texas with the SACROC and North Cross projects. One could make the argument that those first two projects were feasibility assessments so what happened subsequently is the true measure of success. This real proof of maturity (and commerciality) occurred with the advent of several long distance pipelines and implementation of additional large-scale CO_2 EOR projects in the early 1980's. Reminding ourselves again of the languishing oil prices during the 80's and 90's, the growth of CO_2 EOR was present and steady in spite of the challenges of worldwide oil price collapses in 1986 and 1998. Figure 3 demonstrates the worldwide and Permian Basin growth in terms of numbers of active projects and oil production (adapted from Ref 9).



The economics of a company's favored investments in new oil and gas projects are continually in play. For example, new exploration plays like the Wolfberry or Bakken are one way to bring returns to stakeholders in a company but another is to find more ways to get oil out of an existing reservoir. CO_2 EOR is one of those latter approaches and continues to see steady growth as shown in Figure 3. But those types of projects have to compete for the limited bucket of investment dollars with other drilling opportunities. The excitement of drilling the shale plays like the Wolfberry or Bakken has taken center stage for most of the industry today. Waterfloods and EOR projects do not possess quick revenue returns and the shale play projects are, in general, giving faster returns.

Whereas Figure 3 demonstrated steady growth in CO_2 EOR projects (black bars), it shows a leveling of production (yellow bars) since 2006. This is due to two factors. First, there is a normal life-cycle progression where the older floods (twenty years and older) are expected to mature and witness a decline in production. But due to the economics of high oil prices, they continue to be quite profitable and thus encourage continuing purchases of CO_2. But, while still profitable, those projects make fewer barrels per thousand cubic feet (mcf) of CO_2 purchased. Normally, new floods would be coming on line that would be very efficient thus allowing EOR production to continue to grow. But a second factor comes in to play which involves the limited supplies of CO_2. If all of the available CO_2 is contracted and much of it goes to overly mature projects, the oil production must flatten or even decline. To illustrate this limited CO_2 supply point, Figure 4 tracks the supply and demand situation for CO_2. Note that in 2004, at the beginning of the ramp up in oil prices, the growth in demand for CO_2 for the Permian Basin began to outstrip the available supply. And, as with any open market, the supply shortage problem gets attacked (see Tables 1a & 1b) but new CO_2 source projects, together with their pipelines, are expensive and always slow to be implemented. Meanwhile, many pent-up EOR projects await the ability to contract supply and Permian Basin EOR production levels have leveled out with little hope held for change in the short term.

