GHGT-16 Lyon, France October 23-27, 2022

Summary of GCCC Activities:

- Alex Bump (2 talks, chairing 1 session)
- Seyyed Hosseini (2 talks, 1 poster, chairing 1 session)
- Sue Hovorka (1 talk, chairing 1 session, Lead Panelist)
- Tip Meckel (1 poster, chairing 1 session)
- Hailun Ni (1 talk, 1 poster)
- Katherine Romanak (2 oral presentations, chairing 1 session)

GCCC Presentations, Session Chairs, and Lead Panelist Events in order of Presentation Date and Time

Monday, October 24th, 2022

Katherine Romanak, Presenter

Session 1B -Communications, Social Science, and Capacity Building I
Monday, October 24, 2022
11:20 AM - 1:00 PM
Salle Gratte- Ciel 2nd Floor
Oral presentation
The effect of monitoring complexity on stakeholder acceptance of CO2 geological storage projects

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Katherine Romanak, Presenter

Session 2B - Communications, Social Science and Capacity Building II
Monday, October 24, 2022
2:00 PM - 3:40 PM
Salle Gratte- Ciel 2nd Floor
Oral presentation
Attitudes on Carbon Capture and Storage (CCS) within the UNFCCC

Session Chairing

Sue Hovorka, Session Chair

Session 1F -Basalts, low-permeability and mineralisation modelling Track F

Monday, October 24, 2022 11:20 AM - 1:00 PM Tete D'Or room 2 - 1st Floor

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Katherine Romanak, Session Chair

Session 3F - Ecosystem and well monitoring with focus on chemical methods Track F

Monday, October 24, 2022 4:10 PM - 5:50 PM Tete D'Or room 2 - 1st Floor

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Tip Meckel, Session Chair

Session 3G - Membranes Track G

Monday, October 24, 2022 4:10 PM - 5:50 PM Salon Tete D'Or -1st Floor

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Tuesday, October 25th, 2022

Sue Hovorka, Presenter

Session 5B - Storage costs

Tuesday, October 25, 2022
11:20 AM - 1:00 PM
Salle Gratte- Ciel 2nd Floor
Oral presentation
Early stage cost of storage project characterization

Session Chairing & Lead Panelist

Seyyed Hosseini, Session Chair

Session 5F - Multiphysics monitoring I Track F

Tuesday, October 25, 2022 11:20 AM - 1:00 PM Tete D'Or room 2 - 1st Floor

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Sue Hovorka, Lead Panelist

Session 6C Panel discussion 4 -The Challenge to the CCS community posed by upstream emission sources, i.e. methane Track C

Tuesday, October 25, 2022 4:00 PM - 5:40 PM Bellecour rooms 2&3 lower level -1

Wednesday, October 26th, 2022

Alex Bump, Presenter

Session 8B - Site characterisation

Wednesday, October 26, 2022
11:20 AM - 1:00 PM
Salle Gratte- Ciel 2nd Floor
Oral presentation
Criteria for depleted reservoirs to be developed for CO2 storage

Blue indicates in same session below

Seyyed Hosseini, Presenter

E-Poster Session Wednesday
Wednesday, October 26, 2022
2:00 PM - 4:00 PM
Niveau Forum level -2
Oral presentation
Application of pressure transient analysis in characterization of fluid leakage from faults

Tip Meckel, Presenter

E-Poster Session Wednesday
Wednesday, October 26, 2022
2:00 PM - 4:00 PM
Niveau Forum level -2
Oral presentation
Carbon capture, utilization, and storage hub development on the Gulf Coast

Hailun Ni, Presenter

E-Poster Session Wednesday
Wednesday, October 26, 2022
2:00 PM - 4:00 PM
Niveau Forum level -2
Poster Presentation
Monitoring CO2 plume migration with lab-scale ultrasonic experimental setup

Seyyed Hosseini, Presenter

Session 9E -Field-scale reservoir modelling
Wednesday, October 26, 2022
4:00 PM - 5:40 PM
Tete D'Or room 1 - 1st Floor
Oral presentation
Application of machine learning for fast prediction of CO_2 plume and pressure buildup in geological CO_2 storage in offshore Gulf of Mexico

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Session Chairing

Alex Bump, Session Chair

Session 9B - Storage capacities Track B

Wednesday, October 26, 2022 4:00 PM - 5:40 PM Salle Gratte- Ciel 2nd Floor

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Thursday, October 27th, 2022

Alex Bump, Presenter

Session 11B - Trapping Mechanism
Thursday, October 27, 2022
11:20 AM - 1:00 PM
Salle Gratte- Ciel 2nd Floor
Oral presentation
Baffled confinement systems: Characterizing, de-risking and permitting unconventional seals for CO_2 Storage

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Seyyed Hosseini, Presenter

Session 11F - Risk Management for CO_2 Storage
Thursday, October 27, 2022
11:20 AM - 1:00 PM
Tete D'Or room 2 - 1st Floor
Oral presentation
Current state of knowledge regarding the risk of induced seismicity at CO_2 storage projects

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Hailun Ni, Presenter

Session 11B - Trapping Mechanism
Thursday, October 27, 2022

11:20 AM - 1:00 PM
Salle Gratte- Ciel 2nd Floor
Oral presentation
Effects of flow pulsation on CO2 buoyant migration and capillary trapping

