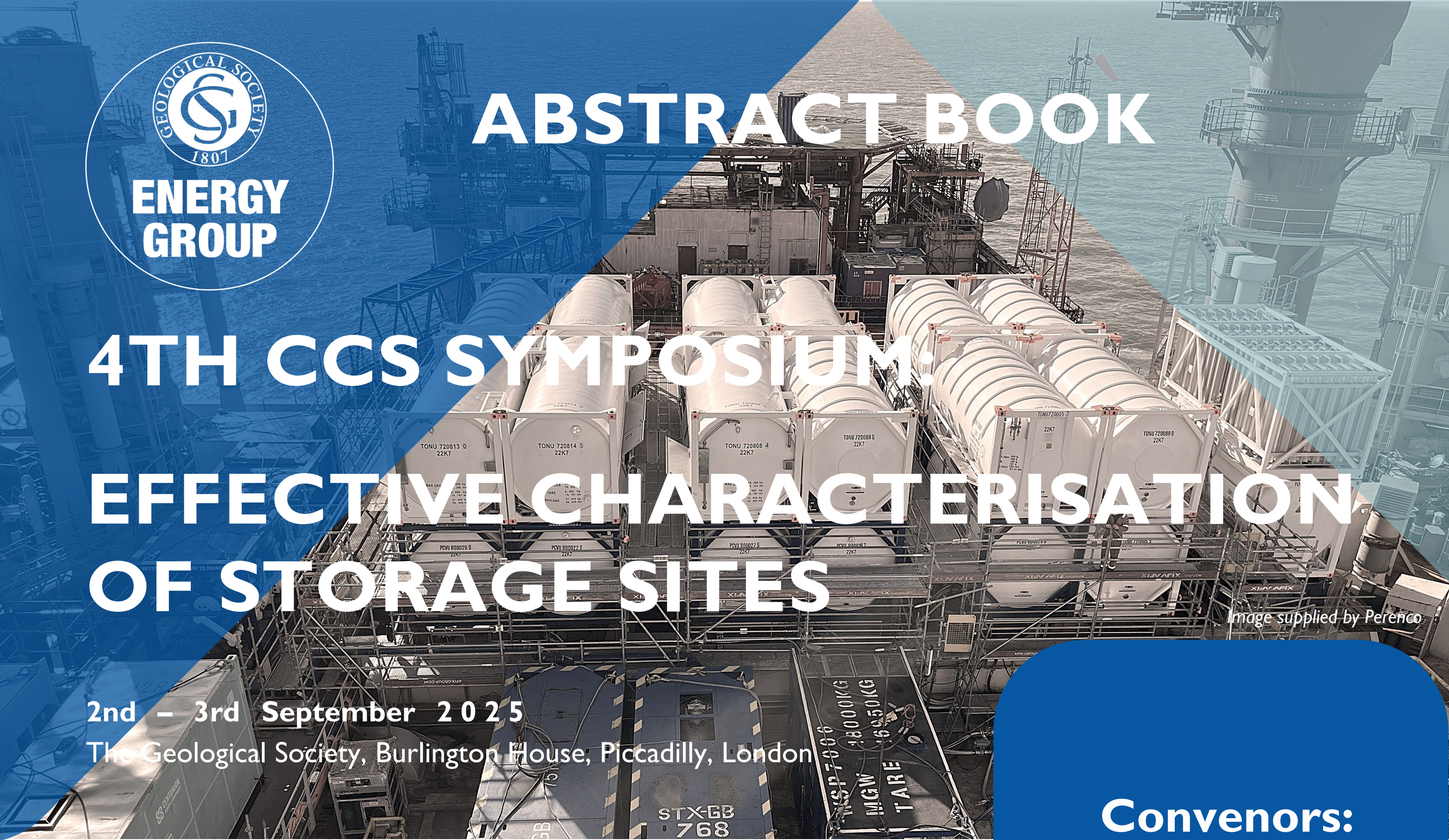
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ENERGY GROUP

ABSTRACT BOOK

4TH CCS SYMPOSIUM:

EFFECTIVE CHARACTERISATION OF STORAGE SITES

2nd – 3rd September 2025

The Geological Society, Burlington House, Piccadilly, London

In the North Sea and beyond, first of a kind CCS projects are reaching FID. To enable success for this nascent industry we are actively seeking real world examples from recent appraisal and testing programmes, including the acquisition and impact of new data and insights gained through advanced modelling. What can we learn from the more established CO_2 storage projects and which uncertainties remain poorly understood?

As an industry it is also important to consider what we realistically need to know to safely inject and how to reduce appraisal timelines, as these impact the full life cycle costs of the projects to the operator and cost per ton to emitter. How do we determine pragmatic, risk-based approaches for appraisal of depleted field and saline aquifer stores, balancing the need to demonstrate containment against commercial reality?

Containment - How best to quantify and address leakage risk?

- Assessment and mitigation of legacy wells
- Predicting fault and seal behaviour under injection conditions
- Assessing lateral leakage pathways that may be overlooked/under-represented?

Injection – Are flow tests always required? What can we learn from injection testing?

- The value of injection vs. production tests and injection fluid type
- Flow assurance challenges in severely depleted fields
- Extrapolating to full field reservoir characterisation

Capacity – How does reservoir geology affect CO2 plumes and pressure over time?

- The impact of reservoir heterogeneities and faults on our ability to inject CO2
- How do pressure constraints limit injection capacity in a hydraulic unit?
- Should depleted field capacity be limited by the original field conditions

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4th CCS Symposium: Effective Characterisation of Storage Sites
2-3 September 2025

The Geological Society, Burlington House and Zoom

Final Programme

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(In Programme Order)

Day one

Opening Keynotes

Keynote – Effective Characterisation – A Regulator's Perspective

Matt Farris

Characterisation of a potential carbon store is an essential first step on the path to acquiring a storage permit. Effective characterisation should demonstrate whether a potential carbon store has sufficient capacity and injectivity; will perform effectively, safely, securely; and can be monitored appropriately. It should focus on the identification and mitigation of risks, needs to be fit-for-purpose and meet the regulatory requirements for a CO2 storage permit.

