

## Enhanced Oil Recovery: Going Beyond Conventional Extraction

By Benjamin R. Cook and Charles F. Mason\*

In 1978, amid growing concerns over exposure to foreign oil producers – particularly OPEC – the U.S. Congress instructed the Office of Technology Assessment to assess the state of U.S. oilfield production. The resulting report indicated that hundreds of billions of barrels of known oil in the United States remained unproduced because it was not economically attainable by conventional methods. The report evaluated the potential for a range of enhanced oil recovery (EOR) techniques to recover significant amounts of this ‘stranded’ oil; a specific focus was on the use of Carbon Dioxide (CO<sub>2</sub>), and its potential for recovering a significant fraction of this oil.

Increased production from existing fields by adopting unconventional techniques such as EOR is comparable to resource growth associated with successful exploration. Indeed, in mature oil provinces, better knowledge of known fields can facilitate more rapid reserve expansion than exploration for new fields. The potential for EOR to increase expected production from existing oil fields has been realized in a number of mature oil fields, particularly those located in the Permian Basin of West Texas, Wyoming and Saskatchewan. Estimates have suggested that recovery rates for existing reserves could be approximately doubled, while the application of EOR on a broad scale could raise domestic recoverable oil reserves in the United States by over 80 billion barrels (Advance Resources International, 2006). Similarly, roughly half of the known oil reservoirs in Alberta may be amenable to CO<sub>2</sub> injection for enhanced oil recovery, which could translate in an additional 165 billion barrels of oil recovered (Babadagli, 2006; Shaw and Bachu, 2003).

At sufficiently high pressures, CO<sub>2</sub> mixes with oil (*i.e.*, it is *miscible*). This causes the oil to swell, which lowers the oil’s viscosity significantly, thereby allowing it to flow more easily to the wellbore. In addition, injecting CO<sub>2</sub> reduces the interfacial forces that cause oil to stick to the surrounding reservoir rock. It also increases reservoir pressure, again facilitating production.

There are several important challenges that must be overcome if EOR is to reach its full potential in any particular field-reservoir. First, starting a CO<sub>2</sub>-EOR operation entails substantial initial capital costs: wells must be made ready to accept CO<sub>2</sub>, which is corrosive; injection, separation and recycling<sup>1</sup> capital must be put in place; and pipeline infrastructure must be available. In addition, there must be a ready supply of CO<sub>2</sub>. It is useful to compare these challenges against those associated with petroleum exploration. Exploration can be quite risky: there is the concern of drilling a dry hole, but beyond that there is the concern that a successful venture may locate insufficient resources to allow profitable production, as may be the case with the Niobrara Shale formation. There is the additional concern of delivering the resource to market, as with the Bakken play; this is less likely to be a concern with EOR, as it is generally undertaken in mature fields which are more likely to be connected into existing pipelines.

The potential for EOR to generate a significant increase in production is illustrated in Figure 1, which shows the monthly production levels over a 20 year period at the Lost Soldier field near Bairoil, Wyoming. By 1989 the field had gone into decline, with production levels falling sharply; CO<sub>2</sub> injections into the field commenced in May of 1989.<sup>2</sup> Shortly thereafter production levels increased dramatically as a result of the CO<sub>2</sub> injection; through 2011, the field has produced an estimated 44.5 million barrels of incremental oil.<sup>3</sup>

While CO<sub>2</sub>-EOR projects are becoming increasingly popular in the U.S. (Anonymous, 2012; Schenewerk, 2012), not all fields are suitable for this unconventional production technique. The experience of Rancher Energy Corp. with the Wall Creek unit in the Big Muddy field in the Powder River Basin illustrates the point. Over its history, the Wall Creek unit had over 150 wells drilled, but when oil prices stagnated in the 1990s these wells were permanently abandoned. Using EOR to resurrect the field would require significant investments in new drilling and well workover; ultimately, the cost was projected to be

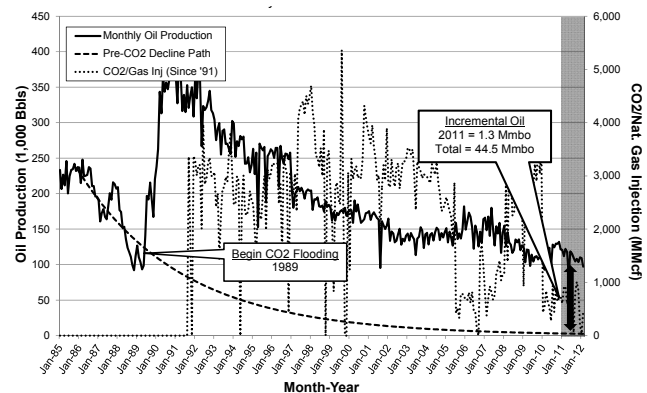


Figure 1  
Lost Soldier CO<sub>2</sub> Units (Bairoil, WY)  
Monthly Oil & Pre-CO<sub>2</sub> Decline Path

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See footnotes at end of text.