FIG. 4 - INCREMENTAL CO_2 SUPPLY AND DEMAND IN THE PERMIAN BASIN

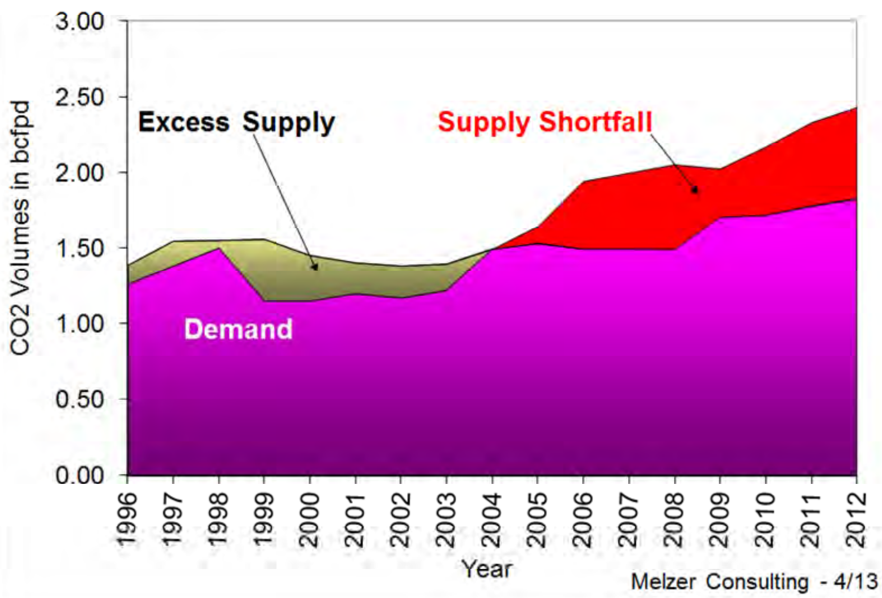


TABLE 1a - CURRENT CO_2 SUPPLY FOR THE PERMIAN BASIN

CO2 SOURCE	STATUS
McElmo Dome/Doe Canyon Source Fields	Pressure Decline in Reservoir Requiring Field Compression; Now @ Limits of Cortez Line Capacity
Bravo Dome	Economically Challenged by Low Reservoir Pressures - Replacement Well Drilling Ongoing - Volumes in Decline
South Permian Nat'l Gas by-product CO_2	Declining volumes due to lack of new drilling due to low natural gas prices
West Bravo Dome	Challenged by Low Reservoir Pressures - Replacement Well Drilling Ongoing - Volumes in Decline
North Bravo Dome	Challenged by Low Reservoir Pressures - New Well Drilling Ongoing - Volumes 10-30 mmcfpd in Aggregate
Sheep Mountain	Volumes in Decline

TABLE 1b - PB CO_2 SUPPLY ENHANCEMENTS

Short and Medium Term (Next 2-4 years)

Ethanol Plants CO2 to the PB (30-50 mmcfpd)

Delaware Basin Associated Nat'l Gas CO2 (30-50 mmcfpd)

Long Term (>4 years)

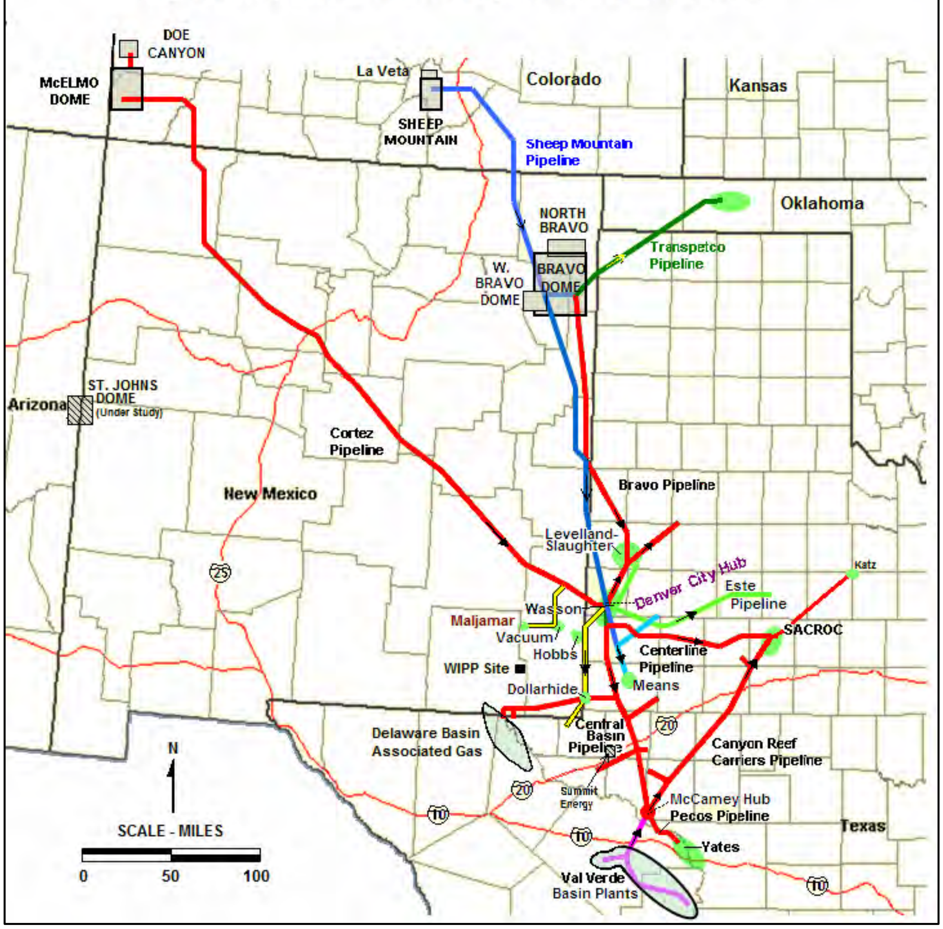
Anthropogenic CO2 from Power Projects (e.g., Summit Energy @ Penwell, Tx)

KinderMorgan (formerly Enhanced Oil Resources) - St. Johns CO2?

