NATIONAL PETROLEUM COUNCIL

Meeting the Dual Challenge

A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage

Appendix H

CO_2 Enhanced Oil Recovery Economic Factors and Considerations

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TABLE OF CONTENTS

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Development costs are an important driver in the economics of carbon dioxide (CO_2) enhanced oil recovery (EOR) projects. These costs are difficult to generalize since they are highly dependent upon the type, size, and location of the project being developed, and the depth of the play.[1] Costs can also vary considerably due to well configurations and whether or not existing field wells and equipment can be repurposed for the CO_2 EOR application. Most CO_2 EOR plays have their own set of idiosyncrasies that can impact overall project economics in positive and negative ways.

There is, however, a broad set of costs that are common to most CO_2 EOR applications. These include:

- Cost of the supply of CO_2 for injection purposes
- Cost to drill a series of CO_2 injection wells and/or converting selected producing wells to injection wells
- Cost to install surface facilities needed to separate, measure, recycle, and transport the CO_2 into the subsurface
- Cost of added compression
- Cost to provide additional surface equipment that is needed.

In addition, there are other economic factors that impact overall CO_2 EOR profitability, particularly those associated with financing these types of projects. This appendix explores each of these factors and examines how the component costs vary and change CO_2 EOR project economics. The appendix borrows heavily from the work prepared by Godec in 2014 that surveys and discusses each of these important CO_2 EOR cost components.[2]

I. CO_2 Acquisition Costs

Godec notes that CO_2 acquisition costs are a very important component of overall CO_2 EOR costs.[3] When coupled with their corresponding recycling costs (discussed later), CO_2 acquisition can account for 25% to 50% of all CO_2 EOR project costs. EOR projects generally acquire CO_2 in one of three different ways. First, the EOR project is integrated as part of a capture-transport-storage application that sources naturally occurring CO_2 and transports it to the EOR site, where it is then used in production operations. Most existing projects currently use this type of acquisition model. Second, EOR projects are part of an integrated project that includes an anthropogenic CO_2 source captured from either a power plant or industrial source and transported to the EOR site. Third, a project may acquire CO_2 from a pipeline, regardless of source, and then use that CO_2 for EOR purposes.

As will be discussed later, the nature of the source (natural or anthropogenic CO_2) and the industry structure can affect overall CO_2 commodity costs, as well as overall delivered CO_2 costs to an EOR site. Industry organization (i.e., if the CO_2 is provided as part of a vertically integrated application) can also affect the terms and conditions under which CO_2 is provided to a particular EOR site, as well as the manner in which that CO_2 is priced.

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[1] Godec, M., 2011. *Global Technology Roadmap for CCS in Industry: Sectoral Assessment* CO_2 *Enhanced Oil Recovery* (United Nations Industrial Development Organization), p. 44.

[2] Godec, M., 2014. *Acquisition and Development of Selected Cost Data for Saline Storage and Enhanced Oil Recovery Operations* (U.S. Department of Energy, National Energy Technology Laboratory) DOE/NETL-2014-1658. p. 18.

[3] Godec, 2011.

II. Well Development Costs

Well development costs are an important component cost of any CO_2 EOR project. Well design and project requirements, in addition to well unit costs, drive overall well development costs for a given CO_2 EOR project.

Well requirements are based on initial assessments regarding how many, and what types of, wells will be needed in a given CO_2 EOR application. The produced water arising from a CO_2 EOR project will affect well requirements since additional wells will be needed to maintain reservoir pressure. There are some instances where existing onsite infrastructure can be repurposed for the CO_2 EOR application. For instance, formerly producing wells can sometimes be used as CO_2 injection wells depending on location and well integrity.

The number and type of injection wells needed for a CO_2 EOR project are difficult to generalize since they are custom tailored depending on the specific properties of each reservoir. Further, well-specific development costs will be a function of the type, location, number, and more importantly, the depth of all such wells. Well costs generally increase with depth and complexity.