16th International Conference on Greenhouse Gas Control Technologies **GHGT-16**

23-27th October 2022, Lyon, France

Criteria for depleted reservoirs to be developed for CO_2 storage

Alexander P. Bump*[a], Sahar Bhakshian[a], Susan D. Hovorka[a], Joshua Rhodes[b] and Samantha Neades[c]

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Abstract

Depleted hydrocarbon reservoirs offer an attractive option for CO_2 sequestration. The performance of such reservoirs and their seals has been proven by hydrocarbon retention and production. Depleted fields also often have a wealth of data, including 3D seismic, well logs and historical production records of flow rates and pressure responses that facilitate accurate prediction of their suitability for CO_2 sequestration. Lastly, depleted fields feature infrastructure that might be able to be reused for CCS. In total, the value of these advantages might be hundreds of millions of dollars in cost savings and years of effort in characterization, permitting and construction.

Not all depleted fields are equally viable for CCS, nor necessarily even suitable. However, inherent differences in location, geology, infrastructure and related variables inevitably result in variations in viability and attractiveness for sequestering the emissions of a given CCS source. Complicating matters, evaluation can be complex. Geologic performance and the value of existing infrastructure depend on the net interactions of a long list of underlying variables. Comparing opportunities is not necessarily easy and evaluation can easily get lost in the details. A clear set of headline criteria and guidelines that honor the multiple ways to satisfy them would facilitate accurate, efficient screening of potentially large numbers of opportunities.

We present the results of a study of depleted fields, designed to create such evaluation criteria. The study consists of three parts. In the first, we look at ten case studies, spanning four continents and a variety of operational and geologic settings. In the second, we look in depth at the impacts of pressure depletion, residual hydrocarbons and the economics of infrastructure reuse versus new build. In the third, we synthesize the insights into a pragmatic set of headline screening criteria with a simple set of guidelines. In brief, these are as follows:

- Injectivity: Projects need to be able to comfortably inject CO_2 at rates equivalent to the anticipated source output. We present a graphical tool for assessing injectivity per well, that allows easy comparison between storage opportunities.
- Capacity: Projects must have sufficient pore space to accommodate the anticipated volume of CO_2 while remaining within acceptable pressure limits. While first-principles calculation of capacity can be complex and fraught with uncertainty, depleted fields offer a reliable shortcut. We recommend a fluid-replacement

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calculation as an efficient means of first-pass capacity screening. Without getting into details of reservoir architecture, porosity, permeability and aquifer connection, historic production records give a reliable view of reservoir performance. We offer both numerical and graphical guidelines for equating net produced hydrocarbons with CO_2 at reservoir conditions.

- Confinement: License to operate depends on retaining CO_2 in a specified injection interval. Depleted fields come with seals proven by the retention of hydrocarbons over geologic time. Thus, we recommend focusing on the elements and circumstances that might compromise that proven integrity, specifically the legacy wells and the maximum injection-related pressure.
- Economics: While depleted fields often come with existing infrastructure, it should not be taken as given that such infrastructure represents a cost saving or is necessarily even reusable at all. For a hypothetical storage project of 1Mt per year with 50km of transport distance, the pipeline is the biggest driver of total project cost. Reuse of an existing line can save significant costs but depends on a number of factors, chiefly pressure rating, capacity and condition.
- Regulatory and public acceptance: Among the cases we studied, the most common difficulties were not subsurface but regulatory and public acceptance. Early, proactive engagement with regulators and the public is key.

We synthesize these recommendations in tabular form with graphical support, attempting to create ways of comparing multiple opportunities clearly and succinctly.

Keywords: depleted reservoirs; storage, screening

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Baffled confinement systems: Characterizing, de-risking and permitting unconventional seals for CO_2 Storage

Alexander P. Bump*[a], Sahar Bakhshian[a], Dallas B. Dunlap[a], Seyyed A. Hosseini[a], Susan D. Hovorka[a], Timothy A. Meckel[a], Hailun Ni[a] and Mariana I. Olariu[a]

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Abstract

Permitting, developing and operating a CO_2 storage site all depend on demonstration and ongoing verification of secure containment. Injected CO_2 and displaced brines must remain confined within a specified reservoir interval lest they endanger shallower fresh-water aquifers and/or leak to surface. Historical experience with hydrocarbon exploration and production has proven the capability of geologic seals to retain buoyant fluids on multimillion-year timescales. That experience has also naturally focused attention on certain types of seals, in particular, regionally extensive marine shales, tight carbonates and evaporites. These are the units favoured in hydrocarbon exploration, precisely because they are regionally extensive and reliable, both of which make them relatively easy to characterize and de-risk.

The same properties also make these formations attractive as confinement for CO_2 storage and indeed, all of the projects permitted to date rely on one or more such seals. However, point-source CO_2 emissions are widely distributed across the globe, transport is expensive and geology is variable. There are many highly attractive geologic reservoirs that do not have an easily-characterized overlying regional seal. One such area is the onshore region south of Perth, the site of the proposed South West Hub storage project. Another is the Mississippi River Chemical Corridor in southeastern Louisiana. Both of these areas have excellent reservoirs and significant local emissions sources but only discontinuous (though abundant) geologic seals. We refer to these as "baffled confinement systems" and if their performance could be de-risked, it could both unlock economically significant local storage resources and open volumetrically significant new potential storage resources across the globe.