Pipelined in from Gulf Coast or East Texas?

Note that the combined stories in Tables 1a and 1b paint a very pessimistic picture for short- to mid-term supply growth. The continued CO_2 shortages have several root causes but perhaps the most important is related to the leading supply source field for the last two decades, the McElmo Dome in southwestern Colorado (see Fig. 5). In truth, the Permian Basin has been very fortunate to have the McElmo Dome as their 'anchor' supply source. If one were able to construct a perfect CO_2 supply source field, the McElmo Dome might be the design. It is deep (9000') so that the CO_2 is in a high pressure, dense state and is very large with an original gas in place of 20 trillion cubic feet (tcf) or more. But, in spite of the large reserves, it has produced approximately half of its original gas in place to date leaving a pressure in the reservoir that is now limiting productivity of the wells. The growing demand for CO_2 in the Permian Basin and the first concerns of pressure depletion at McElmo gave cause for the large investment in the neighboring Doe Canyon CO_2 supply field. Doe Canyon was brought on line and pump stations were added to the Cortez line (Fig 5) in 2009 in an attempt to meet the needs of EOR companies. In 2013/2014 field compression is being added at the satellite gathering stations within the McElmo Dome field to attempt to maintain deliverability and total production volumes. Additional wells are being added at the Doe Canyon field to keep the Cortez pipeline full.

Figure 5 - Map of Permian Basin CO_2 Fields and Infrastructure



GROWTH POTENTIAL OF CO_2 EOR

If there is limited available of CO_2 supplies in a given region like the Permian Basin, then the growth of CO_2 EOR will be constrained, even under a robust oil price environment. So what are the factors for bringing CO_2 supplies in line with the demand (from EOR)? Discovery and exploitation of new pure underground sources of CO_2 like the Bravo or McElmo Domes would be one way. Another might be capture of by-product industrial CO_2. Unfortunately, both are expensive and seen as long-term projects; neither of these is easily accomplished. An example of the former might be the St. Johns Anticline on the border of Arizona and New Mexico (see Figure 5) but it seems to be challenged not only by distance to the Permian Basin (and the commensurate cost of the long-distance pipeline), but with the shallow nature (<3500') of the reservoir and large number of wells required to meet the production levels to justify the project. Other smaller sources are available but challenged once again by pipeline costs to enter the Permian Basin CO_2 pipeline network.

One of the potential long-term drivers of CO_2 EOR growth is related to its ability to permanently store significant volumes of CO_2 in the subsurface. This could be viewed as a commercial subcategory of CO_2 sequestration (also known as carbon capture and storage or CCS). CO_2 EOR is often compared to sequestration in deep saline formations but with one very important difference; i.e., the CO_2 stored can be used to generate revenues hence offering a value for the CO_2 it needs. It has been shown that CO_2 retention in EOR reservoirs is very large and often nearly equal to the amount of CO_2 purchased. The CO_2 that is produced during EOR operations is captured, recompressed and reinjected. The sources of the losses are the infrequent surface plant upsets, often caused by loss of power to the plant whereupon the CO_2 must be flared and some deminimus fugitive emission losses. But these are generally small and relatively insignificant compared to the volumes being purchased. Two recent looks at those losses are from the Denver Unit (Ref 10) and the SACROC floods and facilities (Ref 11), both in the Permian Basin.

As in previous versions of this report (Refs 4 and 5), questions remain whether sequestration and/or CO_2 EOR will become qualified mechanisms for enabling CO_2 emission reductions. Governmental entities seem reluctant to step up and certify those as emission reductions without prolonged study. Thus, the second driver for CO_2 EOR growth – capture of CO_2 and storage in oil reservoirs remains a question in spite of a growing recognition of its value proposition. The first driver (increased oil prices) is fully at work but with the limitations of CO_2 supply that could easily be accelerated by quick adoption of CCS and EOR as certified emission reductions.