The regulations for characterisation of a carbon store are laid out in Annex I of EU Directive 2009/31/EC and comprise an inclusive list of requirements that address:
1) data collection; 2) building the three-dimensional static geological earth model; and 3) characterisation of the storage dynamic behaviour, including sensitivity characterisation, and risk assessment.

Key challenges for licensees include managing uncertainty from the outset, avoiding linear workflows, and resisting reliance on early model assumptions. Petroleum workflows are not always transferable, and depleted reservoirs may behave differently during injection than depletion.

Two elements are particularly critical: (1) assessing legacy well integrity and potential leakage pathways, and (2) modelling and understanding dynamic behaviour. Both must be addressed early and at the right scale to identify constraints to storage, which may alter the definition of the storage site and complex.

Effective characterisation will focus on data, studies and the appraisal required to address risks, incorporating results into static and dynamic models without undue recycling of efforts. The dependencies between the various elements of the characterisation work dictate an iterative and flexible approach and require careful project planning.

Keynote – Endurance – First of the New Generation

Sarah Buchanan

Session One: Basin-scale Characterisation

Hydraulically Open Boundaries and Legal Consequences

Sylvain Thibeau; Alex Bump

There is a long history of basin-scale storage assessment using volumetric methods and storage efficiencies of 4-5%. Bump and Hovorka (2024) pointed out that that requires displacing pre-existing brines. They argued that at the basin-scale, reservoir limits, overpressure and/or legal restrictions on surface discharge combine to create a system that is effectively closed. Using the example of the Texas Coastal Miocene, they calculated a pressure-limited capacity of 20.3Gt, vastly less than the volumetric estimate of 125Gt.
We note that the up-dip boundary of that system is hydraulically open, with reservoirs coming to outcrop ~100 km inland of the model area. Here we use the methods of Thibeau and Adler (2023) to investigate the effect of adding a side aquifer with an open boundary to Bump and Hovorka's model.
Allowing pressure to dissipate up-dip increases storage capacity from 20.3 Gt to 37.2 Gt, i.e. almost doubling the CO2 storage resources. At the end of the injection period (with the coastal Miocene fully pressured), displaced brine moves the base of freshwater up-dip by 0.3-1.3 km. As CO2 dissolves and pressure dissipates, displacement increases further by 0.1-0.7 km. The resulting vertical movement of freshwater is small but nonzero, perhaps resulting in increased streamflow or rejuvenation of old wells.
This work illustrates the impact of boundary conditions and raises new questions for characterization. Not only do we need the physical description of hydraulic boundaries, but we may also need regulatory clarification on acceptable movement of salinity contours.

References

Bump, A. and Hovorka, S.: Pressure space: The key subsurface commodity for CCS. International Journal of Greenhouse Gas Control 136 (2024) 104174
Thibeau, S. and Adler F.: Pressure-derived storage efficiency for open saline aquifer CO2 storage. Geoenergy, Vol 1, 2023

How Collaboration in CO_2 Storage Supports the Effective Site and Risk Characterisation of a Large Connected Hydraulic Unit: A Case Study from the Humberside CCS Project

James C White, John D. O. Williams, Tim Good, Eric Mackay, Martin Grecula, Samantha Luxon, Clare Glover, Pam Raine

The Humberside CCS project, offers near-shore storage potential utilising migration-assisted trapping concepts. The targeted Bunter and Leman Sandstone aquifers form large hydraulic units spanning the on and offshore domain.

The aim of this collaborative project is driven by a requirement to recognise, prevent and mitigate key project risks. Targeted assembly of existing knowledge offers cost effective, integrated evaluation of the licence and adjacent offshore and onshore areas. Leveraging national datasets, held by the BGS and collected over decades can improve regional understanding of the structure and properties of the storage unit and support construction of 3D models to evaluate the dynamic response of the aquifers to CO2 injection.

Assessing information across a range of scales enables characterisation of the subsurface to support effective site and risk evaluation. The project supports acquisition of new sedimentological and petrographic data, alongside re-interpretation of legacy seismic, core and petrophysical information. This approach will support development of model scenarios that will represent subsurface uncertainties

The inclusion of hydrogeological expertise will build understanding of parameters that control regional pore fluid responses to offshore injection. Integration of onshore recharge and abstraction data with the offshore constraints, through dynamic reservoir and groundwater modelling, are a key project objective. Findings will aid stakeholder understanding of risk, whilst supporting regulator interactions.

The project outcomes will enable a robust evaluation of the far-field pressure response in the subsurface; incorporate assessment of regional data and support the ongoing appraisal of the CS028 licence to ensure future safe and permanent storage of CO2

Session Two: Assessing Capacity in Large Saline Aquifers

A First-order Model of Pressure-limited CO_2 Geological Storage Growth at the Basin Scale

Iain de Jonge Anderson, Jennifer J. Roberts, Gareth Johnson, Juan Alcalde

Gigatonne-scale CO2 geological storage (CGS) will be required in the coming decades if global temperature rise is to be limited to 1.5°C by the end of this century. This represents a major increase from current levels, and the industry needs to scale-up quickly if this target is to be realised. While many areas of the world have catalogued their CGS resources, substantial uncertainty remains around how basin-scale pressure buildup may constrain injectivity and storage potential, particularly in rapid growth scenarios.

Forecasting pressure behaviour is usually achieved using sophisticated reservoir simulations, but the data and time required to build and run these prohibits their use on a basin scale. Some reduced order models exist, but they often lack the flexibility to consider different growth scenarios and the evolution of pressure buildup over time.

We have developed a new first-order model to address this gap. The model combines well-established analytical solutions for CO2 injection with a logistic growth framework to represent well deployment over time. At each timestep, the model simulates multi-well pressure buildup and ultimately defines storage capacity based on specific pressure thresholds. This approach enables the efficient prediction of pressure buildup at scale, while remaining computationally light and applicable to areas with limited geological information.

