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Assessing the value of permeability data in a carbon capture and storage project

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ABSTRACT

Acquiring new field information can reduce the uncertainty about the reservoir properties and can (but not necessarily) alter decisions affecting the deployment of a CCS project. The main objective of this paper is to provide a decision-analytic framework to quantify the value of acquiring additional information regarding reservoir permeability. Uncertainty in reservoir characterization translates into risks of CO_2 migration out of the containment zone (or lease zone) and non-compliance with contractual requirements on CO_2 storage capacity. The field we consider is based on an actual, and mature, field located in Texas. Subsurface modeling of the injection zone was conducted using well logs, field-specific GIS data, and other relevant published literature. The value of information (VOI) was quantified by defining prior scenarios based on the current knowledge of the reservoir, contractual requirements, and regulatory constraints. The project operator has the option to obtain more reliable estimates of permeability, which will help reduce the uncertainty of the CO_2 plume behavior and storage capacity of the formation. The reliability of the information-gathering activities is then applied to the prior probabilities (Bayesian inference) to infer the value of such data.

1. Introduction

Carbon capture and storage (CCS) is considered one of the key technologies for reducing atmospheric emissions of carbon dioxide (CO_2) from human activities (IPCC, 2005). Deep saline aquifers and existing mature oil and gas fields are attractive geological formations for the injection and long-term storage of CO_2 (IPCC, 2005). Uncertainties in reservoir properties (e.g., permeability, thickness, porosity) as well as reservoir heterogeneity will ultimately affect the injectivity, storage capacity, and costs associated with any potential sequestration reservoir.

In a typical CCS project, it is the operator's responsibility to guarantee the CO_2 containment, while complying with environmental regulations and contractual requirements. Acquiring new information (e.g., seismic, logs, production data, etc.) about a particular field can reduce the uncertainty about the reservoir properties and can (but not necessarily) alter the decisions affecting the deployment of a CCS project. The value of that information will depend on the quality or accuracy of such tests, the risk preferences of the decision maker (DM), the prior probabilities of the alternatives, and their respective outcomes.

In an exploration campaign designed to obtain permeability values in a reservoir, the completeness of the information-gathering activity will depend on the number of wells logged or cored. Typically the larger the number of wells logged, the more accurate the permeability map will be (Kravchenko, 2003). However, the cost of such tests can exceed their potential benefits. When choosing the optimal number of tests to be performed, their number should be balanced with the sampling costs.

Value of information (VOI) is one of the most useful applications of decision analysis (Bickel et al., 2008; Bratvold et al., 2009). VOI analysis evaluates the benefits of collecting additional information before making a decision (Howard, 1966). Value is added by enabling the DM to adjust their choice to the underlying uncertainty (Bratvold et al., 2009).

VOI has been applied in a wide range of areas including oil and gas (Bickel et al., 2008), hurricane forecasting (Kim and Bickel, 2010), finance (Oksendal, 2005; Stibolt and Lehman, 1993), supply chain (Lee et al., 2000), and bidding (Milgrom and Weber, 1982), among others. The application of VOI in the oil and gas industry has been extensive. Topics in this area are very diverse and include quantifying the value of an appraisal well (Demirmen, 1996, 2001; Wills and Graves, 2004; Kumar and Hara, 2005), valuing logging information (Aggrey et al., 2006; Branco et al., 2005; Prague et al., 2006), and quantifying the value of seismic surveys before the survey is taken (Coopersmith et al., 2006; Ballin et al., 2005; Steagall et al., 2005; Wagonner, 2002; Bickel et al., 2008). Publications in the CCS field, in contrast, are limited.

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In a recent study of VOI in a CCS project (Sato, 2011) illustrates the use of VOI methods to value monitoring programs with varying accuracy. The net present value (NPV) of the project was related to the radial extent of the saline aquifer, which was assumed to be lognormally distributed. The accuracy of the information-gathering activities was not grounded on empirical data, but was rather assumed in order to illustrate a VOI quantification procedure. In this paper, we extend Sato (2011) by applying VOI within the context of a field-management decision.

The objectives of this paper are two-fold. First, we develop a decision-analytic framework to quantify the VOI in a CCS project, which faces uncertainty regarding the permeability of the reservoir. This uncertainty translates into a risk of CO_2 migration out of the containment zone (or lease zone), non-compliance with contractual requirements on CO_2 storage capacity, and leakage of CO_2 into sources of underground drinking water (USDW). Second, we ground our estimates of information accuracy in empirical well logging data and using computational studies.

2. Background

In this section we describe the CCS project analyzed in this paper. This analysis was inspired by an actual project. However, certain geophysical elements of the project have been simplified so that we may focus more directly on the VOI analysis, which we hope will be a comparatively new topic to most readers.