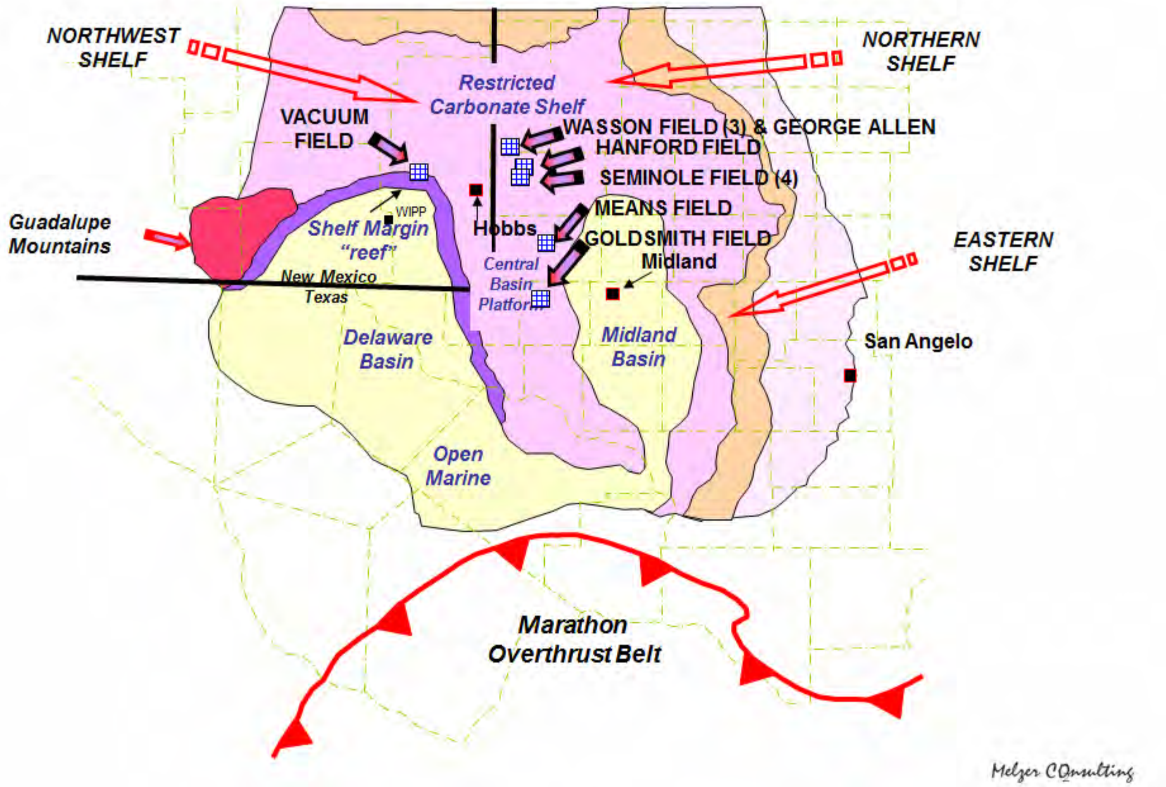
PROJECTIONS FOR CO_2 EOR GROWTH

The new trend in CO_2 EOR in the Permian Basin is flooding below the oil/water contact in what has become known as the residual oil zone or ROZ. These reservoir intervals represent the lower part of a huge paleo entrapment that was flushed of its mobile oil in the early Tertiary Period. As a result, the zones do not have mobile oil in the pore space but still retain 25% to 40% oil saturation in the tight spaces and attached to the rock, much like a water-swept interval in man's waterfloods which have been the targets for CO_2 flooding for three decades or more. Twelve projects have now been deepened to intervals below the historically produced intervals during primary production and secondary flooding. Most projects have been deepening existing wells that were already injecting or producing from the main pay zones (MPZ) above the oil/water contact but two were deployed initially as commingled floods (MPZ+ROZ) while a third is the first to flood in a portion of the field with only a ROZ and no MPZ. Figure 6 shows the location of the twelve ROZ floods while Table 2 lists the projects with their attributes.

Figure 6

MIDDLE SAN ANDRES PALEOGEOGRAPHY

with Location of Industry Documented ROZ Zones/Fields



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as of May '13

Table 2

ON-GOING AND PLANNED ROZ CO_2 EOR PROJECTS IN THE PERMIAN BASIN REGION OF THE U.S.

