CO_2 EOR FLOODING - STATE OF THE UNION

Candace R. Craft and Rebecca J. Larkin
Kinder Morgan CO_2 Company, L.P.

ABSTRACT

CO_2 (Carbon Dioxide) Flooding for EOR (Enhanced Oil Recovery) is in its relative infancy. From the first CO_2 injection project in 1958, to the large miscible floods ongoing in the Permian Basin, this process has proven to be both profitable and an efficient mechanism for hydrocarbon recovery. As oil and gas assets continue to mature with significant reserves left in the ground, the future of CO_2 flooding looks promising. Furthermore, many countries have committed to the Kyoto Protocol, an agreement that in part requires reducing industrial CO_2 emissions (one of the so-called greenhouse gases) as a means to affect climate change. As of November 2003, 84 parties have signed and 120 parties have ratified or acceded (the United States has signed but not ratified the agreement).[1] Countries such as Norway have taken a proactive stance in reducing anthropogenic CO_2 emissions and are backed by their respective governments with tax credits and incentives for reducing emissions and extending the life of some very mature North Sea oil fields. CO_2 sequestration provides a useful, dual purpose solution to start reducing the world's CO_2 emissions with potentially positive implications to global warming as well as flooding to enhance oil recovery. It is likely to be just a matter of time before public opinion, government incentives, and improved technology merge to promote a CO_2 EOR world.

WHAT IS CO_2 FLOODING FOR ENHANCED OIL RECOVERY AND HOW DOES IT WORK?

CO_2 is a unique molecule in that it can improve or enhance oil production when injected into a receptive formation (generally light crudes). With today's technology, an oil field typically goes through three phases in its productive life. The primary phase occurs when wells are produced by natural pressure depletion in typically non-water drive mechanism reservoirs. The secondary phase involves rejuvenating production via restoring and maintaining reservoir pressure, referred to as pressure maintenance. The most common mode of pressure maintenance is waterflooding. In this process, water is injected into the formation to push oil towards a producing well in a mechanical displacement process. Even in the best waterfloods, water can not physically sweep at least a quarter of the reservoir pores because of issues such as mobility ratio, viscosity and relative permeability, and the simple fact that oil and water do not naturally mix. Residual oil is left behind within the "swept" zones. In the tertiary or final phase, an EOR process is employed to capture the bypassed oil. CO_2 flooding is the most popular and widely used EOR process.

Think of CO_2 flooding as a contact sport. CO_2 is injected into a formation. Above a minimum pressure threshold (usually 1200 psi or higher depending upon the fluid chemistry involved) or MMP (minimum miscibility pressure), CO_2 mixes with the oil as a solvent, swelling the oil and reducing its viscosity, and forms a miscible zone that moves through the reservoir and is produced. A miscible zone is one in which two phases are mixed to the point where there is no interface separating them. Oil is literally cleaned from the rock pores when flooded effectively. Even below MMP, CO2 may still cause some swelling with contacted oil, but mainly acts as an energized sweep gas and allows additional recovery though less than that possible under miscible conditions. In either case, the CO_2 must actually touch the oil to enable the flooder to move that oil to the producing well. It is not a delicate process as the flooder has to force this mixture to a producing well, usually using a cyclic combination of water for pressure maintenance and gas containment and CO_2 for physiochemical sweep (Figure 1). Additional expenses are incurred for obtaining the CO_2, expanding facilities for gas handling/processing, and infill drilling or wellbore replacements for pattern realignments, but the reward can be 10% or more additional oil recovery.

PAST CO_2 FLOODS – WHEN DID IT BEGIN?

The first CO_2 injection project was in Oklahoma in 1958, however it was not miscible. The first miscible and large-scale commercial CO_2 flood was in the SACROC Unit beginning in 1972 (Table 1). Thirty-two years later SACROC is still one of the largest CO_2 floods in the world producing 23,000 BOPD, 423,000 BWPD, 18 MMCFD hydrocarbon gas and 160 MMCFD CO_2. Total CO_2 injection at SACROC is approximately 630 MMCFD.

WHERE ARE THE CURRENT CO_2 FLOODS?

Most CO_2 floods are located in the light oil Permian Basin reservoirs in West Texas (Figure 2). Fifty-two CO_2 projects account for 160,000 BOPD or 20% of the Permian Basin's total oil production (Figure 3). It is noteworthy to mention that the use of CO_2, as an injectant, is global. Not only does CO_2 flooding occur in the Permian Basin but also in areas like Wyoming, Mississippi, Hungary (Budafa & Nagylengyel Fields), Turkey (Bati Raman), and Canada.

WHO ARE THE NORTH AMERICAN CO_2 SOURCES & SUPPLIERS?

