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Value of Pore Space for Carbon Capture and Storage

N. Donatien-Roland Diby*[1], D. Nathan Meehan[1], SPE, Texas A&M University.

Abstract

Most newly proposed carbon capture, use, and storage (CCUS) projects target dedicated saline aquifer storage (DSS); most existing projects target enhanced oil recovery. New DSS projects will require leasing pore space for the project; valuation of such pore space becomes increasingly important. How much is onshore or offshore pore space worth? As governments begin to lease offshore pore space for CO_2 storage, determining the fair value of these spaces is important. This paper presents a process to estimate the fair value of pore space, considering different leasing models, including upfront payments, annual rentals, unit royalties, and relevant factors affecting the value of offshore pore space.

Beneficial owners of pore space should be fairly compensated for CO_2 injection rights (Meehan, 2024). Multiple valuation theories exist including alternative use, present value, competitive rents, etc. To determine the value of pore space, this study combines Monte Carlo simulations with net present value (NPV) calculations, assessing reservoirs with varying characteristics such as thickness, permeability, and heterogeneity. The study evaluates economic potential of CCUS projects and calculates the maximum value for the pore space. Bidding strategies for these reservoirs are developed, and the economic implications of different payment structures are analyzed.

Valuation is driven by the economic value of injected carbon, reservoir injectivity, and storage capacity. Significant risks include CO_2 leakage and seismic activity. While high-permeability, high-capacity reservoirs offer substantial value, many scenarios result in negative NPVs. The study underscores the importance of early-stage risk mitigation in enhancing project viability.

This paper introduces innovative approaches to CCUS pore space valuation, particularly by integrating the value of uncertain information into the analysis. The use of Monte Carlo simulation, reservoir modeling, and bidding strategy development provides a novel perspective in this field.

Introduction

Carbon Capture, Utilization and Storage (CCUS) or Carbon Capture and Storage (CCS) is a way to manage climate change and reduce the greenhouse gas emissions. One of the major aspects of the Paris agreement (COP 21) was the commitment to minimize climate change and prioritize steps required for a lower carbon future. Current annual storage of CO_2 is only about 50 million tonnes per year (MTPA). To make a significant impact, this will have to grow by a factor of about 100 by 2050 to the multiple gigatonne (GT) scale. The regulatory framework governing the current Enhance Oil Recovery (EOR) use of CO2 (Marston and Moore, 2008) can, with some additional regulations be applied to Carbon Capture, Utilization and Storage (CCUS) projects. The oil and gas industry is knowledgeable in transporting, injecting, and storing CO_2 in geological reservoirs from long experience with Enhanced Oil Recovery. The federal government has actively supported CCUS technology development by funding initiatives through the Department of Energy and facilitating the acquisition of lease acreage via bidding program in the Gulf of Mexico (GOM). The main economic driver is a US tax credit program that encourages investment in carbon capture, utilization, and storage (CCUS) projects known as 45Q. DSS may be a good target for Gt scale CO_2 geological sequestration due to their vast storage potential and widespread availability. There are significant concerns with DSS. Saline aquifers are already full of a slightly compressible fluid. How will injecting large volumes of dense phase CO_2 increase reservoir pressures and stresses? Saline aquifers are not as well characterized as oil and gas fields because of far fewer wellbore penetrations. While this may limit the potential for leaks from such wellbores it contributes to risks about understanding reservoir heterogeneities. Potential for CO_2 leakage along faults, seismicity, and unplanned plume migration are concerns for DSS.

