CO2 Enhanced Oil Recovery, and the Texas Oil and Gas Lawyer:

"You two should get to know each other."

Enhanced oil recovery ("EOR") involving CO2 injection is a growing industry that, although beginning in the early 1970s, has really heated up in the 2000s. Greater focus on the domestic barrel (because of sustained high oil prices) should serve to promote CO2 EOR, because the U.S. (particularly, Texas) leads the world in this exciting oil and gas production technology. Also, greater concern about global warming and the need to sequester CO2 emissions should serve to promote further CO2 EOR initiatives.

But first and foremost, Texas oil and gas lawyers should familiarize themselves with the basics of CO2 EOR. This informal paper and its bibliography provide a basic primer on the topic.

Overview of CO2 EOR Activities, Worldwide and in the U.S.

U.S. oil reserves, including offshore basins, total 580 billion BBLs – with 190 billion taken so far and 390 billion remaining in place. How to get the billions remaining in place? And can CO2 EOR help?

The oil and gas industry estimates that current CO2 technology can produce an additional 89 billion BBLs from the 390 billion remaining in place. However, under current market conditions (with BBLs selling for more than $40/BBL and CO2-acquisition costs at 80 cents/MCF or less), only half are *economically* recoverable. By promoting CO2 EOR technology and availability, the industry is working hard to increase both the technically recoverable BBLs and economically recoverable BBLs.

U.S. has roughly 95% of the world's CO2 EOR projects, with two thirds of U.S. CO2 EOR projects taking place in the Permian Basin of West Texas and East New Mexico. Canada, Turkey and Trinidad have the remaining 5% of worldwide CO2 EOR projects. There is one pilot project in the North Sea, still in planning stage.[1]

Throughout the 2000s, various sources have estimate that 5-10% of total U.S. oil production comes from active CO2 EOR projects, with traditional or other EOR accounting for the larger 90-95%.[2] Texas's annual oil production consists of 15-20%

[1] The North Sea project is one to watch closely. Some really smart people are working on this project, and BP and the British government are behind it. Google "David S. Hughes Senergy BP" or "David S. Hughes Miller Field" to monitor this project.

[2] This traditional and other EOR oil production mostly comes from Texas, Oklahoma, California, and offshore areas. "Other EOR" includes water flooding, methane injection, nitrogen injection, chemical solution injection, and thermal techniques.

CO_2 EOR-related production, the rest being traditional oil production or other forms of EOR production.

U.S. oil production from CO_2 EOR projects is expected to grow significantly over the next two decades. The percentage of such production already would have grown significantly if only more CO_2 sources (that is, more sources of CO_2 ready for injection) were developed.

Many potential CO_2 EOR projects are "pent up" (to use industry speak) until more CO_2 sources are developed. The industry authorities are fairly split on whether the additional CO_2 sources will come from (1) further developing the established native-CO_2 sources (namely, Colorado's McElmo Dome and New Mexico's Bravo Dome), (2) developing new native-CO_2 sources in places like Utah, or (3) anthropogenic sources (for example, stripping CO_2 from methane gas streams, or sequestering and processing CO_2 from the flue gases of coal plants). The concern over coal plants' greenhouse gas emissions has placed great focus on option (3), although options (1) and (2) are generally more attractive to oil producers because native-CO_2 sources are more effective suppliers of CO_2 for EOR – in short, because options (1) and (2) produce purer CO_2 streams at higher pressures, thereby reducing processing and compression expenses.

Sources for CO_2: Where Does the Commodity-Type CO_2 Come From?

The largest developed native-CO_2 basins in the world are McElmo Dome (in southwest Colorado, initially developed by Shell and Mobil and now operated by Kinder Morgan), Bravo Dome (in northeast New Mexico, initially developed by Amoco and now operated by Occidental Permian), Sheep Mountain (in south central Colorado, initially developed by ARCO, Exxon and Amerada Hess and now operated by BP), and Jackson Dome (in central Mississippi, operated by Denbury Resources).

McElmo and Bravo are the largest of the four native-CO_2 sources. McElmo produces 900 MMCFD; Bravo produces 300 MMCFD. Both produce highly pure CO_2 streams. McElmo produces CO_2 at roughly 1000 psia and, thus, has low compression expenses to send the CO_2 across the 520-mile Cortex pipeline into West Texas. Kinder Morgan claims that Cortez CO_2 arrives at Denver City (in Yoakum County, Texas) at 1800 psia. Bravo produces CO_2 at much lower pressures and, thus, has high compression expenses to send the CO_2 down the 220-mile Bravo pipeline into West Texas, where (like Cortez CO_2) it arrives at the Denver City hub.

Pipelined CO_2 travels in a "dense phase" (almost liquid like) at roughly 1200 psia. Later compression for purposes of injection increases pressure from 1200 psia to 2000 psia or higher.

After the native-CO_2 basins, recycling plants that capture and reuse the CO_2 found in the produced gas streams from existing CO_2 floods are the largest sources of CO_2 injectant. The best recycling plants in the world are in West Texas: the Denver City plant (south

Yoakum County), the Seminole plant (central Gaines County), the Snyder plant (central Scurry County), and the Mallet plant (southwest Hockley County).