CO2 for flooding comes from one of two sources: natural and anthropogenic or man-made. Most floods currently use natural sources, however Kyoto or other future Protocols may alter this balance. The following are naturally-occurring CO_2 sources and their current operators (Figure 2):

a. McElmo Dome (KMCO2)
b. Sheep Mountain (BP Amoco)
c. Bravo Dome (Oxy)
d. St. John's Anticline (under development on the New Mexico-Arizona border)
e. Madden Field (under development in Wyoming)
f. Jackson Dome (Denbury Resources in Mississippi)

Anthropogenic sources include such things as synthetic fuel plants, ammonia plants and ethanol fermentation plants; hydrogen plants and refinery fluid catalytic cracker units (FCCU); and fossil fuel power plants, cement plants and anaerobic digestion (biomass and wastes).[3] The following are current anthropogenic CO_2 sources used for CO_2 flooding:

g. LaBarge Gas Plant (Wyoming)
h. Val Verde Basin Gas Plants (Texas)
i. Ethylene Plant (Red Deer, Alberta)
j. Farmland Industries Ammonia Plant (Oklahoma)
k. Michigan Gas Plant
l. Great Plains Synfuels Plant (North Dakota)

FUTURE OF CO_2 FLOODING

With the continuing maturation of existing oil fields and the international focus on global warming, reducing CO_2 emissions is a target that governments are increasingly imposing on industry worldwide for both economic and environmental reasons. The plugging and abandonment of an oil field is a tremendous burden on government with loss of revenue from taxes, loss of jobs, and increased liabilities associated with P&A (specifically North Sea operations), not to mention one less nonrenewable resource gone. For the net importing nations, increased dependence on foreign oil can be delayed by using time-tested EOR processes. CO_2 flooding is a proven economical method of recovery that companies/countries can not afford to overlook.

Most recently, twelve countries (141 attendees) were represented at the 2003 CO_2 Conference in Midland, Texas. In addition, over the past three years, many members of the international community have attended a field tour of the SACROC Unit in Snyder, Texas from the countries China, Japan, Brazil, Denmark, England, Norway, Scotland, Canada, Croatia, Ukraine, Russians and Austria.

The future of CO_2 flooding depends on a certain type of company with very specific objectives. Larger companies that want to diversify their existing properties, just like one diversifies within a 401K plan, will use low-risk CO_2 floods to offset higher risk offshore projects both home and abroad. CO_2 floods are long term projects (10-20 years) and typically yield a 15 to 20% rate-of-return. A company willing to make that kind of commitment should consider hedging their oil as that helps reduce some commodity price risk. Based on experience (economic reality), a successful CO_2 flood requires the following three necessities:

1.) Cheap source of injectant
2.) Close proximity to CO_2 pipeline or existing pipeline infrastructure
3.) Adequate reservoir size (5 MMBO or more in remaining reserves)

Conventional E&P risks do not apply as the reservoir parameters: source, trap, drive mechanism, and economic size have already been established. The technology and the process just like the oil fields themselves are mature, however, there are margin risks on the revenue associated with the volume and price of oil. Expected costs consist of capital (drilling, completion and facilities), operating expense (fluid handling, power and maintenance) and CO_2 purchases (price and recycle availability).

There is a growing trend to install more CO_2 floods for EOR around the world. Kyoto has put CO_2 emissions in the forefront. EOR tax credits have been implemented in many states with the possibility of fines and penalties in the not so distant future. Emissions credits are currently being traded and companies are looking for ways to postpone the liabilities and loss of

revenue from the P&A of a field. With many roads leading to the use of both naturally-occurring and anthropogenic CO_2 for EOR, the future looks bright for CO_2.

