AN UPDATED ASSESSMENT OF THE CO$_2$ ENHANCED OIL RECOVERY POTENTIAL IN THE VICINITY OF THE WASTE ISOLATION PILOT PLANT

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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 CO₂ flooding (also known as CO₂ 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 CO₂ 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.

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, CO₂ 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 CO₂ enhanced oil recovery (EOR) should also be occurring. Furthermore, with an increased
worldwide focus on reducing CO\textsubscript{2} emissions and CO\textsubscript{2} EOR’s ability to store large volumes of CO\textsubscript{2} in the subsurface, one could possibly set the stage for advantaged and, possibly, dramatic growth in CO\textsubscript{2} EOR. It is because of these fast changing dynamics that it is useful to conduct an updated assessment of the CO\textsubscript{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\textsubscript{2} FLOODING STATUS

CO\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{2}. But, while still profitable, those projects make fewer barrels per thousand cubic feet (mcf) of CO\textsubscript{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\textsubscript{2}. If all of the available CO\textsubscript{2} is contracted and much of it
goes to overly mature projects, the oil production must flatten or even decline. To illustrate this limited CO₂ supply point, Figure 4 tracks the supply and demand situation for CO₂. Note that in 2004, at the beginning of the ramp up in oil prices, the growth in demand for CO₂ 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 CO₂ 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.
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\textsubscript{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\textsubscript{2} supply source field, the McElmo Dome might be the design. It is deep (9000’) so that the CO\textsubscript{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\textsubscript{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\textsubscript{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.
GROWTH POTENTIAL OF CO₂ EOR

If there is limited available of CO₂ supplies in a given region like the Permian Basin, then the growth of CO₂ EOR will be constrained, even under a robust oil price environment. So what are the factors for bringing CO₂ supplies in line with the demand (from EOR)? Discovery and exploitation of new pure underground sources of CO₂ like the Bravo or McElmo Domes would be one way. Another might be capture of by-product industrial CO₂. 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 CO₂ pipeline network.

One of the potential long-term drivers of CO₂ EOR growth is related to its ability to permanently store significant volumes of CO₂ in the subsurface. This could be viewed as a commercial subcategory of CO₂ sequestration (also known as carbon capture and storage or CCS). CO₂ EOR is often compared to sequestration in deep saline formations but with one very important difference; i.e., the CO₂ stored can be used to generate revenues hence offering a value for the CO₂ it needs. It has been shown that CO₂ retention in EOR reservoirs is very large and often nearly equal to the amount of CO₂ purchased. The CO₂ 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 CO₂ 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 CO₂ EOR will become qualified mechanisms for enabling CO₂ emission reductions. Governmental entities seem reluctant to step up and certify those as emission reductions without prolonged study. Thus, the second driver for CO₂ EOR growth – capture of CO₂ 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 CO₂ supply that could easily be accelerated by quick adoption of CCS and EOR as certified emission reductions.

PROJECTIONS FOR CO₂ EOR GROWTH

The new trend in CO₂ 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-swep t interval in man’s waterfloods which have been the targets for CO₂ 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.
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 CO₂ floods implemented since the 2008 report (adapted from Ref 9). The long term trend in Permian Basin CO₂ 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 CO₂ projects in the Delaware Basin was in 1995 (East Ford).

<table>
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<tr>
<th>Type and operator</th>
<th>Field</th>
<th>State</th>
<th>County</th>
<th>Start date</th>
<th>Area, acres</th>
<th>Formation</th>
<th>Pay zone Lithology</th>
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<tr>
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<td>George Allen</td>
<td>Tex</td>
<td>Gaines</td>
<td>1/13</td>
<td>160</td>
<td>San Andres</td>
<td>Dolo</td>
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<tr>
<td>2 XTO Energy Inc.</td>
<td>Means (San Andres)</td>
<td>Tex</td>
<td>Andrews</td>
<td>1/12</td>
<td>160</td>
<td>San Andres</td>
<td>Dolo</td>
</tr>
<tr>
<td>3 Hess</td>
<td>Seminole Unit-ROZ Stage 1</td>
<td>Tex</td>
<td>Gaines</td>
<td>2010</td>
<td>2,380</td>
<td>San Andres</td>
<td>Dolo</td>
</tr>
<tr>
<td>4 Kinder Morgan</td>
<td>Katz, Strawn, Consolidated</td>
<td>King, Knox, Stonewall, Haskell</td>
<td>Tex</td>
<td>Strawn</td>
<td>5</td>
<td>San Andres</td>
<td>Dolo</td>
</tr>
<tr>
<td>5 George R. Brown</td>
<td>Garza</td>
<td>Tex</td>
<td>Garza</td>
<td>11/09</td>
<td>1,778</td>
<td>San Andres</td>
<td>Dolo</td>
</tr>
<tr>
<td>6 Faskien</td>
<td>Harford (San Andres)</td>
<td>Tex</td>
<td>Gaines</td>
<td>7/09</td>
<td>113</td>
<td>San Andres ROZ</td>
<td>San Andres Dolo</td>
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<td>7 Legend Resources</td>
<td>Goldsmith-Landrelli</td>
<td>Tex</td>
<td>Ector</td>
<td>5/09</td>
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<tr>
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<td>Abol (Devonian)</td>
<td>Tex</td>
<td>Crane</td>
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<td>800</td>
<td>Devonian</td>
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<tr>
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SUMMARY

CO₂ EOR flooding in the Permian Basin continues to lead the world in numbers of active projects and CO₂ EOR production. This is because of the early development of supplies of CO₂ and pipelines and the noted successful oil recoveries of the projects, particularly the San Andres formation projects. Nearly 2/3rds 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ EOR production growth is leveling out awaiting new sources of CO₂.

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 CO₂.

REFERENCES


12a) Research Partnership to Secure Energy for America Project entitled "Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas"

12b) U.S. Department of Energy’s Research Project entitled “Using ‘Next-Generation’ CO2 EOR Technologies to Optimize the Residual Oil Zone CO2 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

13  Nash Draw Department of Energy Project
http://baervan.nmt.edu/nashdraw/technology_transfer/workshops/Summary_files/frame.htm