	Type and operator	Field	State	County	Top MPZ Depth, (ft)	Pay zone	Lith-ology	MPZ Start Date	ROZ Start Date
	Active CO_2 miscible								
1	Chevron	Vacuum San Andres Grayburg Unit	NM	Lea Co.	4,550	San Andres	Dolo.	2007	2007
2	Fasken	Hanford	Tex	Gaines	5,500	San Andres	Dolo	7/86	8/09
3	Hess	Seminole Unit-ROZ Phase 1	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	7/96
4	Hess	Seminole Unit-ROZ Phase 2	Tex.	Gaines	5,500	San Andres	Dolo.	7/83	4/04
5	Hess	Seminole Unit-ROZ Stage 1 Full Field Dev	Tex	Gaines	5,500	San Andres	Dolo	7/83	10/07
6	Hess	Seminole Unit-ROZ Stage 2 Full Field Dev	Tex.	Gaines	5,500	San Andres		7/83	5/11
7	Legado	Goldsmith-Landreth Unit	Tex.	Ector	4,200	San Andres	Dolo.	8/09	8/09
8	Occidental	Wasson Bennett Ranch Unit	Tex.	Yoakum	5,250	San Andres	Dolo.	6/95	2000
9	Occidental	Wasson Denver Unit	Tex.	Yoakum	5,200	San Andres	Dolo.	4/83	1995'
10	Occidental	Wasson ODC	Tex.	& Gaines	5,200	San Andres	Dolo.	Nov-84	2005?
11	XTO/ExxonMobil	Means	Tex	Andrews	4,500	GrBrg/San Andres	Dolo.	Nov-83	1/12
12	Trinity CO2	George Allen (BF&GF)*	Tex	Yoakum	4,900	San Andres	Dolo.	12/12	2012
	Planned CO_2 miscible								
13	Conoco	East Vacuum (GSA) Unit	NM	Lea Co.		GrBrg/San Andres	Dolo.		2013
14	Conoco	Maljamar	NM	Lea Co.		San Andres	Dolo.		2013
15	Chevron	Central Vacuum	NM	Lea Co.		San Andres	Dolo.		2012
16	XTO	CA Goldsmith	Tex	Ector	4,200	San Andres	Dolo.		2013
17	Tabula Rasa	East Seminole	Tex.	Gaines	5,400	San Andres	Dolo.		2013
18	ER Operating	Greenfield (GF) ROZ	Tex	Undisclosed		San Andres	Dolo.	n/a	2013

* BF = Brownfield (ROZ below the MPZ)
GF = Greenfield (no MPZ above the ROZ)

Note in Table 2 that all of the ROZ projects target the San Andres formation of Permian age. The San Andres is becoming known worldwide as the home of a huge ROZ EOR potential and is currently the topic of study for three research projects attempting to better define the origins, characteristics, and the geographical distributions of the ROZs (Refs 12a, 12b, 12c).

Table 3 lists the Permian Basin CO_2 floods implemented since the 2008 report (adapted from Ref 9). The long term trend in Permian Basin CO_2 flooding continues to be away from the Delaware sandstones in the Delaware Basin. The San Andres formation is favored and is the most commonly flooded formation in the world. The last of the CO_2 projects in the Delaware Basin was in 1995 (East Ford).

TABLE 3 - NEWLY IMPLEMENTED PERMIAN BASIN CO_2 EOR PROJECTS (since 1/09)

	Type and operator	Field	State	County	Start date	Area, acres	Formation	Pay zone Lithology
	CO_2 miscible							
1	Trinity CO2, LLC	George Allen	Tex.	Gaines	1/13	160	San Andres	Dolo
2	XTO Energy Inc.	Means (San Andres)	Tex.	Andrews	1/12	160	San Andres	Dolo
3	Hess	Seminole Unit-ROZ Stage 1	Tex.	Gaines	2010	2,380	San Andres	Dolo.
4	Kinder Morgan	Katz Strawn, Consolidated)	Tex.	King, Knox, Stonewall, Haskell	2010		Strawn	S
5	George R. Brown	Garza	Tex.	Garza	11/09	1,778	San Andres	Dolo
6	Fasken	Hanford (San Andres)	Tex.	Gaines	7/09	113	San Andres ROZ	Dolo
7	Legado Resources	Goldsmith-Landreth	Tex.	Ector	5/09		San Andres	Dolo
8	Fasken	Abell (Devonian)	Tex.	Crane	4/09	809	Devonian	Tripol.
9	Fasken	River Bend (Devonian)	Tex.	Crane	4/09	400	Devonian	Tripol.