Analogy with petroleum migration and ground water flow suggests that such confining systems can work. Migration losses and slow propagation of the thermogenic migration front (the limit of thermally-matured hydrocarbons) are well known in petroleum exploration. Similarly, experience with contaminated groundwater (including natural variations in salinity), shows that such spread of the contaminate plume is often slow and always finite. Even without extensive seals, natural variations in geologic properties such as permeability and capillary entry pressure slow fluid movement. Pore throat trapping, dissolution, local capillary trapping and even small buoyant traps, all serve to arrest migration and for limited volumes, ultimately stop spread of the plume as a whole. In principle, the same should be true for injected CO_2. The question is how to predict and quantify the confinement

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capacity of baffled systems, given the details of the local geology.

We focus here on the example of southeastern Louisiana, with the aim of using it as an applied case to discover broadly applicable general principles. Within the depth window for CO_2 storage, the geology of this area is characterized by extensive deltaic deposits, including amalgamated channel sands that for excellent reservoirs. Regionally extensive marine shale seals pinch out to the south (down-dip) of the Chemical Corridor, so local confinement relies on the discontinuous muds and coals formed by Miocene channel linings, crevasse splays, floodplains and swamps. Local hydrocarbon accumulations prove that at least some of these are reliable field-scale seals and vertical well logs show that low-permeability facies are abundant. However, predicting specific seals and/or de-risking the performance of the system as a whole is challenging.

We describe the results of a three-pronged effort to quantify and predict the confinement capacity of this system. In the first part, we look at the local geology and use extensive well logs, local hydrocarbon field data and analogue data to create a statistical description of the permeability variations. In the second part, we use physical analogue modelling to investigate the effects of bed-scale permeability variation on the flow and retention of injected CO_2. These models serve to inform our view of which variables matter and to calibrate full-physics reservoir modelling, which forms the third part of our work. In this last part, we use thin, fast-running models to experiment with the effect of varying geometric and petrophysical parameters on migration and trapping of fluids at the field scale.

Keywords: storage; confinement, seal, confining zone, deltaic reservoir, baffled containment

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Application of pressure transient analysis in characterization of fluid leakage from faults

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Abstract

Injection of fluids in deep subsurface geological formations has created a series of challenges in recent decades. Possibility of upward fluid leakage along nearby wells and faults is one of the main issues related to these operations. It is important to ensure that such conduits, if present, can be detected, characterized and treated. Looking for pressure abnormalities in intervals above the injection zones, is one the methods used to monitor the performance of these conduits. We propose a new analytical solution specifically designed to detect and characterize the vertical leakage from a fault of finite length using pressure data collected from monitoring zones. The proposed closed form analytical model would allow to not only distinguish the pressure signal of fault leakage from other possible leakage conduits but also to estimate the leakage rate, length of leaky section of the fault and relative position of the fault with respect to the location of monitoring well. This information would play a critical role in decision making on remediation methods needed to deal with these events.

Keywords: CO_2 geological storage; fault; analyrical model; leakage

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Application of machine learning for fast prediction of CO_2 plume and pressure buildup in geological CO_2 storage in offshore Gulf of Mexico

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Abstract

Geological CO_2 storage has become a hot topic in response to the global interest to achieve net zero emissions. Lack of information in many geological settings, especially for saline storage, requires extensive fluid flow simulations to understand risk and design mitigation plans. Ultimate goal is to run these simulations fast and accurate, allowing us to visualize and demonstrate the confidence in our proposed scenarios to various stakeholders. We have applied and compared a family of deep learning algorithm that use numerical simulations from high-fidelity models to train, learn and predict the behavior of the CO_2 in subsurface. For this purpose, we have used a geological model in offshore Gulf of Mexico with over 200,000 grid blocks to generate injection and post-injection data for 120 injection scenarios. Our models can reasonably predict the CO_2 plume and pressure buildup in the formation, which are critical elements in a successful design and permitting of a CO_2 storage project. Our models offer 1000X speed up compared to high-fidelity numerical simulations, paving the way for implementation of real-time platforms where CO_2 and other relevant parameters of interest can be visualized and reported.

Keywords: Machin Learning; CO_2 geological storage; CO_2 plume; pressure plume

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Current state of knowledge regarding the risk of induced seismicity at CO_2 storage projects