Artificial lift requirements for CO_2 EOR producers present an additional cost compared to natural lift operations. This is because the volume and composition of produced fluids can change significantly over the duration of a CO_2 EOR project, requiring periodic changes to the artificial lift system. A waterflooded producer may produce oil with a low gas-oil ratio and a high water-oil ratio. After CO_2 injection begins, the same producer typically experiences an increasing gas-oil ratio and decreasing water-oil ratio. It is important that the artificial lift system be capable of efficiently removing produced fluids from the well across the full range of operating conditions.

III. Surface Facility Costs – Injection/Recycling Costs

CO_2 EOR projects require a unique set of surface facilities and equipment to capture, separate, and re-inject CO_2. The costs for these facilities can represent one of the more expensive sets of costs at a CO_2 EOR project. Surface facility costs are a function of the various plant component costs needed to facilitate a CO_2 EOR project, which in turn, are a function of the specific field being developed for CO_2 EOR purposes.

Equipment component requirements can be difficult to generalize since every EOR project is unique. There are, however, several common CO_2 EOR plant components that are required, including separation equipment (gas/liquid, water/oil, CO2/hydrocarbon—even though some separation may occur in satellite locations), dehydration, and in some instances, hydrogen sulfide (H_2S) removal. The most substantive cost with a CO_2 recycling plant is typically the compression cost.

Recycling plant capital costs are a function of the scale at which the plant's capacity is developed. Higher plant capacities can potentially lead to some moderate scale economies as higher upfront costs are divided by more production and CO_2 volumes. Godec, for instance, identifies 30 million cubic feet per day of CO_2 as the threshold for lower recycling plant unit costs.[4] This threshold assumes standard temperatures (62°F) and pressures (14.696 pounds per square inch gauge).

The primary annual operations and maintenance (O&M) cost associated with a CO_2 recycle plant will be associated with operating the onsite compression. If this compression runs on natural gas, then recycling plant O&M costs will be dependent on commodity gas price changes. If the compression is run using electricity, then recycle plant O&M costs will be dependent on retail electricity prices.

[4] Godec, 2014, 18.

In some instances, CO_2 EOR facility costs will need to include the costs of capturing, separating, and compressing natural gas liquids (NGLs). Again, Godec notes that the unit costs of these NGL recycle costs will be a function of scale, with higher recovery rates having lower unit costs than plants designed to recover a lower rates of NGLs.[5] Godec identifies a threshold recovery rate of 20 million cubic feet per day as being the point at which unit costs for NGL recovery can start to decrease, driven by the large capital costs associated with developing the necessary compression to collect and move the NGLs offsite to commercial NGL pipeline pressures. The O&M costs for any NGL recovery plant, if needed, will also be driven by compression-related costs and whether the compressor is being run on natural gas or retail electricity.

Last, the CO_2 EOR facilities require a system of pipes and manifolds to move CO_2, water, and hydrocarbons throughout the field. This distribution network, and its costs, will be comparable to a typical gathering system at a traditional oil and natural gas field. Fluid distribution costs will be driven by the level of pipeline capital investment required for the anticipated field operations. Pipeline capital costs will be a function of the pipe diameter and its wall thickness, which will differ from what is traditionally used for natural gas purposes at a production field given the higher operating pressures needed for CO_2.

IV. Additional Compression Costs

Most of the compression costs needed for a CO_2 EOR application would be included in the recycling plant costs noted earlier. There could be some instances, however, where the CO_2 arrives at the field locations at less than optimal pressures. A hypothetical example would be an instance where a former natural gas pipeline is repurposed for CO_2 transportation, but that CO_2 is moved as a gas at relatively lower pressures than is typical. For instance, Dismukes et al. examined opportunities for repurposing natural gas transportation lines for CO_2 transportation, but found few opportunities; however, they recognized that such opportunities are often very field-specific.[6] If such an application were utilized, additional onsite compression would be needed to raise the transported CO_2 pressures to those commonly used for injection purposes. The economics of this application would be based on the relative costs of repurposing an older natural gas transportation line and field-specific compression, versus using a newer line with booster pumps to provide pressure to the delivery location. To the extent that such applications are economic, it would likely be for relatively short distances.