PROJECTIONS FOR CO_2 EOR PROJECTS IN THE WIPP VICINITY

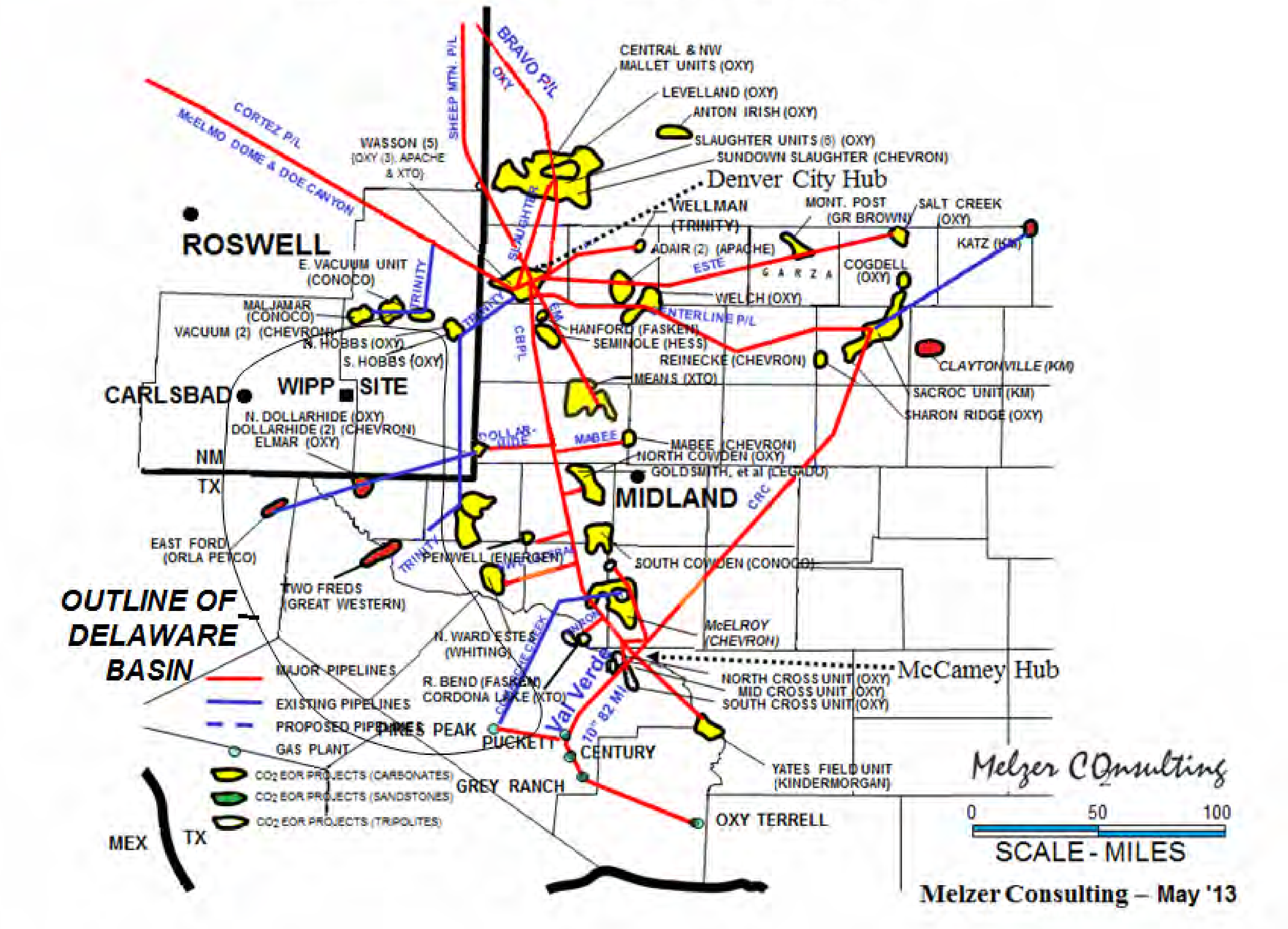
The 2003 and 2008 assessments of CO_2 flooding (Refs 4 and 5) have shown that the oil reservoirs present in the vicinity of the WIPP site are the Delaware Mountain Group Sandstones of the Delaware Basin (Figure 7).