2.1. The storage contract

The operator of a mature and depleted oil field, believed to be suitable for CO_2 storage, is considering signing a contract with a source of anthropogenic CO_2 emissions, or the emitter, to inject four Mt of CO_2, over the next three years, into production Block B. One of the main uncertainties faced by the operator is the storage capacity of the reservoir. If the targeted formation can store the contractual amount of CO_2, or more, the operator will receive a certain amount of money in the form of carbon credits. If the formation cannot store the contractual quantity of CO_2, the operator will be obliged to pay a penalty fee due to failure to meet contractual requirements.

The operator has modeled several scenarios of CO_2 migration, elevated pressure, and injection volume that are based upon different estimates of permeability. Reservoir modeling suggests that it is likely the formation will not be able to store the contractual amount of CO_2 and/or that the plume will migrate outside of the lease area, in which case the operator will have to pay a penalty fee and/or buy new land. The net present value (NPV) of these two scenarios is a function of the amount of CO_2 injected (t CO_2) and the price of the carbon credit per metric ton of CO_2 ($/t CO_2) minus the respective penalty fees for failing to fulfill contractual requirements or regulatory constraints. If the operator decides not to sign the contract, it is assumed that no loss of revenue will be incurred. Table 1 shows a summary of the three scenarios faced by the operator.

As we discuss later, we assume the operator has the option of obtaining more reliable estimates of permeability by logging existing wells or drilling new ones, which will help to reduce the uncertainty of the CO_2 behavior and storage capacity of the formation.

2.2. Description of the field

The field under analysis (Block B) has been idealized based on an actual project located in the greater Houston, Texas, area. The field is a faulted, 4.3 miles (6.92 km) long and 3.7 miles (5.95 km) wide, anticlinal structure formed under the influence of a deep-seated salt dome.

Table 1
Definition of possible scenarios faced by the operator.

Scenario	Definition	NPV ($)
S_1	The targeted formation can store the required volume of four Mt but the CO_2 plume extends beyond the lease area	Carbon credit ($/t CO_2) × contractual amount (Mt CO_2) minus the cost of new land
S_2	The targeted formation fails to store the required volume of four Mt CO_2 while meeting regulatory constraints	Penalty fee
S_3	The targeted formation fails to store the required volume of four Mt CO_2 and the CO_2 plume extends beyond the lease area	Penalty fee plus cost of new land

The field was discovered in 1934 and rapidly developed using 10-acre well spacing, which resulted in high real sweep efficiency and oil recoveries exceeding 60% of original oil in place (OOIP). A cumulative production of 582 million barrels of oil (92.5306 E+06 m^3) and 2.7 billion barrels of water (429.2657 E+06 m^3) has been achieved from this high permeability, 200 md to 2000 md (19.73847 E−14 m^2 to 9.869233 E−13 m^2), Frio sandstone reservoir (Davis et al., 2011). From wireline logs, it is understood that the Frio sands in this field are typical of most sandstones along the Texas and Louisiana Gulf Coast, where porosities are between 28% and 34%.

The injection zone is delimited by three faults and Anahuac shale on top. Based on the hydrocarbon accumulation and the historical records of isolation between zones in both sides of the faults, it is assumed that, for pressures below the original reservoir pressure, these faults will act as a seal. The Frio Formation at Block B is composed of a number of sandstones separated by shales and less permeable sandstones. Multiple sandstones are productive within the field and will serve as the injection reservoir. A recent core taken across the Upper Frio sands indicates the intervals separating the high permeability sands are actually low permeability sands in the range of 20–100 md (19.73847 E−15 m^2 to 9.869233 E−14 m^2), high porosity (30%) sands instead of shale, thus explaining how the high cumulative oil production has been obtained (Davis et al., 2011).

2.3. Reservoir characterization

The Frio Formation of the Gulf coastal plain is well-characterized as an injection zone, and sufficient data were publicly available to perform a basic geologic description of the Frio Formation. In addition, two sandstones of the Upper Frio, in proximity to Block B, were tested by the Bureau of Economic Geology (BEG) at the University of Texas at Austin during the Frio Pilot Project, where 1600 Mt CO_2 were injected and monitored. This testing provided increased confidence during the initial characterization and modeling of the field. The density of the CO_2 at standard conditions (0.101325 MPa and 15.6 °C) is 0.1148 lb/ft^3 (0.00184 g/cm^3). At a depth of 6000 ft (1828.8 m), the density of the CO_2 at critical conditions will be approximately 700 kg/m^3, assuming a typical geothermal gradient of 25 °C/km from 15 °C at the surface and hydrostatic pressure (Angus et al., 1973). A black-oil model software package was used to simulate the behavior of CO_2 plume, the reservoir pressure, and the CO_2 saturation.

Subsurface modeling of the Upper Frio Formation (injection zone) was conducted using well logs from ∼400 wells with ∼350 digital logs, ∼400 raster-image logs, field-specific GIS data, and other relevant published literature. The first step in constructing the reservoir model was to pick formation tops for the Upper Frio sand members and overlying Anahuac shale. A synthetic reservoir was built to simulate the process of CO_2 flooding in the injection