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Abstract

Large volume geologic storage as part of Carbon Capture and Storage (CCS) is one of the high value technologies to reduce atmospheric CO_2 buildup. However, public, government, investor and regulator concerns about the risk of induced seismicity have been growing over the past decade. In this paper, we review the status of seismic monitoring at CCS projects and provide an update on the recent experience with partial analogs such as water injection for hydraulic fracturing stimulation and water disposal.
We reviewed 36 CO_2 storage projects listed in global indexes and determined that for the 31 of them that information about seismic monitoring was found, 60% of them conducted microseismic/seismic monitoring. No CO_2 storage projects have reported felt seismicity. One CO_2 enhanced oil recovery (EOR) project, Cogdell Field in West Texas, has reported felt seismicity. Most of the projects reporting detection had low levels of low magnitude seismicity that was likely related to injection operations, however, either the data quality and sparsity or low energy precluded making detailed interpretations, and 23% reported no detectible seismicity with the various arrays and analysis installed at these sites. Analysis of available results show that technical skill developed in oil and gas industry in microseismic monitoring is high and growing, however application of these skills to CCS site is immature and uneven. Data are too incomplete and interpretations are too site specific for broad quantitative analysis.
Concerns about induced seismicity as a result of injection of any fluid have a long history, however, more specifically, public and regulatory concerns have increased in the last two decades in partial response to clusters of felt events. We review the status of knowledge about these events, which shows that causality is complex. Some can be tied to local injection of large volumes of saline water produced as a by-product of hydrocarbon production, others are linked to smaller more regional increase in pressure, and a few have been linked to the stimulation process itself. Regulatory responses to areas with seismicity includes limiting the per well injection rate, limiting the overall injection volume in a region, limiting the injection interval and plugging back wells that penetrate deeper horizons. Mitigation has been effective in reducing the magnitude and frequency of induced events.
In addition, we review also the regulatory responses to seismic event related to injection of any fluid and concerns in sample areas where responses have been strong, including some US states and Canadian provinces. We believe that it likely that similar responses will be applicable and successful in managing risk of induced seismicity for CCS projects as they develop.

Keywords: CO_2 geological storage; induced seismicity; risk; state of knwoledge

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Early stage cost of storage project characterization

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Many industries are now considering Carbon Capture and Storage (CCS) as a greenhouse gas mitigation technology. In an early step, geologic storage must be located and the feasibility of accessing this storage assessed in terms of volumes stored per year over the project life, cost to transport these volumes to the storage site, ability to purchase or lease the site, obtain needed permits, to provide documentation to validate credits for storage, and any barrier to the project identified and mitigated. As projects begin to develop, they need to secure funding sufficient to answer these questions at the same time that they evaluate the cost of capture for various volumes of CO_2, perhaps from diverse sources. A key question is how much funding is needed to assess the storage options? Storage is not expensive compared to building and executing a capture project; however the capital risk is high because at these early stages the chance of a project not being viable is still high in this still-evolving industry. Many things can cause a project not to proceed, with the cost recovery model failing to meet the significant cost of capture being the biggest risk factor. However, identifying viable storage is also essential to a project advancing. Because the distance between source and sink has a large impact on cost, it may be valuable to consider the cost and value of assessing close but poorly known storage versus better known but more distant storage.

In this study we estimate the early capital needs for developing the storage component. We improve the analysis over previous studies by 1) considering realistic staging of the assessment of the overall project and storage viability prior to permitting 2) considering the variability in storage complex geology both in terms of how much data are needed to show site viability and to obtain a permit, and how much data are already available that may reduce costs in early stages. We consider actual costs, but recognize that a multitude of parameters have significant variability; we therefore normalize costs to focus on site-to site geologic variability.

A team of SECARB USA (project number DE-FE0031830) storage experts examined 63 formations at 39 sites that were selected to represent the range of diversity of newly assessed, as well as well-advanced, storage prospects in the south-eastern part of the US. We inventoried the data needs triggered by the requirements to obtain a Class VI UIC storage permit, the data needs

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that results from the requirement to create geocellular fluid flow models to support that permit, and by pragmatic and best practice inputs such as public acceptance, regulatory readiness, and pore space leasing. We anchored both the needs inventory and the processes for and cost of meeting the needs with data from 9 sites in in the area that have advanced far in characterization.

Results show that the total cost of characterization prior to obtaining a permit is convergent, because the permit and modeling requirements drive projects to obtain the same types of data for all cases. The high cost data that control cost are 1) drilling, coring, core-testing, logging, sampling and testing a characterization well and 2) collection of a 3-D seismic survey to map reservoir and confining system properties over the area of the plume or the area of elevated pressure. In 5 of our case study sites we determined that one or both of these costs could be avoided because the needs are met by available data.

One goal of our study was to examine the feasibility of staging spend for characterization by recognizing a sequence of decision gates: regional storage feasibility, site selection to narrow to one area, detailed site characterization to model the mass of CO_2 that can be stored within the site acreage under planned injection strategy including rates and durations, and site readiness for permitting (figure1). We see significant difference among sites based both on the urgency of the need for data to make decision and the availability of data. In some sites, a well is required to determine storage feasibility (sufficient thickness, injectivity, seal etc.), however in most the study area existing data is sufficient to pass this gate using existing data. For groundwater properties, many sites were able to pass early decision gates because this data was not urgent, however, to get to permit readiness site-specific data are needed. In some sites our evaluation estimated that a 3-D survey cost can be avoided because the available information sufficiently constrains the geometry of the injection zone, or because data can be leased at lower cost.

Actual costs inventoried in this study are nominal or order-of-magnitude because many factors must be evaluated to develop site-specific costs. In particular the cost of wells drilling requires not only depth but drilling rate, number of casings and other factors such as equipment mobilization, coemption for services, cost of material and site access can have large impacts. For 3-D seismic, the largest uncertainty is the required area over which the data are needed.

This study provides a guide for the process and budgeting of pre-permit storage site evaluation, and is intended to allow projects considering CCS to make more strategic decisions of how to integrate storage site evaluation into their overall emissions reduction planning.

