COMMENTARY

Advancing Enhanced Oil Recovery as a Sequestration Asset

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We propose that the US government pilot-tests a reverse Dutch auction for CO2 EOR credits to stimulate the development of advanced CO2 EOR. At an estimated cost of about $25 per metric ton of CO2, this compares favorably with other government programs designed to reduce CO2 emissions. Effective incentives would spur investments leading to gigaton-scale reductions that offset CO2 emissions from the transportation sector.

Carbon dioxide, CO2, injection is an enhanced oil recovery (EOR) technique especially effective at increasing production from deep light oil reservoirs. Studies suggest a global technical potential to sequester from 60 to 360 GT of CO2 over the next 50 years, depending on the amount of CO2 injected underground per barrel of oil produced.1 For context, a path to a 2°C average global temperature increase is expected to require a total of about 125 GT of CO2 storage.2

Achieving gigaton scale CO2 EOR storage goals will require innovation. This work focuses on a government incentive—a reverse Dutch auction—as a sensible policy mechanism to encourage innovation of advanced CO2 EOR (A-CO2 EOR), whose commercial profitability derives from both enhanced production and CO2 storage.

The United States and other countries are struggling to find fair and cost-effective ways to reduce carbon emissions to avoid the risks of climate change. When the oil and gas industry is facing mounting criticism as a business based on conversion of hydrocarbons in the ground to carbon dioxide emissions in the atmosphere, CO2 EOR could be a concrete and positive contribution to CO2 emission avoidance and deserves evaluation.

Introduction

Avoided atmospheric CO2 emissions could be increased by accelerating the use of advanced CO2 enhanced oil recovery (EOR). Today, about 65 million metric tons of CO2 are pumped underground for enhanced oil recovery, mostly in the US. About one third of this CO2 is captured from anthropogenic sources. By doubling the amount of CO2 pumped underground for every barrel of oil produced, avoided emissions could be increased dramatically.

We propose that the US government pilot-tests a reverse Dutch auction for CO2 EOR credits to stimulate the development of advanced CO2 EOR. At an estimated cost of about $25 per metric ton of CO2, this compares favorably with other government programs designed to reduce CO2 emissions. Effective incentives would spur investments leading to gigaton-scale reductions that offset CO2 emissions from the transportation sector.

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At present, CO₂-assisted EOR is about 3% of US domestic oil production or about 300,000 barrels (bbl)/day, mostly from the Permian Basin and the Gulf Coast. Historically, since most of the CO₂ for EOR has come from natural CO₂ reservoirs, there has been little climate benefit. However, if CO₂ EOR using CO₂ captured from anthropogenic sources were increased about 10-fold to a level of 500 MT/year, that would reduce total US emissions by about 9.5%, not an inconsequential part of the emissions reductions that the United States is seeking to achieve by mid-century.

### Operation and Economics of CO₂ EOR

Primary and secondary production typically recovers up to one-third of the oil-in-place (OIP) in a reservoir. A-CO₂ EOR has the technical potential for doubling the recovery of OIP compared with conventional EOR. Normally a CO₂ EOR project will extend for decades with nearly all of the injected CO₂ remaining sequestered in the oil reservoir when produced CO₂ is recycled back into the reservoir.

EOR projects are notorious for the high variability that reflects reservoir location and conditions. Project economics vary depending on the price of oil and the cost of CO₂ over the life of the project. Here, we use generalized results of prior studies of co-optimized CO₂ EOR plus sequestration. For illustration, we focus on the hypothetical oil field described in Table 1 with 180 million barrels OIP. After primary and secondary production, we consider two cases: conventional CO₂ EOR and A-CO₂ EOR.

For this example, A-CO₂ EOR sequesters twice the amount of CO₂ per barrel of oil produced compared with conventional CO₂ EOR. Net emissions, defined as the emissions from burning the oil minus the amount of CO₂ sequestered from the oilfield are illustrated in Figure 1. During primary and secondary production, emissions increase linearly at a rate of 0.43 tonnes CO₂/bbl of oil produced. Once conventional CO₂ EOR begins, sequestered CO₂ nearly offsets the incremental emissions produced when the oil is burned. For A-CO₂ EOR, sequestered CO₂ exceeds the incremental emissions from burning the oil, offsetting not only current but past emissions, eventually for this example, by 70% of all the emissions from primary and secondary production (Table 1, see Figure 1).

