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Enhanced Oil Recovery & CCS

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This paper presents a novel idea which has the potential to generate $10 trillion of domestic economic activity, employ 2.5 million workers for three decades, reduce U.S. greenhouse gas emissions by 300 million tonnes per year, advance technologies to capture carbon dioxide (CO_2) from industrial and utility operations, reduce U.S. dependence on imported oil, and provide significant revenue to state governments.

The idea is based on displacement of a large percentage of currently imported oil with a dramatic expansion of domestic oil production. The increased domestic production is made possible by a process called enhanced oil recovery (EOR), which can produce oil left in geologic reservoirs after exhaustion of primary and secondary oil production systems – oil which would remain underground in the absence of the CO_2 EOR technology. CO_2 EOR is a mature technology and was responsible for about 5% of U.S. oil production in 2006. However, "natural" CO_2 resources, which are used in most current EOR projects, are insufficient to enable oil production at the scale proposed in this paper. Industrial CO_2, captured from gases emitted by processes like coal-fired power plants, can provide the necessary CO_2, but the capture process is not economically viable with currently available technology.

The paper proposes that it might be practical to "bootstrap" this industrial CO_2 EOR industry by providing a portion of federal tax revenues derived from the production of the CO_2 derived domestic oil, and related economic activity, to the entity which would capture the CO_2 and thereby enable the additional domestic economic activity. It is anticipated that the overall system would be "revenue positive," i.e., would provide additional taxes to the federal government, because in the absence of the CO_2 capture subsidy, there would be no additional oil production and none of the resulting profits and taxes would occur.

Introduction

Enhanced Oil Recovery (EOR) is a method of producing oil that changes the oil properties to make it more mobile in the reservoir. EOR generally follows a secondary phase or waterflood and hence is sometimes referred to as a tertiary process.[1] Typically, primary and secondary production technology can produce 20-40% of the "original oil in place" (OOIP).[2,3] If a field is amenable to EOR, and about half of the largest ones are, an additional 5-20% of the OOIP can be recovered.[4,5] EOR is a mature technology. In 2006, EOR accounted for about 13% of U.S. oil production, and 37% of this EOR was "CO_2 EOR."[6]

This paper provides a general overview of CO_2 based EOR[7], describes the potential benefits associated with EOR in the U.S., the principal barrier to achieving that potential, and a possible mechanism to overcome that barrier. For those eager to identify bottom lines, the U.S. Department of Energy (USDOE) reports that 45 billion additional barrels of domestic oil could be produced under the right economic circumstances.[8] This oil has a direct value of $4 trillion, and indirect economic benefits from producing the oil could be greater than this direct value. Moreover, essentially all of the CO_2 supplied to the EOR site would be permanently stored in the geologic formation and such storage would reduce atmospheric emissions of CO_2, a greenhouse gas. Additionally, deployment of CO_2 capture systems for EOR could drive down the cost of CO_2 capture from industrial sources through the experience gained with EOR efforts. However, the majority of these benefits are unlikely to be realized because, for most industrial CO_2 sources, the cost of CO_2 capture is greater than the direct income stream from the oil production can provide. Nevertheless, it may be possible to use innovative tax policy to create a win-win situation, in which both net tax revenues increase and a subsidy can be provided to make the CO_2 capture, and subsequent EOR benefits, practical.

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[1] Primary oil recovery generally means using natural reservoir pressure or pumping to raise oil from its natural reservoir. Secondary recovery involves injecting fluids (water or gases) into the reservoir to drive additional oil to nearby extraction wells. See Schlumberger definitions at http://www.glossary.oilfield.slb.com/Display.cfm?Term=primary%20recovery and http://www.glossary.oilfield.slb.com/Display.cfm?Term=secondary%20recovery .

[2] Enhanced Oil Recovery Scoping Study, TR-113836, EPRI, 1999, http://www.energy.ca.gov/process/pubs/electrotech_opps_tr113836.pdf

[3] Enhanced Oil Recovery / CO_2 Injection, USDOE/National Energy Technology Laboratory (NETL), http://www.fossil.energy.gov/programs/oilgas/eor/index.html .

[4] Ibid.