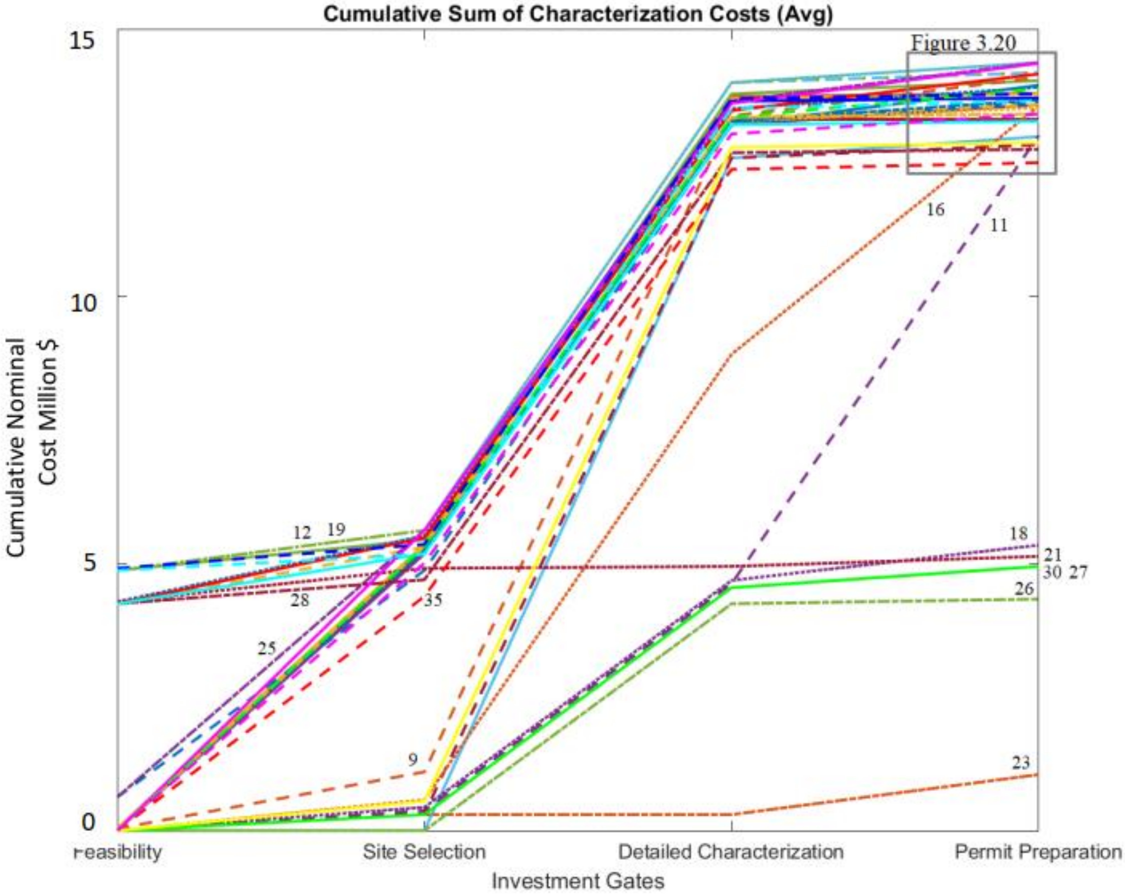

Figure 1. Cumulative nominal average cost for staged characterization.

Keywords: Storage cost of characterization, early stages of project development

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Carbon capture, utilization, and storage hub development on the Gulf Coast

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Abstract

The north-central Gulf of Mexico is one of the most heavily industrialized regions in the United States, spanning approximately 1000 miles from the Louisiana industrial corridor along the lower Mississippi River in the east through the refining and petrochemical centers in the Lake Charles, Beaumont/Port Arthur and greater Houston areas, and further south through Freeport to Corpus Christi. The region hosts diverse power generation, refining, and petrochemical processing facilities, resulting in the nation's largest volumetric concentration of industrial CO_2 emissions, rivaled only by the Ohio River Valley. These emissions sources are concentrated in specific industrial clusters (hubs, ports largely) that allow combining emissions streams to achieve economies of scale in sequestration. The region is currently undergoing globally significant industrial expansion and investment as a result of abundant and inexpensive regional unconventional natural gas availability, and is a growing exporter of liquefied natural gas (LNG). In the Gulf Coast, the diversity of emission source types is a benefit for early capture deployment. The region also hosts vast geologic and engineering expertise, and the subsurface is extremely well-known from decades of hydrocarbon exploration. In the past, CCS has been strongly linked to emissions reductions for coal-fired power. Five additional energy-related sectors are important in this region: (1) Liquefied natural gas (LNG) exports, (2) Enhanced oil recovery (EOR), (3) refining (upgrading) of heavy oil, (4) hydrogen production, and (5) ammonia and fertilizer production. Opportunities to integrate CO_2 emission management within the diverse energy chains in the region are volumetrically significant and include both concentrated and dilute sources. Significant examples of capture, transport, and storage exist. Offshore storage is particularly attractive, as it provides simplified land leasing models (single governmental land owner), proven reservoir quality, and presents fewer risks to both protected groundwater and populated areas. Projects can now take advantage of recently expanded opportunities under section 45Q of the Internal Revenue Service tax code. The region continues to evolve as an active carbon-handling hub, has seen multiple recent business development announcements, and is uniquely suited to justify additional investment in carbon capture, utilization, and storage (CCUS) technologies via a large-scale integrated project development. Continued development of integrated projects will allow the region to continue to grow economically within its strong fossil-fuel handling focus while advancing low-carbon energy technologies that maintain global competitiveness.