Producing CO2 from a methane gas stream is another viable source for CO2 injectant; it is called an anthropogenic ("man made") source. The largest such source is ExxonMobil's La Barge project in Wyoming that produces CO2 from a high-pressure (deep) gas stream containing roughly two-thirds CO2 and one-third methane, helium and nitrogen. ExxonMobil sells some of the produced CO2 to Anadarko and other producers for CO2 flooding in mature oil reservoirs in Wyoming. Closer to home, PetroSource Energy operates five gas plants Pecos and Terrell Counties, Texas, which process CO2 from (methane) gas streams containing high amounts of CO2. The methane streams seem to enter the plants at higher pressures, around the 1000 psia range. PetroSource uses a Selexol solvent process for recovering the CO2. It incurs roughly 10 cents/MCF in recovery expenses and roughly 25-37 cents/MCF in compression expenses to pressurize the CO2 for transportation to market or to its own CO2 EOR projects in the northern part of the Permian Basin.

Producing CO2 from a coal plant's flue gases is a "hot topic" these days, given the concerns over greenhouse gas emissions and global warming. Such CO2 production, like CO2 removal from a methane stream, is considered anthropogenic. Many pilot projects for capturing a coal plant's CO2 emissions are underway, and the technology is *rapidly* developing. An internet search for coal plants utilizing "integrated gasification combined cycle" (IGCC) technology and "FutureGen" plants will reveal many good reading sources about obtaining CO2 injectant for CO2 EOR from coal plants.

Producing CO2 from various industrial plants (like ammonia plants and synthetic fuels plants) is another potential source for CO2 injectant; it is an anthropogenic source. The current project getting most of the industry's attention in this category is the North Dakota synfuels coal plant project by EnCana and Dakota Gasification Company. See http://www.co2captureandstorage.info/project_specific.php?project_id=70 for details about this project.

Cost Basics for CO2 EOR

One ton of CO2 injectant (roughly 18 MCFs)[3] can result in 2 to 3 BBLs of produced oil. This ratio seems to mark an improvement since the 1980s and 90s, when it reportedly took an estimated 12-15 MCFs to result in a single BBL.

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3 Industry commonly uses these conversion formulas:

19 times 1 metric tonne = the number of MCF in a single metric tonne

17.5 times one (U.S. short) ton = the number of MCF in a single ton

In the mid-1980s and 1990s, new CO2 prices ranged between $1.35-$1.50/MCF. The costs depended heavily on compression and transportation expenses and fluctuated with West Texas crude oil prices (to which CO2-pricing formulas were tied). Also, in the mid-1980s and 1990s, recycling CO2 from a casinghead gas stream cost 50-60 cents/MCF. Recycling CO2 almost always costs less per MCF that acquiring new CO2.

In the 2000s, new CO2 prices have ranged from $1.50-$2.50/MCF and recycling costs have risen to 80-90 cents/MCF. Determining the price/cost of CO2 has been very difficult in the 2000s, because such information is highly confidential and oil and gas producers nowadays are less willing to state their CO2 sales prices or acquisition costs in the industry literature.

Injection Technology for CO2 EOR, and Minimum Miscibility Pressure

Miscible CO2 EOR, in short, enhances production of oil and associated hydrocarbon gas (1) by increasing reservoir pressure (as with traditional (methane) gas lifting techniques) and (2) by actually *dissolving* into the hydrocarbon molecules and decreasing the viscosity of oil and associated hydrocarbon gas, thereby allowing the same to flow more easily to producing wellbores. Immiscible CO2 EOR, in short, does (1) and very little (if any) of (2) – that is, immiscible CO2 molecules do not dissolve into hydrocarbon molecules.

Minimum miscibility pressure ("MMP") is that injection pressure (at the surface) that is necessary for the injected CO2 to become miscible in the reservoir. Several factors affect the MMP, including the nature of the reservoir, the nature of the oil in place, surface temperature and reservoir temperature, and the contents of the injected CO2.

Under typical flooding circumstances – that is, a highly pure (near 100%) CO2 injectant, into reservoirs between 4500-6000 feet in depth, producing crudes with 26 ^{o} – 34 ^{o} API – the MMP falls between 1500-2500 psia. For unknown reasons, many CO2 flooders inject CO2 at higher pressures than are necessary to achieve MMP. This "belts and suspenders" mentality causes such flooders to incur higher compression expenses than necessary. Determining the minimum injection pressure necessary for achieving MMP is important because compression expenses – electricity or gas costs of running surface compressors – are a major expense component in CO2 flooding.

"WAG" technology is common with most miscible CO2 EOR. WAG stands for "water alternating gas." It involves injecting CO2, then water, then CO2 again, then water, etc. into a reservoir productive of oil and associated hydrocarbon gas. The precise nature of a given WAG injection strategy (that is, how many CO2 injection wells, how many water injectors, how many dual injectors, and the placement thereof in relation to producers) has been and will continue to be ripe fodder for reservoir engineering conferences. An oil and gas lawyer, for the most part, merely needs some familiarity with the term WAG.

Miscible CO2 EOR, which typically involves WAG technology, can increase production of original oil in place by 10-15% for reservoirs that have undergone water flooding, and