We apply this model to generate pressure-constrained capacity and injection rate curves for the UK under a range of industry growth trajectories, geological characteristics and pressure regimes. Looking ahead, it will be deployed globally, and the results will be incorporated into Integrated Assessment Models to help better constrain projections of CGS scale-up in future climate scenarios.

Storage Capacity Constraints in Unconfined Saline Aquifers – Insights from the Site Characterisation of the Humberside Prospect, Offshore UK

Martin Grecula, Eric Drueppel, Oliver Davis, **Samantha Luxon,** Lesley Seldon, Sascha Alles Emma Westley, Nino Cilona, Sourav Saha, Pamela Raine, Clare Glover

The Humberside CCS licence is ideally positioned and targets stacked Permian and Triassic storage units. However, despite the large theoretical capacity estimated at a play level, effective storage capacity is contingent upon addressing subsurface constraints such as plume extent; legacy wells; geological leak pathways; caprock strength; fault reactivation; and pressure interference. Transitioning from play to lead to prospect level storage resource estimation requires understanding development limits and injectivity constraints imposed by these containment risks. Additional surface constraints, including shipping routes; windfarms and cables; fisheries; and protected areas, can further limit storage potential.
Uncertainty in subsurface parameters, particularly in aquifer plays with limited data, significantly impacts capacity estimation. Acquiring appraisal data is crucial for de-risking containment and evaluating the project's economic attractiveness, thereby reducing the chance of commercial failure. Post-appraisal residual uncertainty necessitates phased development and underscores the importance of monitoring and adaptive injection management.

Session Three: Traditional and Emerging Approaches to Subsurface Evaluation

Keynote – Notes from a New Enterprise: Characterisation for Carbon Storage

Alexander Bump, Siavash Kahrobaei; Rouhi Farajzadeh, Denis Voskov

Geologic characterization is fundamental to assuring safe, permanent carbon storage. At first glance, CO2 storage looks much like hydrocarbon production, suggesting similar characterization needs. Both revolve around subsurface reservoirs and seals, buoyant fluids and 2-phase flow in porous media—how different can they be? In short, very different!

While depleted hydrocarbon fields can be used for storage, CO2 storage is fundamentally different from hydrocarbon production. Injection raises reservoir pressure; disposal is a low-margin business; and the goal of permanent storage eliminates the need for a trap. The net result is to place new importance on old variables, to introduce new ones and even to ask new questions.

The need to displace pre-existing reservoir brines places new weight on large-scale reservoir connectivity and even on the potential role of "non-reservoir." In a world of pressure-limited storage, pore volume compressibility and brine salinity are key controls on storage capacity. Even age-old questions about seals may be reframed by the goal of storage rather than recovery— a well-defined trap and seal may be less important than assuring that injected fluids cannot migrate above a given horizon.

In sum, subsurface characterization is as important for carbon storage as for hydrocarbon production, perhaps even more so, given the narrow financial margins for storage and the need to ensure success. However, the goals, constraints and boundary conditions for storage are different from those of hydrocarbon production, requiring new ideas and new approaches.

Seismic Re-processing and Interpretation to Uncertainties in Sean-Inde CCUS Site Assessment

Gerco Stapel, Jeroen Beishuizen, Xander Campman, Chris Freeman, Axel Hartman, Mieke Kosters, Frederieke Tutuarima

In September 2023, Shell U.K. Limited and Esso Exploration and Production U.K. Ltd were awarded Carbon Storage Licences CS026 (Sean) and CS027 (Indefatigable) under the North Sea Transition Authority's (NSTA) first Carbon Storage Licence round. These licences include a comprehensive Appraisal Phase Work Programme, which mandates the reprocessing of legacy seismic data to enable improved characterization of the Rotliegend (Leman) candidate storage sites, complex and overburden.

The reprocessing aims to reduce key uncertainties related to capacity, containment, and injectivity, which stem from the limitations of the legacy seismic image and velocity models. In particular, the new image should enable the improved interpretation of the primary seal (Zechstein), and its thickness variation across both licenses (current estimates: 85–1200 m for Sean, and 300–1200 m for Inde), allow more detailed fault interpretation within the reservoir (compartmentalization) and overburden (potential leak paths), and depict spill points with more certainty. The updated velocity model should allow for reliable time-depth conversion to support storage site and complex definition.

The reprocessing effort focused on improving seismic image bandwidth and resolution through:
• Broadband processing, including deghosting, debubbling, and multiple passes of both long- and short-period demultiple;
• Velocity model building, using a sonic log-based, depth-calibrated, interpretation-driven approach, enhanced with Full Waveform Inversion (FWI) for the overburden;
• Advanced imaging, employing enhanced Kirchhoff and RTM Pre-stack Depth Migration to resolve complex structures beneath the Zechstein Salt and associated fault systems.

The resulting broader bandwidth and improved image have significantly improved the clarity of the reservoir faults within the compartmentalized reservoir. This, combined with the reduced depth uncertainty, allows for more reliable updates to capacity estimates.

Current interpretations and preliminary attribute analysis indicate that the image quality may be adequate for assessing reservoir quality and potentially deriving additional properties from seismic attributes, which could be used to update injectivity estimates. Further quantitative inversion work is needed to demonstrate this.

This presentation will detail the legacy data limitations and resulting uncertainties, outline the key seismic processing and imaging workflows, and demonstrate how the improved seismic products impact geological interpretation and CCUS site assessment.

Performance Assessment of Distributed Acoustic Sensing (DAS) Arrays for Seismic Monitoring of Offshore Carbon Storage

Antony Butcher, Anna Corbin, Germán Rodríguez, Sacha Lapins, School of Earth Sciences, James Verdon

The current development of multiple Carbon Capture and Storage projects in the UK Continental Shelf, and Norwegian, Dutch and Danish North Sea, will be vital components of a secure, low carbon energy future for the region. The injection of many millions of tonnes of CO2 should also be accompanied by the implementation of a robust seismic monitoring system near large-scale injection facilities, due to the associated increase of the risk of inducing large seismic events during the injection. High resolution monitoring of microseismicity also provides important information about the geomechanical response of the reservoir and leakage risks such as caprock fracturing.

