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CO_2 Capture Project Phase 2 (CCP2) – Storage Program: Closing Long-Term CO_2 Geological Storage Gaps Relevant to Regulatory and Policy Development

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Abstract

The CCP2 (2005-2008) is a consortium is engaged in reducing CO_2 capture costs and improving confidence in CO_2 storage. The consortium has co-funding from EU, Norway and the US DOE. The CCP2 Storage program project portfolio focuses on technical assurance issues of importance to regulators, policymakers and other stakeholders. These include simplified and transparent protocols for assessing the storage project lifecycle, long term well materials stability under CO_2-rich conditions, geochemical and geomechanical interactions impacting the containment system stability and feasibility of novel remote sensing and geophysical techniques for monitoring CO_2 storage. Work has begun on the CCP3 Storage (2009+) program which will continue to address remaining, substantive CO_2 storage issues.

Keywords: CO_2 Capture Project (CCP); CO_2 Geologic Storage; Certification Framework; Well Integrity; Geochemical Geomechanical Simulation; CO_2 Storage Assurance; CO_2 Storage Regulations, CO_2 Storage Policy

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1. Introduction

The CO_2 Capture Project (CCP) is a consortium of eight major oil and gas companies and two associate members engaged in reducing CO_2 capture costs and improving confidence in CO_2 storage. The consortium has co-funding from US DOE, EU and the Norwegian government. Storage Program Phase 1 (2001-2004) entailed assessment of a broad range of technologies and protocols categorized as storage integrity, optimization, monitoring and risk assessment. Individual projects were let to "technology providers" (TPs) and managed by technical points of contact (TPCs) from CCP member companies. Phase 2 of the Storage Program (2005-2009) pursued further development of a subset of these technologies and protocols in addition to addressing remaining technical assurance issues. The CCP2 Storage program projects include (TP institutions):

(a) Certification Framework (Lawrence Berkeley National Lab, LBL; University of Texas-Austin, UT) - development of a simple, transparent and accepted framework for analyzing and evaluating leakage risks from geological storage projects
(b) Wellbore Integrity (Los Alamos National Lab, LANL; Lawrence Livermore National Lab, LLNL; Princeton University and University of North Carolina at Chapel Hill) – field acquisition of casing, cement and formation samples from CO_2 "experienced" wells with analysis, modeling-simulation to forecast long term well stability, and development of engineering solutions to prevent well bore leakage
(c) In-situ Detection of Wellbore Leakage
(d) Coupled Geochemical-Geomechanical Simulation (University of Bergen) – development and integration of numerical codes to depict chemical and mechanical impacts of CO_2 injection
(e) CO_2 ECBM Flow Simulation and Monitoring (Sproule Associates, Lawrence Berkeley National Lab, LBNL) – CO_2 ECBM operational constraints and monitoring using non-seismic geophysical techniques
(f) Remote, Direct Detection of CO_2 and Methane Leakage (University of California – Santa Cruz, UCSC)

Results to date and the implications of projects (a-d) are outlined in the present work whereas those of (e-f) are presented in Kieke et al. [1].

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2. Results and Discussion

2.1 Certification Framework (CF)

The CF study was conceived in early 2005 at which time CO_2 storage project assessment protocols were emerging but regulatory development had just begun. It was recognized that exploration and production (E&P) assessment protocols were directly applicable to CO_2 storage project assessment but the unique behaviors of large volumes of CO_2 injected into the subsurface and the need for "permanent" isolation from the atmosphere were not systematically addressed. The regulatory challenge at the time was to establish the extent to which existing well regulations applied (in the Unites States, the EPA Underground Injection Control program, UIC) to the storage project "system" over the permitting, operations and decommissioning phases.

The CF project was designed to transparently and simply systematize the process for evaluating CO_2 storage projects at each major stage: pre-permitting assessment, operational parameters and decommissioning. The CF uses geologic data as input, employs a catalog of pre-run reservoir simulations (using end member parameters such as depth, thickness, dip, porosity, and permeability) or a user-developed reservoir simulation model. The CF then calculates the volume / flux of CO_2 that migrates out of the target injection interval and through "conduits" (wells or faults) and into non-target receptors, or "compartments" such as hydrocarbon-mineral resources (HMR), underground sources of drinking water (USDW), the near surface environment (NSE), where human health and safety impacts are possible (HS), and into the atmosphere where emissions credits (ECA) might be forfeited. The CF enables assessment of leakage risk, which is defined as the product of the probability of an event's occurrence and the impact of the event occurring. The modeled CO_2 volume / flux that could migrate into a protected compartment, will either be acceptable by established regulations (e.g., US EPA Safe Drinking Water Act impacts) or agreed upon with a regulator or other stakeholders prior to start of injection. A result indicating unacceptable volume / flux would call for data acquisition to confirm leakage potential or rejection of the proposed storage site.