[5] Carbon Dioxide Enhanced Oil Recovery, USDOE/NETL, March 2010, http://www.netl.doe.gov/technologies/oil-gas/publications/EP/small_CO2_EOR_Primer.pdf

[6] Carbon Sequestration Through Enhanced Oil Recovery, USDOE/NETL, Prog053, April 2008, http://www.netl.doe.gov/publications/factsheets/program/Prog053.pdf .

[7] EOR involves injection of various materials into the oil reservoir to change the character of the crude oil, usually to lower its viscosity, or resistance to flow. In addition to CO_2 injection, EOR can use steam, natural gas, nitrogen, or chemicals. Op Cit, NETL, March 2010.

[8] Storing CO_2 with Enhanced Oil Recovery, USDOE/NETL, DOE/NETL-402/1312/02-07-08, February 2008. It is important to clarify that the DOE report assumed that the CO_2 can be delivered, under pressure, to the oil field for $45/tonne. Currently available technologies cannot capture and deliver CO_2 from dilute gas streams (like power plant emissions) for this price.

EOR technology

CO_2 EOR was first used in large scale in Scurry County, Texas, in 1972.[9] Most CO_2 EOR projects in the U.S. use "miscible" EOR – the injected CO_2 mixes with the in-place oil and the mixture swells and becomes less viscous than the original crude oil (immiscible EOR is also possible, but is less productive than miscible EOR.). In many situations, after a period of CO_2 injection (days to several months), water is injected. This cycle is repeated in what is termed "water alternating gas" (WAG) floods. Figure 1 presents a characterization of this process. On every cycle, some of the CO_2 stays behind in the reservoir, and some returns to the surface with the produced oil. The returned CO_2 is recaptured due to its value, and reinjected, so that ultimately essentially all of the purchased CO_2 is permanently stored underground. The "net" (originally purchased) CO_2 needed varies by field, but typical estimates range from 0.25-0.40 tonnes CO_2 per barrel of oil produced.[10, 11] Most current EOR operations use "natural" CO_2, produced from underground reservoirs in a manner similar to natural gas production. However, natural CO_2 resources are limited so some existing EOR operations use CO_2 captured from industrial processes. Expansion of EOR using "industrial" CO_2, such as that emitted from fossil fuel-fired power plants, holds the greatest economic and environmental promise for the U.S.

Potential U.S. oil recovery via EOR

A DOE report[12] assuming crude oil priced at $70 per barrel, and CO_2 delivered to the oil field at $45 per tonne, concluded that 45 billion barrels of additional EOR production is economically recoverable within the U.S.[13] The production would require about 12.5 billion tonnes of CO_2.[14] "Economically recoverable" oil is a subset of "technically recoverable resources" which have been estimated at 87 billion barrels,[15] and "Remaining Immobile oil", which has been estimated at 89 billion barrels.[16] Another useful benchmark is that U.S. oil production in 2009 totaled 2.0 billion barrels.[17] In other words, if the economically recoverable CO_2 EOR were produced over the next 30 years, the annual EOR production would average about 1.5 billion barrels per year, compared to current total U.S. oil production of 2.0 billion barrels per year.