There is, however, a lack of seismic monitoring near offshore injection facilities due to the costly logistics challenges of operating in such settings. The implementation of Distributed Acoustic Sensing (DAS) technology has the potential to provide a cost-effective solution that can complement conventional methods to improve the robustness of seismic monitoring systems. In this study, we aim to evaluate the performance of offshore DAS arrays using a compilation of datasets which include areas within CCS licensees in the North Sea. We first examine for each DAS dataset the detectability of local and regional earthquakes using both conventional seismic processing methods and machine-learning methods (e.g. PhaseNet, N2N, DenoDAS), and then locate the detected events to quantify the location uncertainties associated with the geometry of offshore DAS arrays. Finally, we assess the capability of these networks to provide robust and reliable estimates of earthquake magnitudes.

Delivering Value from Rock Physics and CCS Containment and Capacity Assessment

Eleanor Oldham

For CCS projects it is critical to understand uncertainties and mitigate risks whilst managing costs as efficiently as possible. For this reason, the extraction of maximum value from all legacy subsurface datasets is of crucial importance, and rock physics can deliver on that.

This presentation will use real data from global CCS sites to show how rock physics methods can be used to characterise both the storage and sealing units. The results and insights gained can play a key role in quantifying the capacity of a potential CO_2 storage site and help predict how the rock will respond to the changes brought about by CO_2 injection.

Rock physics templates can be used to characterise both reservoirs and top seal units. Fitting a rock physics model to log data can provide information regarding pore shapes, the degree of cementation and the distribution of intra-reservoir shale. Understanding these properties can, in turn, deliver critical insights for planning a CCS, such as the effectiveness of the storage unit, its permeability (and any preferential flow pathways), and the expected behaviour of the storage complex when subjected to pressure changes from CO_2 injection.

Insights from rock physics analysis of legacy datasets can add value to the planning stages of a CCS project. Integrating this knowledge with conventional geological reservoir characterisation can reduce the uncertainty on storage capacity and optimise the injection strategy; simultaneously maximising the storage potential whilst minimising leakage risks from pressure changes.

Session Four: Pores and Fluids

Simulation and Modelling of Convective Mixing of Carbon Dioxide in Geological Formations

Francesco Zonta, Marco De Paoli, Lea Enzenberger, Eliza Coliban, Sergio Pirozzoli, Sapienza

The geological sequestration of carbon dioxide (CO2) consists of injecting large amounts of CO2 into underground formations with the aim of permanent storage. This process is key in reducing greenhouse gas emissions in the atmosphere and in supporting energy transition. After injection, CO2 combines with the resident fluid (brine) and remains stably trapped in the formation, preventing leakage to the atmosphere. The mixing process of CO2 and brine can take place over hundreds or thousands of years and gives rise to density-driven flows that, in turn, influence mixing. Predicting the evolution of this process is crucial in the design of injection strategies. Naturally, field and laboratory measurements in this field are challenging. Here we employ massive numerical simulations to predict the underground CO2 dynamics, which depends on the fluid properties, on the rock properties and on the morphology of the formation. We systematically investigate the flow dynamics in three-dimensional systems, and provide a robust quantification of the differences occurring with respect to ideal two-dimensional systems. Finally, we derive a simple, reliable and accurate physical model to predict, design and control the post-injection dynamics of CO2.

The Role of Geological Heterogeneity on the Development of Density-driven Convection in CO_2 Solubility Trapping and Migration for an SNS Example

Sirirat Subsakul, Dan Arnold, Eric Mackay, Edmund Stephens

Solubility trapping in carbon capture and storage (CCS) involves dissolved CO2 in formation brine, reducing leakage risks and enhancing long-term security. Density-driven convection, where CO2-enriched brine sinks due to increased density, plays a key role in this process. This mechanism is critical in the North Sea, where large-scale CCS projects depend on effective trapping, especially residual trapping stored further downdip near site boundaries.

This study examines how geological heterogeneity affects the development and extent of density-driven convection, influencing CO2 migration within storage sites. Using high-resolution 2D models of a realistic SNS geological scenario, we analyse the formation and interaction of convection cells, focusing on how heterogeneity impacts trapping near the crest and around injection wells. Notably, heterogeneity, such as cemented zones acting as low-permeability baffles, influences the development and merging of downward convection cells.

Fourteen models (2 km by 200 m) explore various geological factors, including calcrete proportion, permeability, correlation length, trend, dip, salinity, and residual saturation profiles. We also assess the effect of advective forces and geological features on convection development.

The insights gained aim to improve site selection, risk assessment, and long-term monitoring strategies for CCS projects, ensuring more secure and effective CO2 storage.

Day two

Session Five: Reservoir Heterogeneity and Faulting

The Impact of Multiscale Geological Heterogeneity on Migration-assisted Storage in UKCS Saline Aquifers

Dan Arnold, Eric Mackay, Edmund Stephens

This study investigates the controls on CO_2 plume migration and residual trapping in UKCS saline aquifers, considering geological and flow parameters. It utilises two modelling scales: small-scale 'truth' models that explicitly incorporate sedimentological and structural heterogeneities, and large-scale models that simulate overall plume behaviour in typical UKCS CCS regions.

The small-scale models reveal that a grid resolution of around 10 cm is often necessary for accurate simulation when sharp saturation contrasts are present, especially near structural features like tops or permeability layers. Even faults below seismic resolution can significantly influence flow paths by acting as entry pressure barriers. Residual trapping varies with wettability and buoyancy, with saturation levels between 10-40%. Fault zones can act as 'membranes seals,' diverting flow and increasing trapping.

Large-scale models analysed 14 geological scenarios, showing that CO_2 trapped near (within a few kilometers) the injection site can reach approximately 20-25 Mt. Faults and surface features modulate trapping efficiency, with sub-seismic faults slowing plume advance and increasing residual trapping through stacking effects. Sensitivity analyses highlight that the key uncertainties are residual saturation and permeability variations, including trends.