V. Surface Facility Costs – Other CO_2 EOR Costs

There are many other miscellaneous field equipment costs that are required to complete a CO_2 EOR project, and these are typically associated with the scope and location of the project. Godec notes that any CO_2 EOR project will have a host of additional equipment costs (capital and operating) needed to run project equipment and its fluid management systems.[7,8] Some of this incremental equipment may include free water knockout, water disposal, other water treatment costs, and various pumps, and the electricity needed to run these pumps will need to be purchased.

Water treatment requirements can increase the capital and O&M costs associated with separation, filtering, pumping, and waste fluid injection. Retail electricity prices may impact additional fluid lifting

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[5] Godec, 2014.

[6] Dismukes, D., Zeidouni, M., Zulqartain, M., Hughes, R., Snyder, B., Lorenzo, J., Chacko, J., and Hall, K., 2019. *Integrated Carbon Capture, Utilization and Storage in the Louisiana Chemical Corridor* (U.S. Department of Energy, National Energy Technology Laboratory).

[7] Godec, 2011p. 44.

[8] Godec, 2014.

costs, as well as the running of filtration systems, smaller pumps, heaters, and lighting. While these costs collectively are not considerable and do not rival CO_2 recycle plant costs, they can influence overall project economics.

Godec notes that other important costs include those associated with site, field, and well assessments. Other upfront capital expenditures include mechanical integrity reviews of existing/older wellbores and surface production equipment, pressure testing casing and replacing old tubing, installing new wellheads, installing new flow lines as well as addressing any specific localized environmental requirements.

VI. Other Economic Factors

The economic performance of a CO_2 EOR project will be a function of a number of factors that may be beyond the control of the oil and natural gas operator, or of any other market participant. These factors include commodity prices, recovery factors and decline rates, capital cost factors, industry structure, and government policies and incentives (the latter is not discussed in this appendix; see instead Chapter 3). The levels, variability, and uncertainty of each of these factors can have considerable implications for CO_2 EOR adoption and the development of a CO_2 EOR-based carbon market.

A. Commodity Prices

Commodity prices can affect CO_2 EOR development in two different ways. The first is related to the absolute level of crude oil prices, since there is a positive relationship between EOR profitability and high oil prices. Higher oil prices directly improve EOR profitability. Lower crude oil prices may reduce the incentive to engage in these activities entirely, unless state or federal government incentives are offered.

The second is the relationship between EOR adoption decisions and the volatility of oil price movements. In some instances, oil price volatility on its own can create sufficient uncertainty about sustained project economics to discourage the development of CO_2 EOR projects. Some CO_2 supply contracts provide for a reduction in CO_2 price when oil price falls. This provides a buffering effect and may allow CO_2 floods to sustain operation during times of low oil prices.

CO_2 is, and will increasingly become more of, a tradeable commodity that will follow market trends as do other commodities. CO_2 credits are already traded on markets in the Mid-Atlantic region (through the Regional Greenhouse Gas Initiative) and in California, and the prices for these credits can take sharp turns depending upon market conditions and policy expectations.

B. Recovery and Decline Rates

Welkenhuysen et al. show that geologic uncertainty influences the oil producer's view of the economic threshold level for an EOR project.[9] The authors use a series of simulation models to predict producer decisions given changes in both crude oil prices and EOR-based production outlooks. The authors found that geological uncertainty is an important factor. It is likely more important than developing fixed revenue streams through a unit-tax credit like a carbon tax. The simulation modeling, conducted for potential applications in the North Sea, shows that crude oil prices and recovery factors have nonlinear impacts on EOR project profitability. The authors caution that assessing EOR project economics without a strong respect for residual geological uncertainty can lead to erroneous profitability and EOR adoption rate conclusions.

[9] Welkenhuysen, K., Meyvis, B., and Piessens, K., 2017. "A Profitability Study of CO_2 EOR and Subsequent CO_2 Storage in the North Sea Under Low Oil Prices," *Energy Procedia* 114: 7060-7069.