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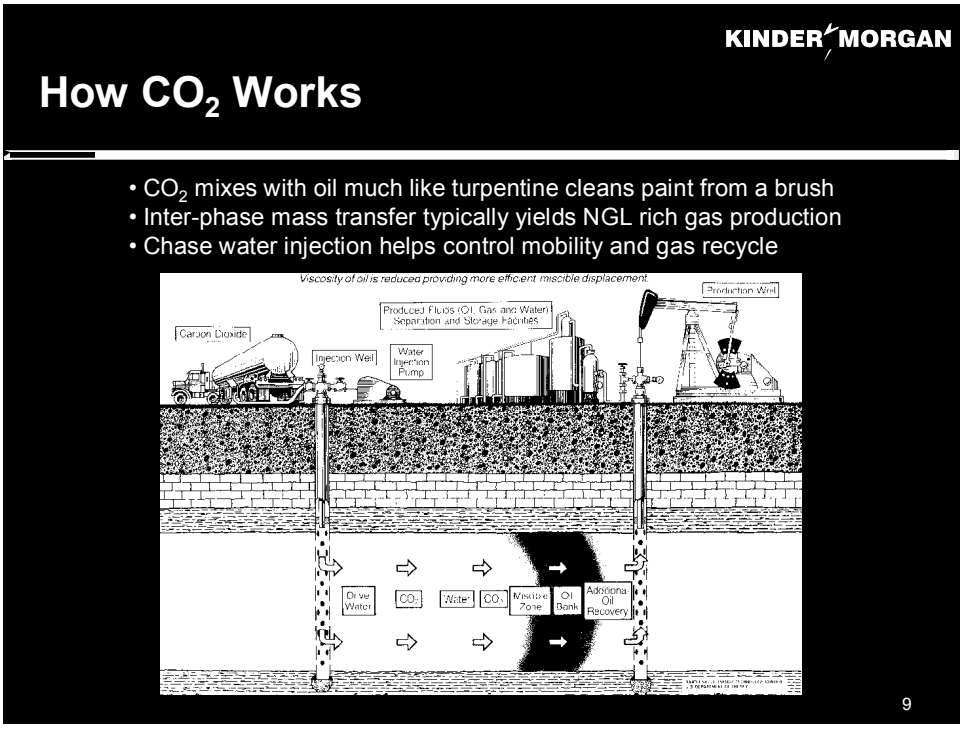