The study emphasises the importance of multi-scale geological characterisation, recommending further research on mesoscale features, fault zone modelling at fine scales, and solubility impacts. Overall, this comprehensive approach enhances understanding of CO_2 storage behaviour, aiding in the prediction and optimisation of reservoir capacity and safety.

Multiscale Characterization of Sedimentological Heterogeneity in the Bunter Sandstone Formation with Application to CO_2 Storage

Shakhawat Hossain, Gary Hampson, Carl Jacquemyn, Matthew Jackson, Dmytro Petrovskyy, Sebastian Geiger, Domenico Chiarella, Luca Colombera,

Effective CO2 storage in subsurface reservoirs requires an understanding of the effects of geological heterogeneity across various scales. We address multiscale reservoir characterization using nested, hierarchical models in which properties resolved at smaller scales are systematically upscaled and used as inputs for larger-scale models. This approach preserves the effects of critical heterogeneities while enabling computationally efficient simulation of CO2 plume behaviour and trapping efficiency. This study develops a multiscale reservoir characterization framework for the Bunter Sandstone Formation, a Triassic fluvial succession widely targeted for CO2 storage across northwestern Europe, including at the Endurance CO2 storage site, offshore UK. The results of facies analysis of core and outcrop analogues, minipermeameter measurements, thin section petrography, and numerical modeling have been integrated to characterize heterogeneity at scales ranging from lamina (mm) to architectural elements (10s m). Twelve lithofacies were identified and grouped into three facies associations, and three architectural elements were defined based on the stacking patterns and geometrical configuration of lithofacies. Facies-scale permeability varies over three orders of magnitude (0.18–5400 mD), and is primarily controlled by grain size, clay content, and cementation. Representative Elementary Volume (REV) analysis revealed that the effective permeability for different lithofacies stabilizes at scales significantly larger than those of typical core plugs and exhibits high anisotropy. Effective permeability correlates linearly with the proportion of high-permeability (clay-poor) lithologies in each facies. The resulting values of effective permeability for different facies were populated in architectural element-scale models. Simplifying these models of architectural elements by grouping lithofacies into two or three permeability-based categories resulted in estimated values of effective permeability at this scale that are within 10-20% of those for models containing twelve distinct lithofacies. These findings indicate that simplified architectural element-scale models generated within a nested modeling framework can preserve key flow properties while enabling efficient simulation of CO2 storage reservoirs.

Characterizing the Invisible and the Forgotten: The Impact of Sub-seismic Faults and Non-Reservoir on CO_2 and Brine Migration in Deltaic Reservoirs

Alexander Bump, German Chavez, Seyyed Hosseini

Hydrocarbon data, workflows, and experience are enormous assets in screening and developing CO2 storage sites. However, the goals and constraints of storage are fundamentally different to those of hydrocarbon production and often push developers away from conventional traps toward sparsely drilled synclines. Similarly, permitting requires forecasting of both the CO2 and pressure plumes over the life of the project and for decades beyond. Accurate models are critical to right-sizing leases and minimizing the risks of legacy wells. In short, they are critical to financial success.

Subsurface uncertainty thus takes on new importance. Could sub-seismic faults or channels divert CO2 in unexpected directions? What impact does the scarcity of non-reservoir data have? To address these questions, we used global analog databases and extensive characterization of local, seismically visible features to extrapolate the properties of their sub-seismic brethren. We then extracted a single flow unit from the full reservoir model of a real Gulf Coast project and created over 80 variants, experimenting with channel geometries, fault properties, and non-reservoir permeability. For each, we simulated 30 years of injection, followed by 170 years of shut-in.

While faults could indeed divert the plume, realistically sub-seismic ones had minimal impact. Channel geometries made a larger difference, but really only in the migration distance along the depositional axis. Surprisingly, the most impactful variable was the permeability of the non-reservoir fraction, which had an outsize effect on the size and shape of the pressure plume. These results suggest new priorities for data collection and modelling focus.

Coupled Modelling Requirements for Geological Carbon Sequestration and Handling of Geological Structural Complexity

Dan Roberts, Kyle Mosley, Glyn Richards, Joe Eyles, Fiona McLean, Olivia Milton-Thompson, Mark Cottrell, Lee Hartley

Meeting ambitious climate targets is projected to require Geological Carbon Sequestration (GCS) at scale, necessitating a more rapid appraisal and qualification of potential storage sites. Developing coupled numerical models that address the interplay between multiphase flow, thermal contraction, and mechanical deformation during injection is key in appraising subsurface risks and developing an effective monitoring and verification scheme that permits safe long term operation of a storage site. Complex and tight coupling between these fields is further complicated by subsurface structural complexity and heterogeneity, for instance in the form of networks of rock fractures and faults, which can have important implications for the operation and monitoring of storage sites and need to be suitably realised in modelling. Fractures, both induced and natural, can impact the dynamics of CO2 plume migration and the locations of observed microseismicity. Notable examples include;

(a) In Salah storage site, Algeria, where inclusion of pre-existing discontinuities within coupled modelling workflows resulted in good agreement with observation and may explain early CO2 breakthrough identified in adjacent wells,

(b) The Decatur site, US, where microseismicity was inferred to occur largely on critically stressed fracture networks in Precambrian basement rocks that were challenging to detect and represent in simulations a priori.

A novel workflow is introduced that permits definition of geologically realistic in situ fracture networks and conditions them for integration into coupled numerical models. A Thermal-Hydro-Mechanical-Chemical (THMC) modelling toolkit that has been assembled to support the modelling workflow is outlined. The modelling tools are demonstrated in quasi-conceptual realisations of selected storage sites, using open-source datasets. A specific advantage of the workflow(s) demonstrated through these models is the potential for rapid reassessment and redefinition of modelling inputs such as the nature and characteristics of fractures within the subsurface. Such flexibility is important; monitoring, modelling and verification is a continuous process where uncertainties can be addressed as the site matures and more data become available. Deviations in the observed subsurface response relative to predictions, for example due to the influence of unidentified subsurface geological complexity, will need to be rationalised and addressed in updated modelling efforts.