These sandstones have been characterized as reservoirs that have not performed well under any type of flooding due to their compartmentalized nature. Strata Exploration's Nash Draw project (Ref 13), conducted as a part of the U.S. DOE's Class III Program, provides considerable insight to flood possibilities and possible sweep efficiency characteristics necessary for a good flooding project. The project was originally formulated to evaluate water and CO_2 flooding but it became necessary to adapt it to exploration technologies related to strategic infill drilling due to the laterally variable and non-continuous nature of the reservoir.

Poor sweep efficiencies lead to lower cumulative oil production, faster maturation of a project and high CO_2 "breakthrough". Poor efficiencies can be partially offset by higher oil prices since oil is always produced with the large volumes of CO_2. Reservoir compartmentalization, such as that possessed by the Delaware Mountain Group of sandstone, does not effectively allow *good sweep* and opens up its sister problem, *early communication* of CO_2 from injector to producers, so the economics of CO_2 flooding for the Delaware sandstones are not aided as much by an increased oil pricing environment.

Figure 7

PERMIAN BASIN CO_2 EOR PROJECTS (BY LITHOLOGY TYPE) AND PIPELINE SYSTEM INFRASTRUCTURE



SUMMARY

CO_2 EOR flooding in the Permian Basin continues to lead the world in numbers of active projects and CO_2 EOR production. This is because of the early development of supplies of CO_2 and pipelines and the noted successful oil recoveries of the projects, particularly the San Andres formation projects. Nearly 2/3^{rds} of the currently active project activity and almost all of the recent project growth have been San Andres projects on the Central Basin Platform or Northwest shelf.

The early attempts at CO_2 EOR in the Delaware Basin projects in analogous geologic conditions to the WIPP site occurred 18 years ago, but have been not been replicated because of poor oil recovery. The reservoirs in the vicinity of the WIPP site, as in the case with Delaware sandstone reservoirs in general, have some characteristics that pose serious problems to overcome in a flooding effort. These negative characteristics are due primarily to lateral variability of reservoir properties commonly referred to as compartmentalization of the sandstone reservoirs. This reduces the reservoir sweep efficiency, shortens the project life and reduces the cumulative production of a project.

The success of the San Andres formation floods has been due both to the lateral sweep efficiencies and the thick oil columns present in the formation. Both of these attributes are also characteristic of the residual oil zones in the San Andres formation and the reason the interest in new EOR has been concentrated in the ROZ intervals. The closest San Andres fields to the WIPP site lie on the San Andres carbonate shelf approximately 20 miles to the north.

The growth of CO_2 flooding prior to 2001 occurred in oil price environments averaging around $20/barrel. The new oil price environment is clearly one large reason why the numbers of projects will continue to increase and, should CO_2 EOR storage/sequestration be endorsed as a creditable offset to greenhouse gas emission streams, will expand to even greater levels. However, in the short term, the Permian Basin's CO_2 EOR production growth is leveling out awaiting new sources of CO_2.

If oil continues to become more valuable, drilling of the Delaware sandstone reservoirs in the Delaware Basin in general, and also in the vicinity of the WIPP will continue. However, Delaware sandstone flooding projects will not be common due to the challenges of the sweep efficiency of the floods in those types of reservoirs and the pent-up numbers of preferable San Andres projects competing for limited supplies of CO_2.

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12b) U.S. Department of Energy’s Research Project entitled “Using ‘Next-Generation’ CO_2 EOR Technologies to Optimize the Residual Oil Zone CO_2 Flood at the Goldsmith Landreth Unit, Ector County, Texas”

12c) Research Partnership to Secure Energy for America Project entitled “Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres

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