C. Capital Cost Sensitivity, Escalation, and Uncertainty

King et al. examined cost and profitability outcomes (on a net present value, or NPV, basis) using an integrated systems approach (integrated source-to-sink cost analysis) and found that under all scenarios, the profitability of a CO_2 EOR application using anthropogenic CO_2 was negative.[10] However, the negative profitability improves (less negative NPV cash flows) as costs are reduced. In fact, the authors note that if CO_2 acquisition and recycling costs are low enough, it is feasible that some CO_2 EOR projects could flip to positive NPV cash flows.

The ability to keep recycling costs down will largely be a function of how much existing/legacy field equipment, particularly wells, can be repurposed. If existing wells can be used for production and injection, it is likely that overall unit costs can be driven down. If existing in-field equipment can be reused, particularly piping and compression, overall field distribution costs may be lowered, as well. These are big “ifs” and underscore that: (1) cost estimates are usually a function of CO_2 EOR project specifics and can be difficult to generalize, and (2) there can be unknowns and uncertainties that can affect final costs that increase project risks and reduce profitability.

Cost escalation can also affect the profitability and economics of a CO_2 EOR project. While high oil prices are good for CO_2 EOR projects, they often drive higher drilling activity that often puts pressure on drilling and field service costs. Unanticipated cost escalation can have negative effects on overall CO_2 EOR profitability, even in high oil price environments. Increases in future recycling plant upgrade costs and other capital maintenance expenses can also negatively affect CO_2 EOR project economics.

Last, geography can have an important impact on capital costs for CO_2 EOR projects. Dismukes et al.,[11] King et al.,[12] and Dubois[13] show that having numerous anthropogenic CO_2 sources and EOR projects in close proximity to one another can reduce overall project capital costs and improve project economics, primarily by reducing expensive transportation and compression costs. Compression is the most significant operating cost in the transport of CO_2. Therefore, oil fields that are in close proximity to several anthropogenic sources, particularly lower-cost industrial capture sources, are likely to have greater profitability than those spread over larger areas.

D. Industry Structure

Roussanaly and Grimstad note that even though CO_2 EOR projects have existed in the oil and natural gas industry for more than four decades, recent proposals, which increasingly emphasize the CCUS benefits of such projects, can strongly influence business model decisions and profitability.[14] The authors note that if the CO_2 capture and transport activities are handled by an entity other than the oil field operator, potentially competing development objectives may arise.

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[10] King, C.W., Gulen, G., Cohen, S., and Nunez-Lopez, V., 2013. “The System-Wide Economics of Carbon Capture, Utilization, and Storage Network: Texas Gulf Coast with Pure CO_2 EOR Flood,” *Environmental Research Letters* 8: 1-16.

[11] Dismukes et al, 2019.

[12] King et al., 2013

[13] Dubois, M.K., Byrnes, A.P., Pancake, R.E., Wilhite, G.P., and Schoeling, L.G., 2000. “Economics Show CO_2 EOR Potential in Central Kansas,” *Oil and Gas Journal.* Vol. 98, Issue 23: p. 11.

[14] Roussanaly, S., and Grimstad, A., 2014. “The Economic Value of CO_2 for EOR Applications,” *Energy Procedia* 63: 7836-7843.

Al Mazrouei et al. show that industry structure can have implications not only on profitability but also on EOR infrastructure is development decisions.[15] The authors employ simulation to establish that an integrated approach to EOR project development can result in outcomes quite different from, and better than, those achieved by multiple players acting independently. Thus, facilitating a competitive and healthy CO_2 EOR industry will be important for the efficient scale up of CO_2 EOR projects.

[15] Al Mazrouei, M., Asad, O., Abu Sahra, M., Mexher, T., and Tsai, I., 2017. "CO_2 Enhanced Oil Recovery System Optimization for Contract-Based versus Integrated Operations," *Energy Procedia* 105: 4357-4362.