Lessons From the Field: Impact of CO_2-filled Fault Zones and Capillary Heterogeneity on CO_2 Plume Behaviour and Reservoir Pressure Evolution

Idris Bukar

Faults in subsurface reservoirs are often represented in flow models merely in terms of transmissibility across their faces. This can range from a fully open scenario to a fully closed scenario where they serve as transmissibility barriers. The flow of CO2 along fault zones at the Illinois Basin – Decatur Project site has been previously observed by Bukar et al. (2025). This changes the roles of faults from potential permeability barriers to conduits that allow the vertical migration of CO2 across reservoir layers bypassing heterogeneities, thereby creating irregular patterns. We find through modelling that such patterns are consistent with observed saturation profiles at wells; these observations would otherwise have been impossible to reproduce without vertical flow of CO2 along faults. We also find that that a combination of these CO2-bearing faults zones and layered heterogeneities with non-zero capillary entry pressures can create pressure compartments in a reservoir due to multiphase flow effects rather than permeability. This allows the history matching of observed pressures without the need for impermeable mudstones. Such lessons would prove valuable for design and predictive modelling of future CO2 storage projects.

Thermo-poro-mechanical Modelling for Fault Stability Evaluation

Silvia Monaco

In the context of greenhouse gas mitigation and transition towards renewable energy, the deployment of Carbon Capture and Storage (CCS) and geothermal energy systems are gaining momentum. Many studies have investigated the geomechanical implications of fluid injection into subsurface reservoirs, with the objective of minimizing the risks associated with hydraulic fracturing and fault reactivation, both of which may induce microseismicity.
A fault stability workflow is adopted in Eni by using Abaqus which allows for building the finite element geomechanical model and evaluating the stress evolution according to the pressure evolution applied as boundary condition at different time steps. The stress change on the analysed fault allows for understanding the fault behaviour in terms of stability. However, this standard approach, commonly used during field production operations, must be revised to account for the thermal effects introduced by the injection of CO_2 colder than the storage layers. Specifically, thermoelastic contraction of the rock matrix can lead to a reduction in effective normal stress on pre-existing faults, thereby increasing the likelihood of fault reactivation.
In the present work, thermal effects on reservoir geomechanical behavior during CO2 injection have been investigated. Thermal elements have then been introduced in the construction of the finite element geomechanical model to analyse the impact of decreasing temperature during CO2 injection; the temperature field, calculated by the fluid-flow simulator, is applied as boundary condition at different time steps in the geomechanical model while thermal and elastic properties are assigned considering reservoir rock characteristics. The methodology was first validated using a synthetic model, with results compared to analytical solutions. Then, a realistic model has been run to analyse the impact of decreasing temperature on the fault stability: results are shown both in terms of stress evolution on the fault and with reference to the slip tendency which is the indicator of the stability of the fault.

Session Six: Injection

Keynote – Project Poseidon CO_2 Injection Test: How We did it and what We Learned

Chris Furby

Project Poseidon represents one of the most strategic and capable CCS projects in the world. It aims to convert the UK's largest gas field, the Leman field, to a Carbon Store and where possible, repurpose existing infrastructure.

In Q1 2025, the Project Poseidon Joint Venture, operated by Perenco, successfully conducted a CO2 pilot injection test, injecting 3500 tons of CO2 into the ultra-depleted Rotliegend sandstone. Over a two-month period, CO2 was transported to the Leman site and injected from a jack-up rig with an injection spread into a recompleted, previously gas producing well. Cyclical injection was designed to evaluate the behaviour of CO2 in gaseous, supercritical, and liquid phases, and to monitor the behaviour of the storage unit to inform future development options.

The injection well was equipped with a comprehensive DAS and DTS downhole fibre-optic array and multiple pressure sensors to monitor CO2 behaviour from the wellhead to the reservoir perforations. DAS VSP and Spot Seismic technology was also acquired before and during injection to assess their efficacy as future MMV options.

The test achieved repeated injection at commercial rates and has significantly enhanced the understanding of CO2 phase management in ultra-depleted reservoirs, operational requirements, safety protocols, and MMV options for depleted reservoirs. This test is the first of its kind in the UK and has proven that CO2 injection is possible into mature UK, SNS gas fields.

How Selected Cased-hole Logging Delineates the Downhole Dynamics of CCS Wells During Brine and CO_2 Injection Tests

Saida Machicote, Marco Pirrone

Downhole well surveillance during Carbon Capture and Storage (CCS) processes is essential for ensuring the integrity and efficiency of carbon dioxide (CO_2) injection and storage. This study discusses a comprehensive monitoring approach for CO_2 injection wells, aimed at characterizing flow paths and identifying active reservoir units during preliminary brine injection and subsequent CO2 injection. The proposed approach considers data acquired using Pulsed Neutron Logging (PNL), High-Definition Temperature (HDT) profiles, and Advanced Noise Logging (ANL), during injection and shut-in phases. In this regard, time-lapse PNL is crucial for evaluating the fluid saturation changes behind casing and identifying the injected fluids in the reservoir from a static perspective. Conversely, from the dynamic standpoint, ANL is a key acquisition for mapping flow paths in complex borehole completions and recognizing active units. Then, HDT surveys often provide definitive proof for delineating the actual injection scenario. As evidence, a case study application is presented in which these advanced data acquisitions were performed during brine (prior to CO_2 injection operations) and CO2 injections. The integrated interpretation of these datasets provided valuable insights into well and reservoir behavior during the critical early phases of the ongoing CCS project. These findings proved valuable not only for this specific case, but also demonstrated the versatility and diagnostic power of the employed measurement techniques, as well as the importance of comparing the main findings from brine and CO2 injection scenarios.

Will Two-phase CO_2 Tubing Flow be Stable – Or Should it be Avoided?