Beyond pre-permitting assessment, the CF will also be useful in updating the leakage risk during and after operations. A considerable value of the CF is that it offers a common structure for both the project proponents and stakeholders to assess CO_2 leakage risk through the project's lifecycle. As such, it provides a vehicle for the project proponent to demonstrate project performance and security and thereby continue operations and permit decommissioning.

To date, the CF Team has applied the methodology to two case studies. The first is a hypothetical storage facility at the site of an existing natural gas storage facility near Katy, Texas USA. The model injection site was placed in the saline water leg (2134m deep; 15m thick; dip 1^o) of a depleted natural gas field bounded by a growth fault with injection of 0.8 MTPA CO_2 for 30 years. In this case, the simulation indicated that CO_2 was guaranteed to encounter a well. Assuming an extremely degraded well (100mD permeability vertically along the well), the well flow model indicated that minor CO_2 flux might be present in the near surface environment. There would be minor soil impact but no human health or safety impact. It is evident from this case study that without data on well (or fault) transmissivity to CO_2, the probability and impact of CO_2 migration out of the target injection interval are highly speculative.

The second CF case study was on the "Kimberlina" site in the San Joaquin Basin of California USA. This is a prospective site for Westcarb's Phase III (US DOE Regional Partnership) injection of 0.25 MTPA CO_2 for 4 years. The study included assessment of the geologic system (without nearby well control), hydrogeology and specialized assessment of well and fault transmissivity. Due to the lack of nearby wells and models indicating a thick shale cap rock and faults that are unlikely to be transmissive to CO_2, the CO_2 leakage risk was deemed "very low" or "improbable" with respect to entry into protected compartments. The results of the study indicate that the site is suitable for an injection project of this size. Oldenburg et al. [2] detail the results of these case studies. Specialized studies related to the CF project will be presented at the GHGT-9 Conference (Washington DC, Nov. 2008).

The CF Team proposes to further develop the process with a focus on specialized simulation capabilities (e.g., reservoir heterogeneity, conduit flow) as well as conducting additional case studies.

2.2 Wellbore Integrity (WI)

Wellbore integrity was a part of the original CCP program and continues to be widely perceived as a major containment issue for CO_2 storage. Experimental studies have indicated that Portland cements, used widely in oil and gas production, are unstable when exposed to CO_2-rich fluids. However, wells completed with such cements have been operated for decades in natural CO_2 production and CO_2 EOR settings with little or no indication of CO_2 leakage evident as a result of CO_2-induced cement degradation. A possible explanation is that well systems (cement, casing materials and country rock), provide a barrier to fluid movement that individual well components cannot, particularly as they are not exposed in field applications to the aggressive flow conditions employed in laboratory studies aimed at accelerating reactions. The CCP2 WI study surveyed CO_2-exposed wells via comprehensive logging suites, retrieved well materials and conducted analyses to assess the extent of *in situ* alteration. For a subset of these surveys, well models (including defects) will be constructed, history matched to observed conditions, and forward simulated to assess the fate of well materials exposed to CO_2-rich fluids over extended time. Finally, the findings of the WI studies will be used to develop a well design to avoid defects and inform possible new intervention techniques.

Two surveys (2006 and 2007) were conducted on a 30 year old Colorado USA well that had been producing natural CO_2 since 1985. The reservoir and cap rock sections of the well are comprised of clastic sediments, which presumably would accelerate cement degradation due to the relative lack of buffering without the presence of abundant carbonate minerals. Logging analysis indicated good cement bond. Core samples recovered were intact and showed tight interfaces with casing and the country rock. Analysis revealed varying extents of chemical alteration (carbonation) of the cement with impacts on permeability (generally showing slightly increasing cement permeability towards and within the CO_2 reservoir interval and some associated loss of mechanical strength). Alteration appears not to have impacted hydraulic isolation as indicated by a vertical interference test and current pressure data above and below the caprock. The results of this study are detailed in Crow et al. [3]. Using the field and analytical results from this study, a joint modeling and simulation study has been contracted to LANL and LLNL for delivery in 2010.