This raises critical questions: What is the fair value of such storage? How should the worth of these pore spaces be determined? Answering these questions is essential for incentivizing investments and ensuring the economic viability of large-scale CCS projects

Methods

This paper presents a process to obtain the fair value of pore space, considering different leasing models, including upfront payments, annual rentals, unit royalties. Relevant factors affecting the value of offshore pore space will be analyzed by combining Monte Carlo simulations with net present value (NPV) calculations with a goal to realize positive cash flow. Monte Carlo provides the risk analysis enabling investors to make better data-driven budgeting decisions. Additionally, the effects of CO_2 injection on geological formation are assessed and acknowledge with varying characteristics such as depth, thickness, porosity, permeability, salinity and heterogeneity. A CO_2 storage simulation model is developed to question the outcomes of CO_2 injection in saline aquifer which offers insight into the project outcome. Optimum Bidding strategies for these reservoirs are determined on tracts of unknown value by estimating the value of the parcel and then bid some fraction of our estimated value.

Results

Below are the results of one output generated from the valuation model which include the results of the forecast based on the earnings before interest, taxes, and depreciation and amortization, along with some example outcomes of the bidding process and the proposed CO_2 storage simulation in a real aquifer. Figure 1 combines the project Net Present Value profile with a Monte Carlo Simulation at different discount rate during 30 years of Cash Flow operation for a triangular leasing rate distribution in between $80.00 and $130.00 $/acre, the NPV profile provide a probabilistic view of the feasibility of the project. Figure 2 shows the Optimum bid fraction against 15 opponents for the bidding process. Figure 3 represents possible geological CO_2 Injection reservoir modeling within a designated saline aquifer storage, representing the injectivity of the CO_2 in the subsurface.

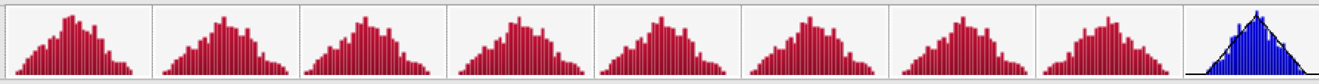
Name Description Cell Function	IRR Output	5% NPV Output	10% NPV Output	20% NPV Output	30% NPV Output	40% NPV Output	50% NPV Output	Lease Output	Lease / Rentals Input
General									
Graph									
Statistics									
Minimum	9.574720%	$ 790,511,585.59	-$ 43,881,823.04	-$ 479,427,289.97	-$ 505,777,162.92	-$ 453,650,287.57	-$ 390,293,352.48	$ 13,309,571.17	$ 80.309
Maximum	9.650026%	$ 798,544,308.14	-$ 35,849,100.49	-$ 471,394,567.41	-$ 497,744,440.37	-$ 445,617,565.02	-$ 382,260,629.92	$ 21,342,293.72	$ 128.777
Mean	9.611871%	$ 794,486,344.07	-$ 39,907,064.56	-$ 475,452,531.48	-$ 501,802,404.44	-$ 449,675,529.09	-$ 386,318,593.99	$ 17,367,535.24	$ 104.794
Std. Deviation	0.015685%	$ 1,673,209.23	$ 1,673,209.23	$ 1,673,209.23	$ 1,673,209.23	$ 1,673,209.23	$ 1,673,209.23	$ 1,673,209.23	$ 10.096
Errors	0	0	0	0	0	0	0	0	0

Figure 1: Monte Carlo simulation, Net Present Value (NPV) profile with triangular leasing distribution