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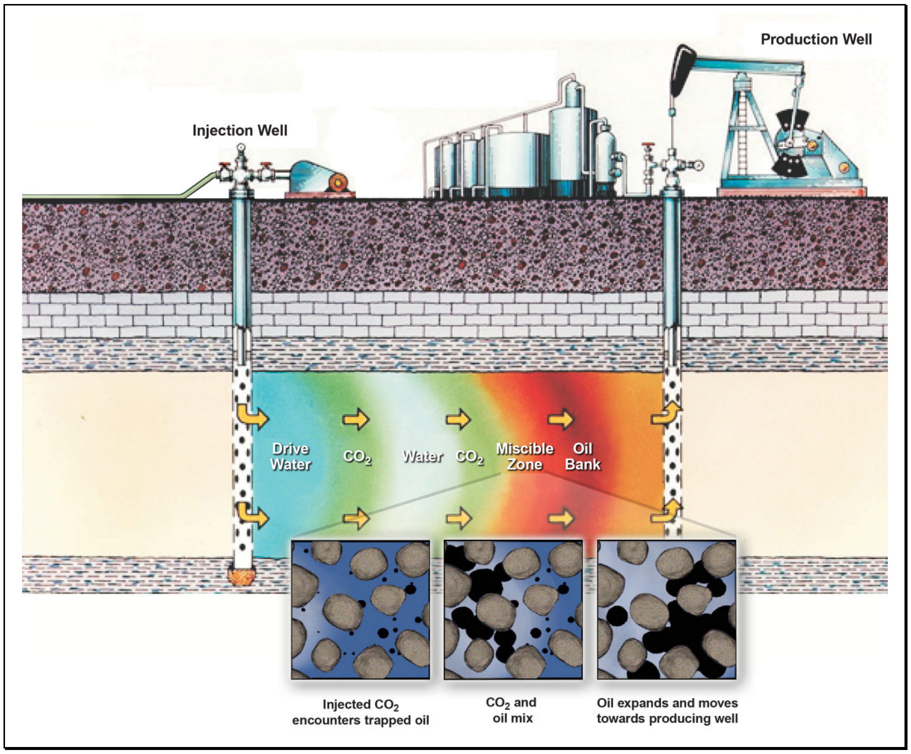
[9] Summary of Carbon Dioxide Enhanced Oil Recovery Injection Well Technology, J. Meyer, Contek Solutions, report prepared for the American Petroleum Institute (API), 2007.
[10] Op. Cit., API, 2007.
[11] Op. Cit., NETL, February 2008.
[12] Ibid.
[13] "Economically recoverable" assumes that the CO_2 can be delivered at $45/tonne. As discussed below, this is not generally the case. Additionally (also discussed below) current markets do not appear to support a $45/tonne price for delivered CO_2.
[14] Ibid.
[15] Ibid.
[16] Fact Sheet: CO_2 Enhanced Oil Recovery, USDOE Office of Petroleum Reserves, http://fossil.energy.gov/programs/reserves/npr/CO2_EOR_Fact_Sheet.pdf .
[17] USDOE/EIA, http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRFPUS1&f=A .

Figure 1. Typical CO_2 "WAG" flooding EOR (Source: USDOE/NETL)



Potential benefits of EOR

Like any other basic economic activity, the production of oil via EOR produces direct benefits (e.g., the value of the oil), indirect benefits via other economic activities that support the EOR process (like production of steel pipe for the injection and production wells), and induced economic activity via purchases made using the salaries of employees engaged in these direct and indirect economic activities (e.g., for food, housing, clothing). Some EOR benefits are quantifiable and can be monetized, such as the revenue from sale of produced oil. Some benefits are quantifiable but have uncertain monetary value, such as the future value of reducing CO_2 emissions to the atmosphere in response to a carbon tax or other federal legislation on greenhouse gases. Other benefits can only be discussed qualitatively, but include the following:

- Increased energy security, due to reduced oil imports
- Improved balance of payments for international trade
- The value of reduced adverse impacts from climate change
- The ability to maintain domestic GHG-intensive industries because a low cost option for reducing greenhouse gas(GHG) emissions exists (could include fossil-based power, cement production, refining)
- The increased value of underground oil resources which can only be exploited via EOR

Barriers to EOR

Current technologies for capturing CO_2 vary dramatically in cost, depending on the industry. For example, CO_2 capture from a natural gas processing plant or ammonia fertilizer production might cost only $12 per tonne CO_2 because the cost for CO_2 separation from the process gases is part of the basic operation. In contrast, CO_2 capture from a new coal-fired power plant, or natural gas-fired power plant, might cost $80-100 per tonne, and more for first-of-a-kind facilities. With oil priced at $70 per barrel, a DOE report estimated that CO_2 for EOR might have a value of $45 per tonne, delivered to the oil field.[18] Moreover, the entity capturing the CO_2 would have to pay a portion of this amount to transport the CO_2 to the EOR field. The above scenarios would result in some conditions under which EOR projects would proceed and some in which they would not. Normally, this is how markets should work, and is not a "market failure"[19] which might merit government intervention. However, in this situation, the benefits generated downstream of the oil production are not shared with the entity which provides the CO_2 enabling those benefits. This lack of connection between benefits and rewards may lead to an inefficient marketplace which fails to maximize U.S. economic benefits.