Keywords: CO_2 geologic storage; Gulf Coast; Gulf of Mexico; 45Q Tax Credit; regulatory

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Monitoring CO_2 plume migration with lab-scale ultrasonic experimental setup

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Abstract

In geologic CO_2 storage, seismic survey is an important method to monitor both the CO_2 plume migration extent and the saturation values during the injection and the post-injection periods. In order to increase the accuracy of CO_2 saturation quantification in heterogeneous domains with seismic surveys, we built a lab-scale ultrasonic experimental setup that is capable of acquiring high-resolution 2D images by applying seismic survey principles. Currently the setup can detect heterogeneous structures such as a metal rod and the water/beadpack interface through ultrasonic imaging. Going forward, we plan to use this setup to image two-phase fluid flow experiments conducted with surrogated fluids selected to mimic supercritical CO_2 behavior at reservoir conditions in saline aquifers.

For the lab-scale ultrasonic system, we mount two piezoelectric transducers (Olympus, 1 MHz) on motorized gantries on a rail to acquire wave propagation data by varying the transducer locations while producing and receiving elastic signals of the sand tank. The tank is packed with heterogeneous glass beads, and either air or heptane can be injected below a low permeability layer to mimic CO_2 plume buoyant migration through the domain. There are three main components in the lab-scale ultrasonic system. They are: a) an ultrasonic signal generation and receiving system, b) motors and their control system, and c) a sand tank. Component a) consists of a pulser (to generate source signals), an oscilloscope (to receive signals), and two transducers. Component b) consists of a rail (to mount the gantries with transducers), two motorized gantries (one for each transducer), and an ARDUINO® control box (to command the motors). Finally, component c) is a thin sand tank that is similar to a Hele-Shaw cell so that the plume location can be visually examined.

We use MATLAB® to communicate with both the oscilloscope and the Arduino control box in order to program the motor motions and the ultrasonic data acquisition details. For the preliminary experiments, we acquire ultrasonic data with a signal frequency of 1MHz over a 20cm-long section of the sand tank. The stepper motors used in the setup are capable of making highly accurate steps at the millimeter resolution. To acquire ultrasonic data, first we fix the location of the gantry carrying the source transducer at one end of the tank and let the gantry carrying the receiver move away from the source making 41 stops in total with 0.5cm in between each stop. At each stop, the source shoots the same ultrasound signal 1000 times and the receiver listens for 500 microseconds after each shot. Finally, all 1000 received signals are stacked to increase signal-to-noise ratio, and the receiver gantry moves to the next stop. The source and receiver transducers can also switch roles so that even though they are mounted on a single rail, it is possible to have the source at every one of the 41 locations and the receiver at every other location.

Processing of the ultrasonic data acquired through this lab-scale setup is similar to conventional field-scale seismic data processing. After velocity analysis, we can perform normal move-out corrections, stacking, and migration

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to obtain the 2D image of the sand tank. Currently, zero offset experimental results have shown that the setup can correctly identify a brass rod submerged in water in the middle of the tank as well as the interface between water and the top of the beadpack for a water-saturated packed tank. For future experiments, we will first use the setup to detect air/water density contrast, and then move on to the heptane/glycerol+water mixture surrogate fluid pair, which has a lower density difference. Finally, it is possible to combine this lab-scale ultrasonic experimental setup with the light transmission visualization system so that both ultrasonic and visual data can be acquired at the same time. The acquired visual data can yield accurate saturation values which can then be used to inform the ultrasonic setup. It would be desirable to be able to ultimately use the lab-scale ultrasonic setup alone to not only detect CO_2 plume extent but also quantify CO_2 saturation values.

Keywords: CO_2 geologic storage; beadpack experiments; 2D ultrasonic imaging; seismic survey; multiphase flow in porous media

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Effects of flow pulsation on CO_2 buoyant migration and capillary trapping

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Abstract

Small-scale (mm-dm scale) capillary heterogeneity has been shown to have a significant impact on CO_2 plume migration and trapping. While plenty of pore-scale and core-scale physical fluid flow experiments exist that investigate how capillary heterogeneity affects CO_2 flow and trapping, larger tank-scale experiments have been scarce. In this study, we present two intermediate tank-scale experiments demonstrating a dynamic multiphase flow phenomenon caused by the presence of capillary heterogeneity known as flow pulsation. Experimental results show that strong flow pulsation can cause CO_2 to unexpectedly breach capillary barriers early, and this could have significant implications for geologic CO_2 storage.