In the summer of 2008, a survey of a second well, a CO_2 EOR producer well at Buracica Field, Reconcavo Basin, Brazil, was completed.

2.3 *In situ* Detection of Wellbore Leakage

A well design capable of trapping migrating CO_2-charged fluids would provide an opportunity to detect wellbore leakage early using standard logging tools. Schlumberger constructed a bench scale pressurized vessel for the study. The vessel was loaded with sediment and brine and with and without CO_2 charge and was logged using a Reservoir Saturation Tool (RST) that detects the energy spectra and time decay of gamma rays induced by neutrons. It was determined that the RST tool could not contrast the readings in the CO_2 non-charged vs. charged runs in IC mode (inelastic capture, ratios of carbon to oxygen present in wellbore vs. surrounding sediments). This contrast was evident in Sigma mode (effective area within which a neutron passes to be captured by an atomic nucleus). The project was completed in 2006 and no further work has been conducted.

2.4 Coupled Geochemical-Geomechanical Simulation

A priority issue in CO_2 storage is an understanding of processes that may change petrophysical characteristics of the reservoir (e.g., dissolution of rock cements in the near wellbore environment and precipitation of minerals distally) and the geomechanical integrity of the reservoir and cap rock. Accurate depiction of multiphase CO_2 behavior in the subsurface over extended time requires simulation of fluid flow, reactive transport and geomechanics. Although a number of simulations couple the former two, the latter is typically not included in assessments or is run as a stand-alone simulation. The CCP2-funded University of Bergen study seeks to explicitly couple these processes using RetrasoCodeBright (RCB) as a platform. RCB is based on Retraso, a code for solving reactive transport problems and CODE-BRIGHT, which models thermo-hydraulic-mechanical processes for multiphase fluids in 3D. Modifications to the code were made to handle non ideal gases (equations of state) and rates of dissolution of CO_2 in water. The mathematical equations for the system are highly nonlinear and are solved numerically. The approach can be viewed as employing spatial (finite element method) and temporal (finite difference) discretization.

To date, a simplified model system and sensitivity study (with set dimensions; range of quartz and calcite fraction end members; porosity; pressure and temperature) has been conducted. Two sets of simulations are run: 1) realistic gravity and 2) without initial gravity (extreme case where flow is dominantly lateral such as in shale / sand interbeds). Simulation to 100 years shows that pH values decrease significantly in the vicinity of the injection point but remain above 5.0 due to the buffering effect of calcite. Additional models and sensitivity studies will be conducted using mineralogy and conditions more representative of natural reservoirs. A detailed discussion on the approaches used and preliminary case study results are found in Kvamme and Liu [4].

3. Conclusions

From its beginning, the CCP2 Storage program aimed to address remaining assurance issues through development of lab testing procedures, simulators, assessment protocols and a field study. The Certification

Framework provides a platform for site assessment, surveillance of operations and projections of CO_2 plume behavior that will be critical from the permitting through to the decommissioning stages of CO_2 storage projects. The Well Integrity study squarely addresses concerns about wellbore leakage through field well surveys followed by analysis, model building and simulation of well performance over an extended time frame. The results will be used to improve wellbore design as well as to identify new intervention procedures. The *in situ* Detection of Wellbore Leakage study establishes the resolution threshold for detecting CO_2 leakage in a modified well design. Coupled Geochemical-Geomechanical Simulation offers a new approach to more accurately depicting CO_2-water-rock interactions with consequences for reservoir and cap rock porosity and permeability distribution and mechanical integrity.

The upcoming CCP3 Storage program (2009-2013) will further develop existing technologies and protocols that show promise in enabling CO_2 storage. In addition to laboratory and simulation activities, field trials will be conducted to establish the suitability of monitoring tools and elucidate subsurface processes.

4. Acknowledgements

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5. References

[1] D. Kieke, et al., GHGT-9 (2008)
[2] Oldenburg et al., GHGT-9 (2008)
[3] Crow et al., GHGT-9 (2008)
[4] Kvamme and Liu, GHGT-9 (2008)