David Hughes

Highly pressure depleted gas reservoirs are prime targets for CO2 storage especially in the UK. Injecting into such a low pressure environment will likely involve initially injecting the CO2 as a gas, but as the pressure in the reservoir increases this will no longer be possible. When the weight of the gas column minus the pressure loss from friction becomes insufficient to achieve the bottom hole injection pressure (BHP) required (for a given injection rate) then the fluid in the tubing will turn two phase (liquid below with equilibrium gas above). This will persist for intermediate reservoir pressures until the reservoir pressure has increased such that an all liquid CO2 column is necessary to achieve the required BHP.

The temperature of the CO2 is a very important consideration. For instance if the temperature of the CO2 is maintained significantly above the critical temperature (31.0 °C, 87.8 °F) throughout, then two phase flow in the tubing can be avoided altogether.

This might easily be achievable if, for instance, the CO2 temperature from the last stage of compression can be maintained through an insulated pipeline to the well head. However, if the CO2 arrives cold it would require additional undesirable capital and operating expenditure to heat the CO2 at the well head.

There is very little industry experience of two phase downwards tubing flow of CO2. This talk will review published experimental results and reported CO2 and acid gas disposal project experience.

Sub-surface Modelling of Formation Fluid Movement in Response to CO_2 Injection in, at and Around Legacy Wells

Liz Chellingsworth, Ed Stephens, Tim Wynn, Fiona Walker, Jackie Mullinor

TRACS evaluated the impact of pressure changes induced by CO2 injection on the movement of formation fluid at legacy wells in the Southern and Central North Sea. The evaluation was based on real world scenarios and plausible injection schemes.

Fluid escape rates depend on the expected pressure transients at the location of legacy wells and these are a function of caprock strength and formation architecture of the store. Scenario models were used to assess potential efflux and fluid escape rates. The scenarios combine stylised type columns for a variety of locales across the basins, and stylised fluid escape paths and cross flow paths. We used single and dual wells in Eclipse models to quantify the impact of the pressure transient on formation fluid in the wellbore and in nearby shallow permeable zones. The impact of faults connecting these zones to the environment was also assessed.

The key parameters affecting fluid escape volumes and rates are (1) the permeability-height of the shallow formations (2) the permeability of cement and (3) density of fluids in the store. Cement permeability may not be zero, for instance because of cement degradation over time; it is one of the largest unknowns spanning several orders of magnitude.

The results show variability in fluid efflux and fluid escape rates between locales. We investigated the effect of high salinity fluid in the Bunter on the movement of overlying low salinity formation. We noted the potential impact of halite creep in the SNS on sealing micro-annuli in halite sections.

DARTS-well: An Open-source Coupled Well-reservoir Model for Subsurface CO_2 Sequestration

Sajjad Moslehi, Siavash Kahrobaei, Rouhi Farajzadeh, Denis Voskov

Subsurface CO2 sequestration is a promising strategy for advancing carbon neutrality and accelerating the transition to sustainable energy. However, the distinctive behavior of CO2 during these operations, particularly in the case of cold liquid CO2 injection into depleted hydrocarbon reservoirs, introduces significant challenges related to wellbore injectivity and integrity. Addressing these challenges requires the development of a robust numerical model to gain deeper insights and optimize the interaction between wellbore and reservoir dynamics.
In this work, we introduce DARTS-well, an open-source, coupled wellbore–reservoir numerical model specifically designed for CO2 disposal in subsurface formations [Moslehi and Voskov, 2025]. The model begins with the development of a multi-segment, multi-phase, non-isothermal wellbore formulation based on the Drift-Flux Model (DFM), which is validated against the commercial transient wellbore simulator OLGA for selected CO2 injection scenarios. This wellbore model is then coupled with the Delft Advanced Research Terra Simulator (DARTS), a validated reservoir simulation platform widely used in energy transition studies [Khait and Voskov, 2017]. The coupled model employs the Operator-Based Linearization (OBL) method, using state-dependent operators for thermodynamic properties that are either interpolated from predefined tables or generated on the fly. This OBL-based parametrization efficiently handles complex physics while reducing computational overhead, making the model well-suited for simulating subsurface CO2 sequestration. To demonstrate the model's capabilities, we present simulation results for CO2 injection, including liquid CO2, into depleted hydrocarbon reservoirs.

Moslehi, S. and Voskov, D., 2025, March. DARTS-well: An Open-Source Coupled Wellbore-Reservoir Numerical Model for Subsurface CO2 Sequestration. In SPE Reservoir Simulation Conference (p. D031S011R002). SPE.
Khait, M. and Voskov, D.V., 2017. Operator-based linearization for general purpose reservoir simulation. Journal of Petroleum Science and Engineering, 157, pp.990-998.

Session Seven: CO_2 Storage in Basalts

Harnessing Igneous Geochemistry and Geochronology for Enhanced Carbon Sequestration in Basaltic Formations: From Mineral Dynamics to Global Scalability

Gaurav Kumar,

Basaltic formations have emerged as promising candidates for geological carbon capture and storage (CCS) due to their abundance of divalent metal cations (Ca^{2+}, Mg^{2+}, Fe^{2+}) that facilitate rapid and stable mineral carbonation. The CarbFix project in Iceland exemplifies this potential, achieving over 95% mineralization of injected CO_2 within two years (Matter et al., 2016).

This presentation explores the integration of igneous geochemistry and geochronology to enhance the predictability and efficiency of CO_2 sequestration in basaltic systems. We address the complexities of the "multi-source and multi-sink" inverse mass balance problem, where primary silicate dissolution releases cations that can form various secondary minerals, including carbonates, smectites, and zeolites. Laboratory experiments often lack quantitative data on the paragenesis and abundance of these secondary minerals, hindering accurate geochemical modeling. We advocate for the use of trace elements and multiple isotopic tracers, alongside advanced analytical techniques, to better constrain experimental data. Geochronological tools, such as U-Pb and Ar-Ar dating, are vital for understanding the natural alteration history and long-term stability of basaltic reservoirs. Factors like pH, temperature, pCO_2, water/rock ratios, and the existing weathering state of basalts influence reaction kinetics and mineralization pathways. Case studies, including the Deccan Traps and Columbia River Basalt Group, illustrate how geochemical and geochronological assessments can refine CO_2 storage capacity estimates and risk assessments.