Flow pulsation is a form of incoherent flow that occurs when the grain sizes are large or the flow rates are low. To investigate this specific flow phenomenon we conducted two tank-scale two-phase flow experiments with the light transmission visualization method in beadpacks. The size of the tank is 0.6m by 0.6m by 2cm. Two different sizes of glass beads are used to pack the tank, the coarse-grained matrix (average grain size: 0.689mm) and the fine-grained lamination (average grain size: 0.457mm). Two simple fine-bead lamination layers exist in the domain to act as capillary barriers. Flow experiments are conducted with surrogate fluids specifically selected to mimic the properties of supercritical CO_2 and brine at the typical reservoir conditions in water-wet saline aquifers. Heptane is used to represent the CO_2 phase and the glycerol/water mixture is used to represent the water phase. The tank is initially completely saturated with the glycerol/water mixture. Then heptane is injected through an inlet at the bottom and let rise through the domain until it eventually breaks through and leaves the tank via an outlet at the top. The tank is illuminated with a backlit LED panel and flow images are captured by a high-resolution monochrome camera in a dark room throughout the drainage process to compute the saturation fields.

At the flow rate of 0.02 mL/min, the capillary number is low enough that this is firmly within the capillary- and buoyancy-dominated flow regime. Strong pulsation behavior can be clearly observed from the camera images. As we increase the flow rate to 0.2 mL/min, although the flow regime is still capillary-dominated, we are now at the boundary between coherent and incoherent flow regimes. Therefore, while in one experiment at this flow rate we observe strong pulsation behavior throughout the entire drainage process, in another experiment at the same flow rate we observe the transition from strong pulsation behavior to stabilized flow. In one of the experiments it is also observed that strong flow pulsation releases large pulses of heptane from the lower capillary barrier into the upper capillary barrier region and can cause heptane to breach the upper capillary barrier early before flowing underneath and around. Finally, when the flow rate is further increased to 2 mL/min, strong pulsation behavior completely disappears as we are now within the coherent flow regime.

Three possible causes of early breaching are proposed, a) capillary fracturing, b) local viscous forces, and c) buoyancy forces. Out of the causes proposed, it is most likely that a combination of high buoyancy and local viscous

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forces caused early breaching to occur. Strong pulsation causes heptane to invade pore spaces deeper within the upper capillary barrier than it otherwise would and eventually leads to early breaching. When occurring at scale, early breaching could potentially allow CO_2 plume to migrate upward faster than predicted. Comparison to previous tank-scale experiments shows that even when the same two grain sizes are used, a more heterogeneous domain with a greater number of capillary barriers suppresses flow pulsation and retains more heptane. Therefore, it is desirable to select geological formations with greater small-scale heterogeneity to slow down upward CO_2 plume migration and to improve CO_2 storage capacity.

Keywords: CO_2 geologic storage; beadpack experiments; incoherent flow; small-scale heterogeneity; multiphase flow in porous media

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The effect of monitoring complexity on stakeholder acceptance of CO_2 geological storage projects

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Abstract

Over the past decade, much of the research on CO_2 geological storage has focused on developing reliable monitoring technologies and approaches to indicate retention of CO_2 in the subsurface for emissions accounting and environmental protection. Most recently, an emphasis has been placed on down-selecting tools and optimizing monitoring approaches for cost-effectiveness. One area where significant optimization of monitoring has evolved is in the development of stoichiometric methods to replace baseline approaches in environmental monitoring. Environmental monitoring provides assurance to stakeholders that resources (groundwater, soil, atmosphere, seawater, and human health and safety) are being protected. The safety of geological CO_2 storage is of primary importance to stakeholders and environmental monitoring is a critical link between the public and the project. In this study, we seek to understand; 1) how stakeholders may respond to optimization (e.g. simplification) of environmental monitoring plans and 2) under what circumstances might lay stakeholders prefer complex, data-rich approaches that are intellectually inaccessible to them and require them to trust scientists explicitly, as opposed to simple approaches that can be easily learned, understood and even implemented by the stakeholder.

The multinational project, Act On Offshore Monitoring (ACTOM), is developing a computational toolbox for creating optimized monitoring plans at offshore CO_2 storage sites. The toolbox considers legal, regulatory and technical issues in addition to social acceptance within a responsible research and innovation (RRI) framework. RRI is a European concept, similar to "environmental justice" in the USA that encourages scientific research to consider the impacts of technology development on society and the environment. RRI encourages high ethical standards, gender equality, environmental integrity and engagement of communities directly affected by a technology such that they fully understand the implications of the application of that technology.

With these concepts in mind, the ACTOM project is seeking to understand how different kinds of monitoring programs are viewed by the public and which ones are more likely to garner public support. Of particular interest are the constructs of message complexity, need for cognition and social norms. When presented with messages, audiences do not process them uniformly. Rather, individual differences, such as a preference for detailed, scientific content or a predisposition for mentally-challenging tasks, influence how different people might process the same information differently. From this starting point, we examine under what circumstances stakeholders feel more

secure with extremely complex and scientific approaches versus simpler approaches in which they could understand and even take part in the monitoring. Individuals who prefer complex messages and enjoy effortful cognition might trust rigorous approaches that are extremely in-depth and complex, where large and varied data streams are collected and analysed with complex algorithms in a way that requires the stakeholder to trust the scientist. Conversely, those who find cognitive effort onerous might prefer simpler approaches in which answers are immediate and the stakeholder can understand and even participate in the monitoring activity, similar to a citizen scientist approach.