Figure 1

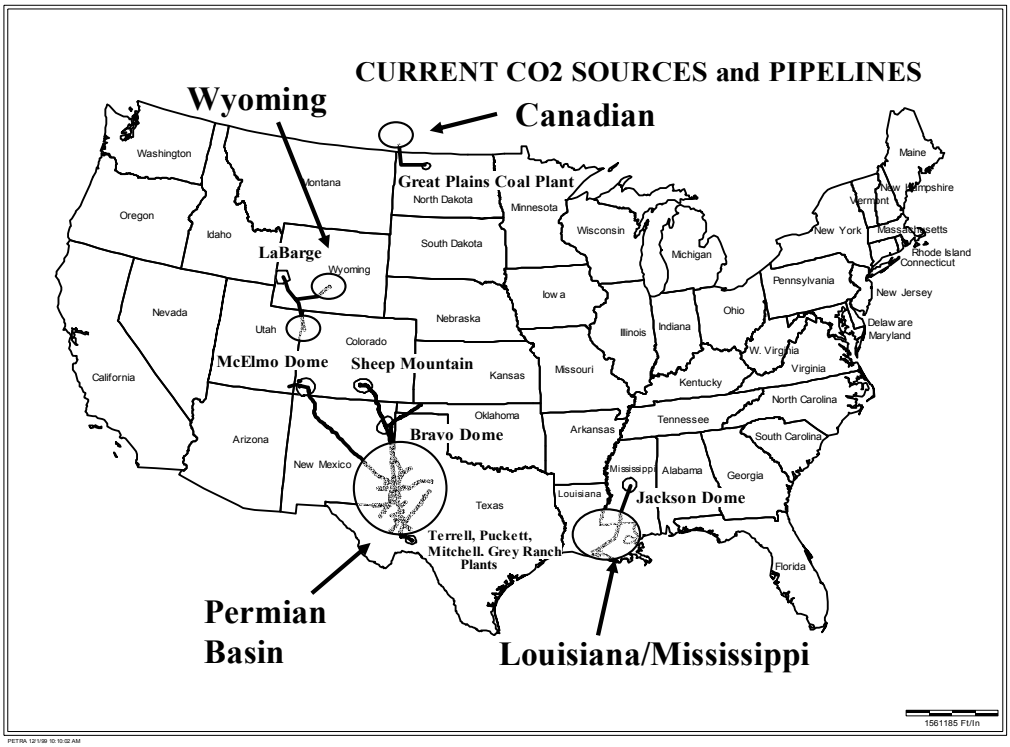

Figure 2

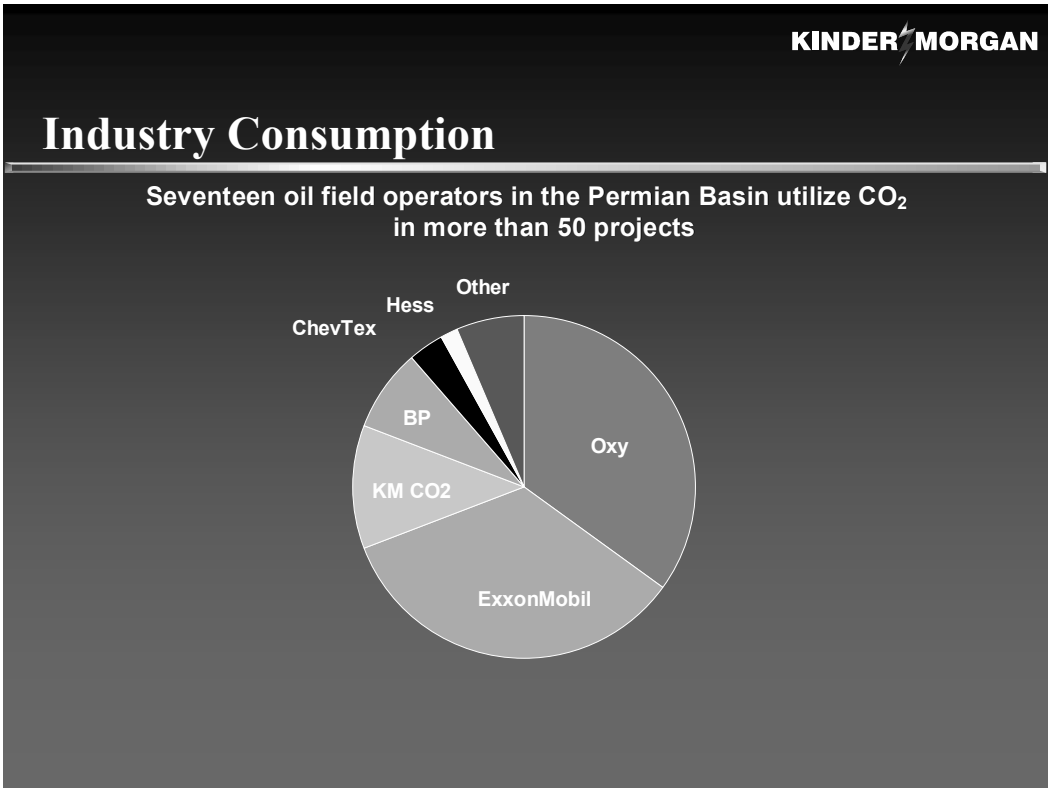

Figure 3

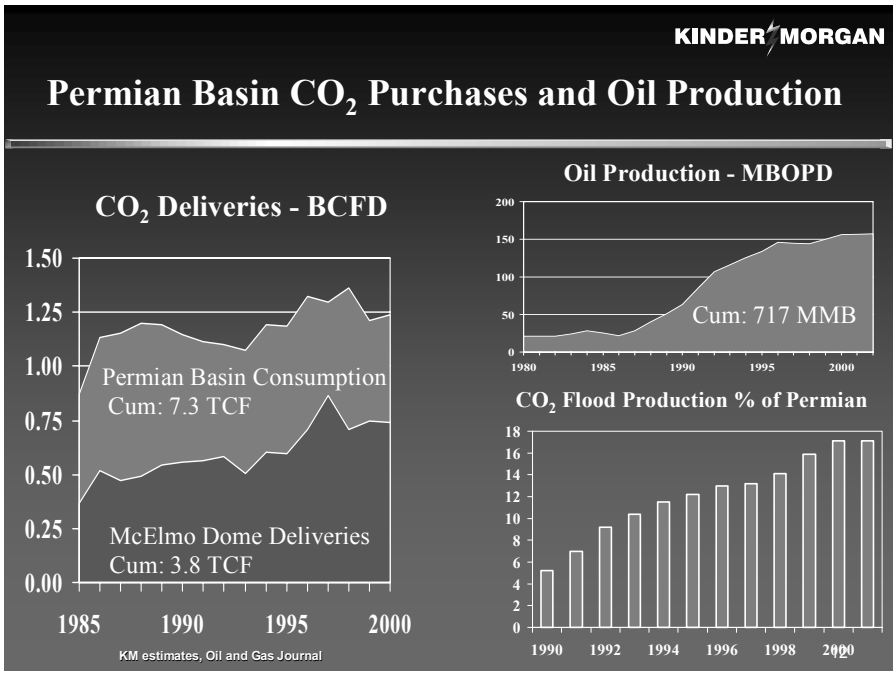

Figure 4

Table 1

The First CO_2 Projects…

Project	Operator	Location	CO_2 Start
K&S-33-Post Oak[1]	Oil Recovery Corp.	Oklahoma	Apr'58
Mead-Strawn[2]	The Pure Oil Co.	Texas	Dec'64
Domes Unit[3]	Cities Service Co.	Oklahoma	<Dec'65
N. Meadow Ck. Fd.[4]	Continental Oil Co.	Wyoming	< Sep'66
Budafa[5]	NKFV	Hungary	1969
SACROC Unit[6]	**Chevron**	**Texas**	**Jan'72**
N. Cross Devonian[6]	Shell Oil Co.	Texas	Apr'72

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