Two circumstances make the increased production of domestic oil using CO_2 EOR different from most business situations. First, in the absence of the EOR production, the oil required for transportation and other purposes in the U.S. would be imported. Hence, the EOR activity retains money within the U.S. economy where it can support jobs and secondary economic activity, such as manufacture of steel pipe for the CO_2 injection wells and oil production wells, as well as government tax revenues from profits and wages linked both to the oil production and to secondary economic activity. None of this economic benefit would flow to the U.S. if the oil were imported. Second, several "public goods" or benefits external to the normal economy, including environmental benefits, energy security benefits, technology advances, and balance of payment benefits, are associated with the domestic oil production. These differing circumstances are explored further in the two scenarios presented below.

Two EOR Scenarios

For purposes of this discussion, posit two possible scenarios:

1. <u>BAU scenario</u>. Limited EOR continues, using natural CO_2 in the Permian Basin and Gulf states and CO_2 from natural formations and industrial facilities with relatively low capture costs (ammonia plants, ethanol plants, and natural gas processing plants) in the Rockies and Mid-Continent.
2. <u>Recycled Tax scenario</u>. EOR is substantially expanded by subsidizing CO_2 capture at relatively high capture cost industrial sources (such as power plants), using federal tax revenues from oil production and downstream economic activities.

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[18] Op. Cit., DOE/NETL, February 2008. Note that the report did not imply that adequate volumes of CO2 could be captured and delivered for $45/tonne, only that, if they were, then the EOR production would be economical. As discussed above, a limited amount of CO2 could be produced for well below $45/tonne, but the majority of emission sources are much more costly to control with current technologies.

[19] "Market failure is a concept within economic theory wherein the allocation of goods and services by a free market is not efficient." http://en.wikipedia.org/wiki/Market_failure .

Under the Recycled Tax scenario, we assume that expanded EOR is essentially "CO_2 starved;" that the direct sale of produced oil is insufficient to cover the costs for producing the CO_2 needed for the additional EOR;[20] but that direct sales revenues supplemented by recycled tax revenues would be sufficient to make the CO_2 capture from very large point source emission streams economically viable (profitable). The first two assumptions are supported by government studies.[21,22] The third assumption is speculative at this point. However, the magnitude of the economic benefits is large and may warrant a detailed examination. A superficial examination of benefits provides the following information:

- The RIMS-II Input-Output economic model, maintained by the Department of Commerce's Bureau of Economic Analysis (DOC/BEA), provides a "Final Output Multiplier" of 1.9 for additional oil and gas economic activity in the 7 states with greatest ongoing oil production.[23] That means for every dollar of revenue associated with oil production, another $0.9 is generated in downstream economic activity.
- A white paper by the Texas Bureau of Economic Geology concluded that, for Texas, total economic activity associated with oil production is 2.9 times the value of the oil produced.[24] The paper also estimated 19 jobs for every annual value of $1 million of produced oil.
- DOE has concluded that 45 billion barrels of oil could be produced via EOR if oil was worth $70/barrel and CO_2 were available for $45/tonne. The current price of oil is $90/barrel. The report also concluded that CO_2 resources beyond current natural and "low cost" industrial CO_2 (such as from a natural gas processing facility) would be needed to recover 95% of this potential.[25]
- In contrast to the DOE assessment, others have suggested that a more realistic price for CO_2, delivered to oil fields under pressure, will be in a range between $15-25/tonne,[26] or possibly $30/tonne.[27]
- DOE estimates that early CCS capture projects for power plants will cost $95/tonne CO_2, and that figure could drop to $44/tonne for units commencing operation after about 2025, with successful R&D.[28]

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[20] This assumption is based on the projected viability of CO_2 EOR if CO_2 can be provided at $45/tonne, combined with estimates that CO_2 capture from dilute gas streams, like power plants, is much greater than $45/tonne, as presented below.

[21] Op. Cit., DOE/NETL 2008.

[22] Accelerated Coal Program & CCS RD&D, J. Markowsky, Assistant Secretary for Fossil Energy, USDOE, Presentation to Edison Electric Institute, 20 July 2010. Timing is based on author's assumption of 10 years to design, permit, and construct a new power plant with CCS.