As well, social norms can be a powerful factor in message acceptance. Social norms signal to group members those behaviors, attitudes and beliefs that are accepted and preferred. In the context of novel or complex ideas, social norms are useful heuristics to indicate what kinds of adaptive behaviors or beliefs should be adopted in otherwise ambiguous contexts. Our study examines the role of social norms to see which referential group (scientist support or community member support) holds more influence in audience processing of different monitoring programs.

We rely on a 2 by 2 factorial experiment in which we manipulate message complexity (complex v. simple) and social norm (support from scientists v. support from community members). Subjects were randomly assigned to one of four conditions shown in figure 1 (complex message with scientist support; complex message with community member support; simple message with scientist support; simple message with community member support). In addition to the experimental stimuli, subjects were also asked about their need for cognition, attitudes toward science and scientists, attitudes about climate change and support for CCS. Our sample is drawn from residents in states bordering the western Gulf of Mexico (Texas, Louisiana, Florida) where CO_2 geologic storage is being planned both onshore and offshore. The results offer important implications for public outreach efforts to key stakeholders. It is also planned that these results will be compared to a sister survey being given in Norway where CO_2 storage has been ongoing offshore for decades.

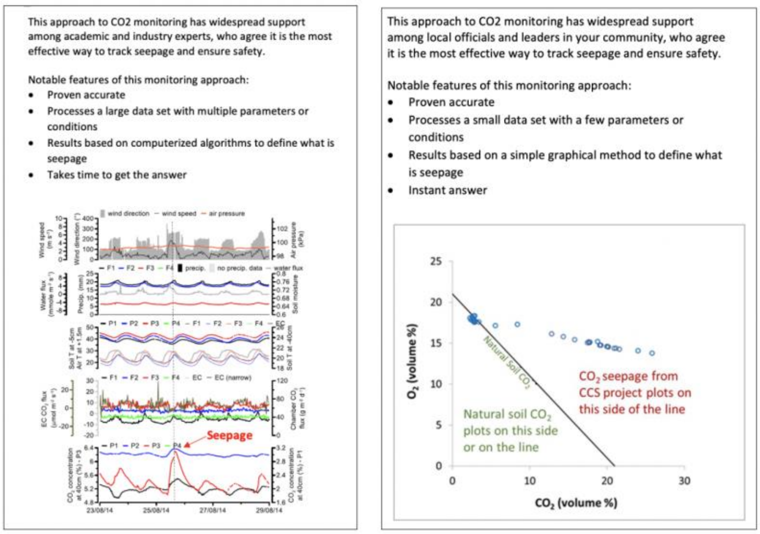

Figure 1: Experimental stimuli showing complex monitoring message and scientist social norms (left panel) and simple monitoring message and community social norms (right panel)

Keywords: CCS; monitoring; process-based; stakeholder acceptance

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Attitudes on Carbon Capture and Storage (CCS) within the UNFCCC

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Abstract

Since 2013, IEAGHG and The University of Texas at Austin (UT) have partnered with the Carbon Capture and Storage Association (CCSA), Bellona Foundation, and the International CCS Knowledge Centre to conduct several official UNFCCC side-events to input technical information on CCS into the Conference of the Parties (COPs). For six COPs these were the only official Side-events on CCS. Since 2007, Linköping University has distributed surveys to delegates at the COPs, and from 2015 onwards, their surveys were distributed to the attendees at these official CCS Side-events, as well as to delegates attending the COPs in general.

The original focus of the survey questions targeted investment preferences for mitigation activities, and specifically on BECCS. However, we identified that an expanded assessment of the data could provide additional insights on CCS on fossil energy as well as BECCS, and thus we attempted to use the survey to gain information on the impact of Side-events on UNFCCC attendee views on CCS. More specifically, the data enabled us to investigate whether UNFCCC attendees' views were changing over time and how different countries (developed and developing) and different groups such as country negotiators and business, environmental and research non-governmental organizations (NGOs) view CCS. We also assessed any differences that might exist between those who were surveyed within the official Side-events and those who had not been to the CCS Side-event but were questioned in the general COP environment. Given the importance of CCS to mitigating emissions in developing countries, it was also of interest to compare the responses from delegates residing in Annex 1 (broadly equaling developed countries, including economies in transition) and non-Annex 1 (broadly equaling developing countries) to assess any differences in awareness and/or perceived importance of the technology in their countries.

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Such information could help to define the audiences in UNFCCC COPs that need information on CCS and enable information presented in the side-events to be more tailored to these groups.

A key finding was that that a positive change in attitudes occurred over this time period for both fossil CCS and for BECCS, starting from COP24. Using a unique data analysis method, we ascertained that, in some instances, popularity of BECCS increased due to an increased acceptance of CCS despite lower opinions of bioenergy. Business and research NGOs had the most positive views of CCS, and environmental NGOs the most negative views. Delegates that attended CCS side-events had more positive attitudes towards CCS than non-attendees. Developing countries had a larger need and a greater appetite for information on BECCS than developed countries, but a need for information was seen to exist in both.

The results suggest that CCS information at COPs should be targeted to developing country delegates and to environmental NGOs. Overall, the main conclusion is that more information is needed on CCS in the UNFCCC COPs.

Reference:
Note this GHGT-16 paper will be a summary of the key results of the work which has been published in full as:
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https://doi.org/10.3390/en14030629

Keywords: CCS; BECCS, UNFCCC; negative emissions; side-events; stakeholder perceptions