\$200 million. When Rancher announced its plan in 2008, the spot price of oil was over \$90/barrel; but after the spot price collapsed several months later, Rancher was unable to service its debt and declared bankruptcy.

This experience highlights the importance of conducting a thoughtful analysis of the economic viability for a candidate oil field for EOR. In particular, it is paramount that the feasible range of production and oil price outcomes be considered to identify the likely profitability of the project.<sup>4</sup> In general, suitable reserves have oil gravities between 22° – 48° API, proven waterflood performance, and depths in excess of 2,000 feet. Moreover, given the large capital outlays and associated risks of implementing EOR, an internal rate of return at or above 20% is in order to ensure economic viability.<sup>5</sup> In retrospect, it seems that Rancher was overly optimistic about the profitability of the Muddy Creek venture.<sup>6</sup>

One final point seems germane. In the event that the country of origin has in place a carbon policy that either implicitly or explicitly places a price on carbon, CO<sub>2</sub>-based EOR projects have the potential to generate an additional revenue stream. To the extent the injected CO<sub>2</sub> is obtained from an anthropogenic source, as in the examples we discussed above, the adoption of EOR facilitates carbon sequestration (Leach et al, 2011).

While the value associated with this revenue stream is likely to be small in comparison to oil revenues, it can nevertheless be substantial. For example, in the Lost Soldier field case discussed above, the average monthly purchase was slightly larger than 1 million cubic feet CO<sub>2</sub>, which translates into about 33 thousand cubic feet (Mcf) per day. If we assume a carbon price of \$20/ton, which is roughly on par with the recent European history, this would correspond to a price of \$1.16 per Mcf, suggesting potential carbon sequestration revenues on the order of \$38.28 per day. To compare this value to the revenues associated with oil production, we note that the gross utilization ratio of injected CO<sub>2</sub> to oil produced was on the order of 11 thousand feet per barrel.<sup>7</sup>

#### **Footnotes**

<sup>1</sup> Because the CO<sub>2</sub> mixes with the oil in the reservoir, the output stream also contains a mixture of oil and CO<sub>2</sub>. Thus, before the oil can be delivered to market the CO<sub>2</sub> must be separated from the oil. In principle, the CO<sub>2</sub> could then be vented, but at historic prices and recycling costs it has generally been economic to re-inject the CO<sub>2</sub>. The fraction of injected CO<sub>2</sub> that reflects recycled gas varies over the life of the project, but is commonly on the order of 55%.

<sup>2</sup> The source of the CO<sub>2</sub> is the Exxon natural gas / helium plant, in southwest Wyoming. The gas processed at this plant contains relatively large levels of CO<sub>2</sub>, which must be removed before the gas can be marketed; this gas is captured and delivered via pipeline to the Bairoil field.

<sup>3</sup> In 2011 alone CO<sub>2</sub>-EOR projects in Wyoming produced an estimated 6.6 million barrels of incremental oil, which represents 12.1% of oil production in the state (Cook, 2012).

<sup>4</sup> See van 't Veld & Phillips (2010) for discussion.

<sup>5</sup> See Cook (2011) for a Monte Carlo analysis that suggests these criteria.

<sup>6</sup> One could argue that Rancher was simply unlucky, inasmuch as it was hard to envision the dramatic drop in crude prices that sealed its fate. That point noted, Rancher bet a very large amount of money on the venture, paying \$74 million for that field as well as two others, and that it may have underestimated the expense associated with shoring up the existing well infrastructure and overestimated the likely productivity of EOR in the field (Mullen, 2011).

<sup>7</sup> Of course, the oil produced from EOR will ultimately generate CO<sub>2</sub> emissions, e.g., from burned gasoline. Aycaguer et al. (2001) find that this indirect effect is roughly of the same order of magnitude as the sequestered CO<sub>2</sub>.

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