By bridging the gap between experimental observations and modeling predictions through advanced geochemical and geochronological approaches, we can significantly improve the selection, characterization, and monitoring of basaltic formations for secure, long-term CO_2 sequestration.

Controls on CO_2 Storage Potential in the Antrim Lava Group, Northern Ireland

Jonathan Alexander, David McNamara, Elisabetta Mariani, Richard Worden, Mark Cooper, Graham Andrews,

In-situ mineral carbonation in mafic rocks offers a permanent and secure method of geological CO_2 storage. However, the rate and storage capacity of carbonation in such lithologies are strongly influenced by secondary alteration, porosity loss, and geochemical reactivity. This study assesses the Antrim Lava Group (ALG) in Northern Ireland, the most extensive mafic volcanic unit across the British Isles, for its suitability as a carbon storage reservoir. A national screening across the island of Ireland identified 29 geochemically feasible mafic and ultramafic lithologies, with the ALG as the most promising, based on scale, proximity to emitters, and favourable mineralogy. Petrographic and SEM-EDS analyses show unaltered ALG samples contain abundant forsterite, augite, and labradorite. However, alteration to iddingsite and clay minerals, along with pervasive Ca-rich zeolite precipitation, reduces effective porosity and may limit injectivity. Preliminary research, including logged borehole core data and outcrop fracture analysis, provides insight into fracture intensity and alteration at reservoir scales. These structural and mineralogical heterogeneities are key to understanding how CO_2 fluid-rock interactions may evolve during injection. Further work will assess whether secondary phases, such as zeolites, enhance carbonation via cation release during potential dissolution or inhibit injection by blocking flow paths. This study highlights the importance of integrating petrology and drill core data when assessing altered mafic reservoirs for carbon storage.

Poster presentation

Integrating Dissolved CO_2 Storage with Geothermal Energy Production: A Feasibility Study in Carbonate Reservoir

Sophie Godefroy, Si-Yong Lee, Carrie Holloway, Adeline Moignard, Arnaud Van der Beken, Nicolas Marty, Christophe Kervevan

Mitigating climate change through the reduction of greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), is paramount in addressing global warming. One approach is the geological storage of CO_2 in deep saline reservoirs that are not suitable for potable water use.
This study investigates the feasibility of co-injecting brine and CO_2 dissolved before reaching the reservoir into a geothermal energy zone within a carbonate reservoir, where geothermal doublet wells have been in operation for decades. The primary objective is to evaluate the potential integration of CO_2 storage with ongoing geothermal energy production, and to assess the interactions between these systems.
To this end, we utilized a high-resolution geocellular model of the study area (Catinat, 2023) and a high-resolution reservoir simulator. This model focused on the vicinity of the existing geothermal doublets. A series of reservoir simulations were then conducted to analyse the behaviour of CO_2 brine co-injection near these wells.
Our analysis focuses on understanding both the spatial and temporal evolution of the CO_2-dissolved plume, with particular attention to delineating the advancing front of the plume. Preliminary findings suggest that the plume resulting from the migration of dissolved CO_2 brine could reach the geothermal system, in particular the nearby doublets. Ongoing work is focused on optimizing the location of the CO_2 injection well within the geothermal region to minimize these risks and ensure the safe co-existence of both technologies.

Subsurface CO_2 Storage Potential of the Gas Shales from the Longmaxi Formation: An Integrated Geochemical, Geomodelling and Imaging Investigation

Maisie He, Dr. Sudeshna Basugupta

Carbon geological sequestration is integral to China's energy transition strategy and achievement of net zero. The objectives of this study are, to assess the CO2 storage potential of gas shales from Longmaxi Formation in Sichuan Basin China, and constrain how intrinsic shale properties can control their storage capacity. We determined the theoretical CO2 storage capacity of the shales to compare with saline aquifers from the same basin conducted in the formation and site scales also considering the shale intrabeds within the sandstone reservoirs and further constrained by geomodelling (with Permedia). The CO2 storage capacity of the three shale gas fields Changning (South), Weiyuan (Centre) and Fuling (East) areas can be up to 25 GT.

Core samples from the Pengye 1 well, located in the northeast where substantial sediment deposition occurred during upper Silurian were analysed for their composition, mineralogy and adsorption capacity, with detailed imaging of the pore structure. BET (Brunauer–Emmett–Teller) results suggest that specific surface area varies from 19 to 60 m^2/g decreasing progressively with depth from 2095 to 2140 m, correlated to the pore volume. The TOC content shows a weak trend of reduction with depth but given their very low (0.03 - 2 wt %) content, and association of pores with other phases identified using detailed imaging with SEM and CT scan, TOC cannot be the only controlling factor. We will discuss the factors controlling these variations in porosity in the context of composition, mineralogy and pore structure and its implications for the overall storage capacity.

Integrated Assessment Models Should Better Constrain CO_2 Geological Storage Projections

Iain de Jonge Anderson

The availability of large-scale CO_2 Geological Storage (CGS) strongly influences the feasibility and costs of ambitious climate pathways in Integrated Assessment Models (IAMs). IAMs describe transformation pathways across energy, land-use, economy, and climate systems, with CGS playing a central role in many scenarios. However, how IAMs handle CGS has faced recent criticism. Here, we examine how nine leading IAMs constrain CGS. We find high variability (> 75 %) in geological storage potential limits, driven by differing treatment of regions and reliance on outdated and/or methodically inconsistent sources. Literature based cost assumptions have recently been corrected upwards and may therefore be currently too low in IAMs, while CGS growth constraints are still being developed. We define a series of recommendations for the IAM community, as well as for the geoscience and engineering community, which will improve confidence in CGS projections and wider climate change mitigation pathways.

Geological Society
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