ECONOMIC INCENTIVES FOR CO2 SEQUESTRATION IN OIL RESERVOIRS

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Overview

CO_2 concentration in the atmosphere has increased significantly from the pre-industrial age to today. This increase is of interest because CO_2 is a greenhouse gas and may cause global warming, other changes in the environment, and economic damages. It is possible that reducing emissions may be economically optimal. Therefore, technical and economic studies of CO_2 capture and storage (CCS) are needed to inform the policy debate and to determine the optimal course of action.

The global oil and gas industry may have an important role to play if CCS projects are pursued. The industry is experienced in planning and operating large and complex injection projects. Geological storage is possible in mature oil reservoirs, deep saline aquifers, coal seams, and other settings. Over 35 million tons of CO_2 have been injected into oil reservoirs for the purpose of enhanced oil recovery (EOR) (Moritis, 2002). Therefore, it is likely that coupled EOR and CCS projects will be part of a global CO_2 storage solution if one is needed.[1]

This paper develops a bottom-up analysis of a coupled enhanced oil recovery (EOR) and CCS project in a mature oil reservoir. A *coupled* EOR and CCS project is defined here by the following two features: (i) CO_2 is injected into the reservoir until original reservoir pressure is attained (that is, more CO_2 than would be injected in a conventional EOR-only project), and (ii) the reservoir is not in contact with an aquifer nor has it been flooded in secondary or tertiary oil recovery. In a conventional EOR project, the cost of CO_2 greatly affects the quantity of CO_2 purchased and therefore the quantity of oil recovered. The implication of this relationship for a coupled EOR and CCS project is that the cost of CO_2 will have to be lower to provide a private incentive for operators to inject CO_2 beyond the normal economic limit, all things being equal.

The core of the bottom-up analysis is a compositional reservoir simulator that accounts for geological setting, reservoir physics and injection methods, and the configuration of wells. The simulator provides accurate and consistent estimates of reservoir performance over time. Reservoir simulation results are used in conjunction with experimental design and a project economic model to develop estimates of project performance and economics. Regression analysis is used to generate simplified response surfaces for key project variables and these are used to carry out a probabilistic analysis.

The purpose of this research is to develop a general understanding of coupled EOR and CCS project economics, and to estimate the level of direct economic incentives that may be required to motivate these projects. Many types of incentives are possible, including general tax credits, storage based credits, production based credits, and modified accounting rules (e.g. accelerated depreciation). Here, the analysis is designed to estimate a CO_2 storage credit that would be paid to operators who engage in coupled EOR and CCS projects. The credit is computed in units of dollars per thousand standard cubic feet of CO_2 stored ($/MSCF). In summary, this is accomplished by computing the CO_2 credit that makes project net present value (NPV) equal to zero.

Methods

Reservoir Simulation

The simulation of coupled EOR and CO_2 sequestration projects is complex. Reservoir simulators must account for geological setting, reservoir physics and injection methods, and the configuration of wells. For example, different reservoir types such as carbonate and sandstone reservoirs have different responses to CO_2 flooding based on reservoir characteristics. The injection method is also important. Water-alternating-gas (WAG) injection methods can enhance sweep efficiency and increase oil

[1] Currently, the Weyburn project is the only on-going commercial coupled EOR and CCS project (Malik and Islam, 2000). Carbon dioxide is transported from a North Dakota coal-gasification plant through pipelines and is injected into the Weyburn oil field. Other forms of geological CO2 storage have been studied, but to date, very few have been implemented.

recovery compared to continuous injection, but the methods result in different volumes of sequestered CO_2. Tighter well spacing increases sweep efficiency but also causes CO_2 to be recycled earlier in the project (increasing costs). In this study, we performed detailed 3D compositional reservoir simulation using CMG's GEM simulator.

Uncertainty and Design of Experiments

Within each of the 8 reservoir scenarios there is technical and economic uncertainty. A goal of this study is to perform a probabilistic analysis of these uncertainties to depict a range of possible outcomes of performance and economics. One approach would be to specify inputs to the reservoir simulator as random variables and simulate numerous outcomes. But if the number of uncertain variables is large, and the solution time for each case if long (as it is here), then this approach is not feasible in practice. Instead, we use experimental design to reduce the number of simulations to be run. A fractional 3-level factorial experimental design method was used to reduce the number of simulations.

Project Economic Model

The results from each case run in the reservoir simulator are inputs into a project economic model. The economic model accounts for all major cash flows and non-cash items. This includes revenue, royalty, costs, depreciation, taxes, EOR tax credits, etc. and computes the net present value (NPV) for the project. For each case, we compute the CO_2 credit that makes project NPV equal to zero. It is unclear at this stage how such a credit scheme would be implemented in practice. For this research, we assume that the credit is paid during the operation of the project, and that it is paid as a constant nominal credit. This approach is used so that the credit can be easily compared to the market price assumption.[2]

Response Surface Modeling and Probabilistic Analysis

Response surface modeling refers to the process of using regression analysis to relate the results for key project variables from the reservoir simulator and project economic model to the uncertain variables. In the last step of the analysis, the response surfaces are used to develop a PDF of the CO_2 credit for each case. We assume the variables are statistically independent. For each realization, the response surface is used to estimate the CO_2 credit.

Results and Conclusions

We find that coupled EOR and CCS projects are unlikely to be initiated in a low oil price environment unless some form of CO_2 credit is provided; coupled projects are economically unattractive because of the large probability of negative NPV outcomes. In a high price environment, coupled EOR and CCS projects are more economically attractive, but such projects are unlikely to be initiated on their own merits; operators in these cases are likely to pursue conventional EOR projects and would need to be compensated for CO_2 stored beyond the normal economic limit. The technical performance and economics of these projects is complex, but it appears clear that any design of a CO_2 credit scheme includes (at the least) differentials based on reservoir characteristics, CO_2 injection method, and the configuration of wells.

Additional analysis is desirable on the following issues:

- For conventional EOR projects with positive NPV, estimate the credit required to motivate investment in coupled EOR and CCS.
- Increase the number of scenarios and the number of uncertainties for probabilistic analysis.
- Implement the probabilistic analysis with jointly distributed variables.
- Estimate global CO_2 storage capacity for coupled EOR and CCS projects.
- Evaluate other financial structures for coupled project incentives (e.g. accelerated depreciation).

[2] Other computations are of course possible. For example, one could set CO_2 price to zero and compute the CO_2 price that makes NPV equal to zero.