The economics of a CO₂ EOR project is sensitive to oil price, the acquisition cost of CO₂, and additional cost associated with the EOR activity. Table 2 shows the range assumed in this work for “high,” “reference,” and “low” oil prices averaged over the project life. Table 2 includes the CO₂ acquisition cost and other costs associated with CO₂ EOR activity. The values in Table 2 are subject to challenge but the trends of CO₂ price and margin with increasing oil prices are robust.

The margins are highly sensitive to oil price. Without an imposed charge on CO₂ emissions, Table 2 shows that the projected cost of an A-CO₂ EOR is not financially attractive to the owner/operator compared with conventional CO₂ EOR. The incremental costs to break even with traditional CO₂ EOR range from $22 to $32/T CO₂.

### Policy Options

The preferred approach of an economy-wide greenhouse gas emissions charge is unlikely in the near term. If, in the future, a charge is adopted at sufficiently high levels, the value of using the pores in oil reservoirs for sequestration will be greater than the value of the oil displaced, and the economic motivation for CO₂ EOR production and sequestration will reverse.

In the absence of a carbon emission charge, there is no commercial...
Table 2. Economic Analysis of CO2 EOR and A-CO2 EOR

<table>
<thead>
<tr>
<th>Oil Price ($/bbl)</th>
<th>Conventional CO2 EOR (2.5 bbl/T)</th>
<th>A-CO2 EOR (1.25 bbl/T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>CO2 acquisition cost ($/T)</td>
<td>−39</td>
<td>−29</td>
</tr>
<tr>
<td>CO2 acquisition cost ($/bbl production)</td>
<td>−15</td>
<td>−12</td>
</tr>
<tr>
<td>Other related costs ($/bbl)</td>
<td>−35</td>
<td>−35</td>
</tr>
<tr>
<td>Net pretax margin ($/bbl)</td>
<td>50</td>
<td>28</td>
</tr>
<tr>
<td>CO2 EOR production (million barrels)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Project EOR margin ($ million)</td>
<td>1,488</td>
<td>854</td>
</tr>
<tr>
<td>CO2 injected (MT)</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>CO2 price to break even ($/MT)</td>
<td>22.25</td>
<td>27.35</td>
</tr>
<tr>
<td>Project margin ($/million) if credited with the social cost of carbon ($30/T) for incremental storage</td>
<td>1,786</td>
<td>955</td>
</tr>
</tbody>
</table>

*This range is narrower than the EIA 2017 AEO’s $30 to $194 per barrel in 2030.

*A rule of thumb is that the acquisition CO2 cost in $/MCF (1,000 cubic feet) is between 2% and 4% of the oil price in $/bbl. Cook, B.R. (2012) The Economic Contribution of CO2 Enhanced Oil Recovery in Wyoming’s Economy. The Enhanced Oil Recovery Institute, University of Wyoming. Working paper. p. 20.

*Includes royalties, allocated EOR equipment allocation, taxes, recycling cost, and other site operation and maintenance costs associated with CO2.

justification for private industry to invest in A-CO2 EOR technologies. In this circumstance, the government objective should be to adopt policies at reasonable cost that will encourage EOR owner/operators to explore A-CO2 EOR to position the industry to deploy this technology more rapidly when there is an economy-wide price on carbon emissions. The government has the choice of several policy mechanisms for this purpose:

- A tax credit for EOR. Since 2008, qualifying CO2 EOR facilities have been eligible to receive a tax credit of $10/T, with a cap of a total of 75 MT, referred to as the 45Q tax credit. In 2018, Congress raised the 45Q credit to $35/T for CO2 EOR and $50/T for storage in saline formations and removed the cap.14

  The 45Q tax credit will incentivize conventional CO2 EOR. But this tax credit mechanism is not targeted to incentivize A-CO2 EOR. Furthermore, the use of tax credits suffers from “leakage” to financial intermediaries, and in the circumstances where oil prices are low, few oil and gas firms are in a position to take advantage directly of the incentive. Recent cuts to corporate tax rates also make tax credits less attractive than in the past.