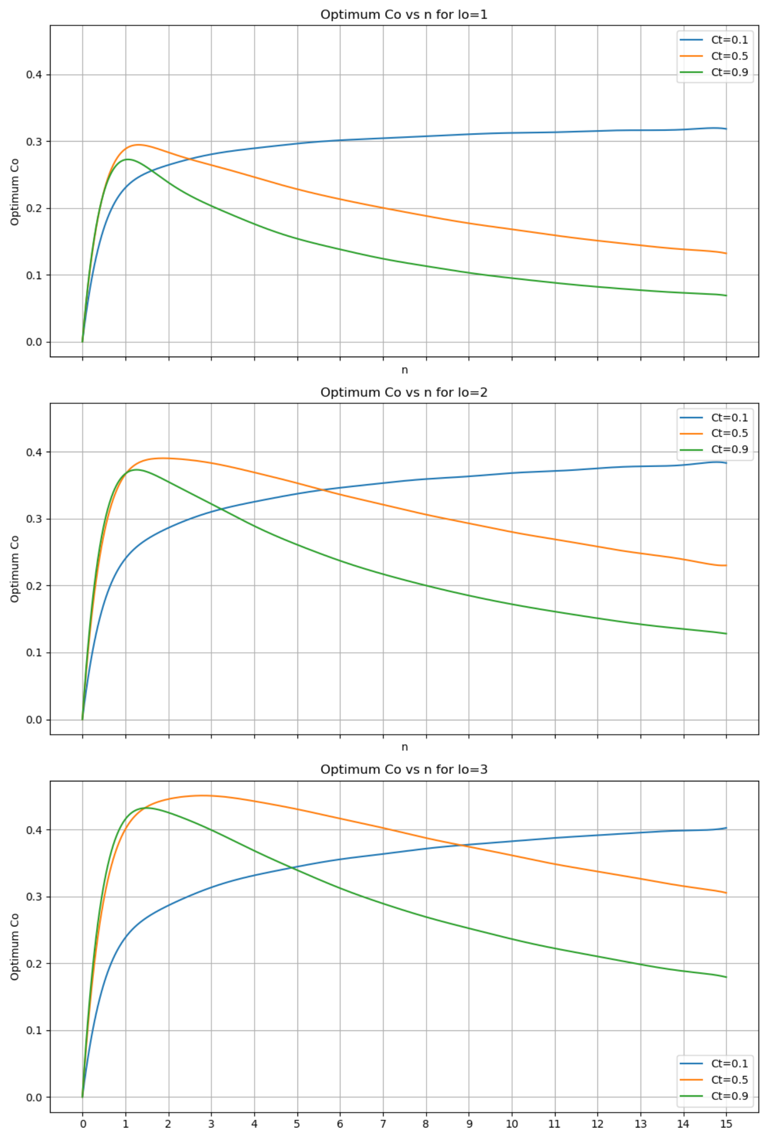


Figure 2: Optimum Bidding Fraction if contestant is the better estimator. Our L=1, their L= 2 (top), if variances are equal. Our L=2, their L=2 (middle), if we become better estimator than the competition. Our L=3, Their L=2 (bottom)