[23] Regional Input-Output Modeling System (RIMS II), Table 3.5: Total Multipliers for Output, Earnings, Employment, and Value Added by State, for Oil and Gas Extraction, retrieval by Author, 13 December 2010.

[24] CO_2 Enhanced Oil Recovery Resource Potential in Texas – Potential Positive Economic Impacts, TX Bureau of Economic Geology, April 2004.

[25] Op. Cit., DOE/NETL 2008.

[26] Personal communication with S. Melzer, Melzer Consulting, December 2010.

[27] Personal communication with M. Moore, Blue Source, Deceember 2010.

[28] Op. Cit., USDOE, 20 July 2010.

- Assuming the capture system owner received \$25/tonne CO_2 after paying for pipeline delivery of the CO_2 to the oil field, a \$73/tonne gap remains in the cost of CO_2 capture in order to make the capture system viable with current technology.
- Assuming 0.25 tonne CO_2 per barrel of produced oil, an additional revenue stream of \$18 per barrel of oil is needed for the capture system to "break even."
- If one assumes a \$20/barrel profit from the oil production, taxed at 30%, and downstream economic activity (0.9-1.9 times the value of the oil, or \$63-133 per barrel) taxed at 6% (30% tax on 20% profits), then federal tax revenues would be about \$12 per barrel. This appears to fall short of the amount needed (assuming all this tax revenue could be recycled to the CO_2 capture facility), but the above methodology is crude and intended only to establish a ballpark estimate. Also, to the extent that the oil production is on federal lands, additional federal income could be derived from royalty payments.[29]
- EOR projects can also produce natural gas liquids, which have additional value and would reduce the amount of recycled taxes needed to reach profitability.
- Current tax rules provide a \$10/tonne CO_2 tax credit for geologic storage of CO_2 associated with EOR activities, limited to the first 75 million tonnes of CO_2 storage certified by the EPA and the first 10 years of storage.[30] Given the potential demand for CO_2 for EOR (12.5 billion tonnes CO_2) and the cost of capture, this measure does not resolve the cost "gap." However, it does demonstrate one approach by which federal EOR-related tax revenues could be recycled to offset a portion of CO_2 capture costs.

These two scenarios paint dramatically different outcomes in terms of economic activity related to CO_2 EOR. However, the expanded benefits of the Recycled Tax scenario are, to a degree, predicated on a set of unverified assumptions as well as the ability to adjust federal tax rules.

Conclusions

CO_2 EOR has the potential to produce 45 billion barrels of domestic oil. This oil has an approximate value of \$4 trillion at the current price of oil, and more under prices projected by DOE/EIA. Job multipliers used by the State of Texas suggest that, if the oil were produced over a 30 year period, the increased economic activity would support 2.5 million additional jobs over that period. The produced oil would have a final value to the U.S. economy of \$8-12 trillion due to the multiplier effect of activities enabled by the increased domestic oil production, or roughly 2% of U.S. Gross Domestic Product (GDP) over 30 years. This oil will probably not be produced under current economic conditions, because insufficient benefits from the overall economic activity flow back to the entity providing the CO_2.

A simplified analysis of possible tax revenues from increased domestic oil production suggests that it may be possible for expanded CO_2 EOR to be "self-funded" by recycled tax revenues. In

[29] In 1998, 25% of US oil production was on leased federal land, and the average royalty collected was 13%. Reforming the Federal Royalty Program for Oil and Gas, Congressional Budget Office, November 2000.

[30] US Code, Title 26, Subtitle A, Chapter 1, Subchapter A, Part IV, Subpart D, Section 45Q.

other words, it may be possible to achieve rather large economic, employment, and environmental benefits by diverting some of the CO_2 EOR related tax income (which would otherwise not be realized) to subsidize CO_2 capture at large point sources. Given the large potential benefits from expansion of EOR production with recycled tax revenues, a more detailed analysis of this issue is recommended.

The U.S. Carbon Sequestration Council (www.uscsc.org) is a not-for-profit, 501(c)(3), organization established as an authoritative source of information to inform and to educate on all matters pertaining to carbon sequestration.