- A direct payment also does not incentivize development of A-CO2 EOR beyond what would be expected under market conditions. To be effective, the level of payment would need to be sufficiently high to offset the current cost of CO2. However, the great diversity and uncertainty in the discounted net present value to owner/operators of multiyear EOR projects makes this approach more expensive than a targeted benefit.

- What is needed is a policy mechanism that allows the government the flexibility to adjust the amount of assistance provided to the firms prepared to undertake new projects at various levels of support. A reverse Dutch auction is an ideal mechanism to achieve selective encouragement of A-CO2 EOR. In a reverse Dutch auction, the government would annually solicit bids from owner/operators of new A-CO2 EOR multiyear projects that, over the life of the project, specify the amount of CO2 sequestered, the ratio of CO2 sequestered to oil production, and the amount of annual payment sought from the government (which is assumed to be constant over the life of the project). These bids will reflect each firm’s willingness to implement A-CO2 EOR. In contrast to conventional tax credit or direct payment subsidy programs that offer the same benefit to all eligible firms, in a Dutch auction the government selects the price that yields the desired cumulative amount of A-CO2 EOR.

It is difficult to predict the outcome of such reverse Dutch auctions for CO2 EOR credits. The sizes and prices bid will depend on the oil price. It is quite possible that a $20 per metric ton CO2 payment would be sufficiently attractive to result in greater CO2 EOR use in 2040 than the 700 million bbl/day predicted by the Energy Information Administration (EIA) in its 2014 Annual Energy Outlook (AEO). Rebound effects need to be evaluated that could increase oil consumption by the shift of the supply curve to a lower market clearing price.

The design of all these incentives for CO2 EOR confronts several complications:

- Should a benefit be extended to both low-cost natural sources and high-cost anthropogenic sources of CO2? Low-cost natural or anthropogenic sources (high-purity sources of CO2 from refineries and ethanol plants can be compressed and dehydrated for about $20–30 T/CO2) of CO2 can jump start the process, but in the future, anthropogenic CO2 will increasingly come from coal, oil, and natural gas combustion, which incur higher CO2 capture, purification, and pressurization costs (ranging from $60 to $90/T CO2 depending on the source).15
The availability of a CO₂ gas pipeline distribution system is likely to be the greatest constraint to the expansion (at reasonable cost) of A-CO₂ EOR. A pipeline capacity constraint will lead to an increase in pipeline tariffs, a reduction in expected margins for A-CO₂ EOR, and hence attenuation in desired growth.

An A-CO₂ EOR project will have a life of 10 years or more. The project entrepreneur must estimate the variability in oil prices and CO₂ acquisition cost in assessing the discounted present value of the project. Under current market conditions, there is a strong positive correlation between oil price, CO₂ cost, and return on CO₂ EOR projects.

How successful government policy will be at encouraging A-CO₂ EOR use and technology advance is uncertain for the reasons mentioned above. This uncertainty suggests that payments for A-CO₂ EOR using anthropogenic CO₂ with the Dutch auction proposal for CO₂ EOR be considered an experiment rather than a policy to be permanently adopted. A decade of experience will determine the merit of this policy incentive to encourage A-CO₂ EOR.

Experience gained from the expansion of A-CO₂ EOR will also be beneficial for assessing the costs and risks of CO₂ sequestration in deep saline formations, which have the potential for even larger amount of sequestration, but lack the financial and energy security benefits of CO₂ EOR. Let us assume a 3-year experimental program with ten projects selected per year, each with a 10-year lifetime, and 300,000 bbl/per day produced for the entire program. If the government accepted an average bid for CO₂ of $25/T, the annual per project cost would be $22 million for 0.88 MT of CO₂ sequestered. The total program cost over the lifetime of the program would be $6.6 billion for 264 MT of CO₂ sequestered. The expense of the proposed CO₂ EOR program should be compared with other government programs designed to reduce CO₂ emissions. While largely presented in the US context here, the reverse Dutch auction could equally well be applied in other oil-rich countries seeking economically efficient policies for reducing emissions.


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