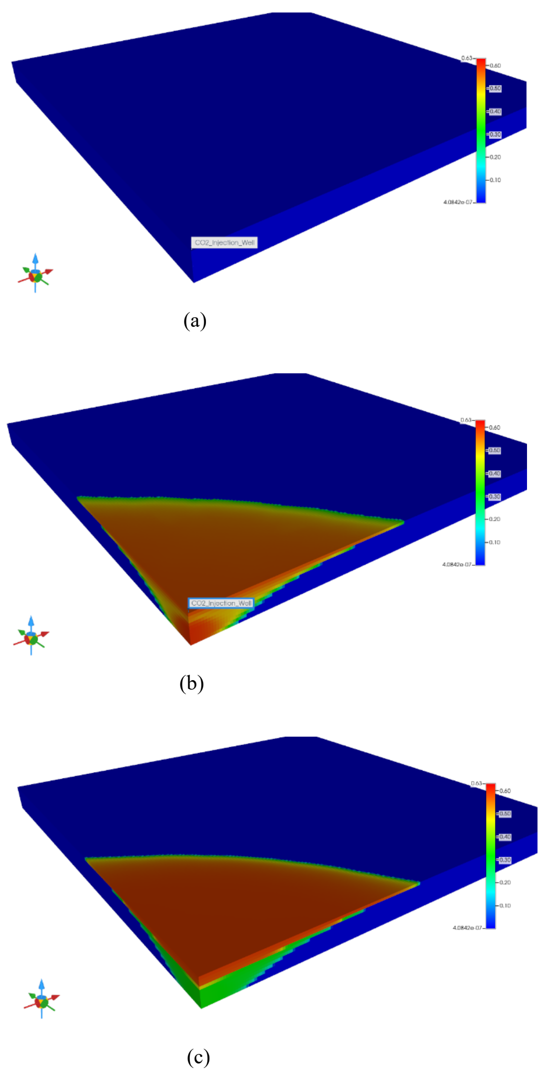


Figure 3: Geological CO_2 Reservoir Storage Simulation; (a) shows the reservoir initial condition, (b) Injection after 10 years of injection and (c) Reservoir from year 10 to year 39

Discussion

The Inflation Reduction Act (IRA) included incentives to capture and store CO_2 increasing the tax credits to $85 per tonne for geologic sequestration through a period to 12 years (Chalmin A., 2022). The example project is designed to store about 3.2 Mt CO_2 per year for 25 years within a dedicated saline aquifer while generating cash flow from the 45Q less the CAPX, OPEX, Royalties and Lease. These cash flows are discounted to Present Value using various discount rates in order to validate or reject a project forecast. Given the circumstances of uncertainty of the leasing price as shown on Figure 1, a triangular distribution was used to better represent the price range. Monte Carlo Simulation is a useful tool to be using wherever data are not available (Nawrocki David, 2001). Monte Carlo simplifies the mathematical computations to be considered in estimating uncertainty in cash flow from an investment revealing probabilistic scenarios where deterministic data are unavailable or out of reach.

As a rule of thumb, prior to bidding on a tract of unknown worth the first step is to estimate the value of the tract, once a value is determined then we bid some fraction of our estimate (Dougherty and Nozaki). A bidding strategy is essential to place an optimum bid offer while accounting not solely about the value of the parcel(s), but also the predicted behavior of the contestants (Brown, K. C. ,1969). One method to acquiring lease is seal competitive bidding. The model presented and displayed in this paper representing Figure 2 is identical to that used by Capen et al. In this process, participants use existing data to submit an estimate of the tract's value. The Bureau of Ocean Energy Management (BOEM) evaluate the bids by comparing to their own valuation of the tract, then concludes if the bid is high enough, then allocate the lease to the high bidder (Dougherty and Nozaki). Proceeding as such ensures that publicly available resources are allocated at a fair value while keeping transparency in the bidding process. As a result of the model, optimum bid fraction is largely influenced by the precision of our estimates and the number of the competitors.

Existing CO_2 geological storage projects in saline aquifers had been proved to be technologically feasible (K. Michael et al.). The injection of CO_2 into saline aquifers had been done with great success by existing projects and/or operations highlighting injectivity as key for success in Carbon Capture and Storage projects. Figure 3 the reservoir geological static model discussed in this literature. The model features a total 400,000 of grid blocks, with a lateral dimension of 10,000 ft in the x and y directions and a depth of 40 ft. The heterogeneous static model represented above was a built and simulated using CMG - GEM (Generalized Equation-of-State Model). This model has a max permeability of 80 to 100 mD and a porosity of 20 – 25%. The geological heterogeneity of the reservoir presents an opportunity for CO_2 injectivity and ensures effective storage capacity within the saline aquifer.

Conclusions

The use of Monte Carlo simulation coupled with Net Present Value (NPV) forecast provides amore robust estimate of the project valuation over the operational period. Approaching the project this way showcases comprehensive view of all possible outcome, enabling data-driven decision making for precisely assess the worth of the pore space. In such competitive market were companies are willing to acquire tracts by offering the high price and bid aggressively possible bidding strategy is essential. Knowing your optimum bidding fraction will not help only to maximize the odds of securing the lease but also guarantee that no money is left "on the table." The application of reservoir modeling reduces the uncertainty in the evaluation feasibility of the project while providing a better understanding of the subsurface and a detailed assessment of the formation's injectivity.

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