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7th International Workshop on Offshore Geologic CO_2 Storage

Technical Report 2025-TR01
January 2025

IEAGHG

About the IEAGHG

Leading the way to net zero with advanced CCS research. IEAGHG are at the forefront of cutting-edge carbon, capture and storage (CCS) research. We advance technology that reduces carbon emissions and accelerates the deployment of CCS projects by improving processes, reducing costs, and overcoming barriers. Our authoritative research is peer-reviewed and widely used by governments and industry worldwide. As CCS technology specialists, we regularly input to organisations such as the IPCC and UNFCCC, contributing to the global net-zero transition.

About the International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate is twofold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy. The IEA created Technology Collaboration Programmes (TCPs) to further facilitate international collaboration on energy related topics.

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This report was prepared by Angela Luciano, and edited by Nicola Clarke, Tim Dixon and Katherine Romanak

IEAGHG would like to thank the Steering Committee for their efforts in facilitating this workshop:

- Tim Dixon, IEAGHG (Chair)
- Katherine Romanak, BEG (Co-chair)
- Nicola Clarke, IEAGHG
- Susan Hovorka, BEG
- Tip Meckel, BEG
- Owain Tucker, Shell
- Paulo Negrais Seabra, Independent Consultant, Brazil
- Darin Damiani, US DOE
- Sarah Leung, US DOE
- Charles Jenkins, CSIRO
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International Workshop on Offshore Geologic CO_2 Storage

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Greater PORT ARTHUR CHAMBER OF COMMERCE

In person attendees to the 7th International Workshop, Port Arthur, Texas

Baker Hughes

carbon ventures

ExxonMobil

VIRIDIEN

U.S. DEPARTMENT OF ENERGY | Fossil Energy and Carbon Management

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Executive Summary

The 7th International Workshop on Offshore Geologic CO_2 storage was held in Port Arthur, TX on September 17-18th, hosted by the Port Arthur Chamber of Commerce and co-organized by the University of Texas and the IEAGHG. There were around 60-70 in-person attendees, with over 200 participants joining online.

This workshop was established 8 years ago to promote knowledge sharing about offshore CO_2 storage. The first workshop was held in 2016 in Austin, Texas, followed by workshops in Beaumont, Texas (2017), Oslo, Norway (2018), Bergen, Norway (2020), New Orleans, Louisiana (2022), and Aberdeen, UK (2023). Over the years, the workshop has grown to involve over 30 international CO_2 storage projects from countries like Norway, the Netherlands, and the United States.

There is a lot of storage potential offshore and there are many benefits to offshore storage. Often close to the industrial areas where a lot of the sources are and many legal aspects such as pore space ownership is more straightforward. Port Arthur was chosen as this year's as it is a large energy hub with rapid developments in CCS.

With over 20 offshore CCS projects, both commercial and research-focused, discussed in presentations representing 12 countries, key topics included challenges and solutions related to depleted oil and gas fields, shipping for offshore injection, public engagement strategies, risk management concerning potential leakages, challenges associated with CO_2 phase changes, well risk management exercises, CO_2 stream analysis, and regulatory frameworks.

Day 1

Session 1: Welcome

The 7th International Workshop on Offshore Geologic CO_2 Storage kicked off with a warm welcome from hosts Joe Tant, CEO of the Port Arthur Chamber of Commerce, and Dr Betty Reynard, president of the Lamar State College, Port Arthur. With 742 energy facilities, Port Arthur is the energy hub of Texas, the region is proud of its success and proud to be part of the energy sector and has a close relationship with the facilities and keen to be part of the future direction of energy transition.

Tim Dixon and Katherine Romanak, co-chairs of the workshop series, followed. This workshop now running for nearly a decade, started as an initiative from the University of Texas and the Carbon Sequestration Leadership Forum, and the workshops began in Austin, Texas, in 2016 and has since been held in various locations, including Beaumont, Texas (2017), Oslo, Norway (2018), Bergen, Norway (2020), New Orleans, Louisiana (2022), and Aberdeen, UK (2023). Over the years, the series has seen significant advancements in CCS technologies and their applications.

At the previous workshop in Aberdeen, several significant conclusions were reached. Despite the development of numerous CCS projects, the global scale remains insufficient to meet the growing demand and the critical role that CCS must play in mitigating climate change. A strategic approach to spatial resource allocation, especially when considering competing marine activities, is essential. Additionally, the permitting process needs to accelerate to keep up with the urgency of CCS deployment. Other insights highlighted that a 'Just Transition' is being recognized with CCS projects, MMV plans are maturing - with early projects setting precedence - and community engagement is essential for success. Confidence in environmental monitoring tools is growing, but innovative solutions are needed in locations with other use of the marine environment, as demonstrated by challenges in the North Sea, where seismic monitoring access has been restricted due to wind farm development.

This year, Port Arthur, TX was selected as the site for the workshop due to its prominence as a major energy hub with extensive infrastructure. Several large-scale CCS projects, both onshore and offshore, are slated for launch in the region. The workshop will conclude with a field trip to tour several of these facilities and the pump station of the existing CO_2 pipeline, offering a glimpse into the area's future CCS development.

Session 2: International Project Roundup

Gulf of Mexico - Tip Meckel, GCCC

The Gulf of Mexico (GoM) is a major hub for energy technologies, many of which intersect with CCS. The abundance of methane from the shale gas revolution has positioned the region as a global leader in LNG exports, while methane cracking is expanding hydrogen production and driving ammonia production. The Department of Energy is also investing $7 billion in hydrogen projects, creating hubs throughout the United States.

Future developments are likely to include exporting energy products like LNG, hydrogen, and ammonia, and potentially importing CO_2 by vessel for storage in the GoM. The GoM basin's geology provides extensive opportunities for CO_2 storage both onshore and offshore. One important consideration of development in the regions is to stay above the overpressure zone.

Several projects are already underway in Texas state waters, such as the Bayou Bend Project, operated by Chevron, TotalEnergies, and Equinor, which has drilled the first offshore CCS characterization well in the U.S. just off the coast of Port Arthur. ExxonMobil, BP, and Repsol are among the companies holding leases granted by the Texas General Land Office (GLO), which has leased substantial acreage for CCS, generating significant revenue through lease bonuses and anticipated royalty payments, which would fund around $10 billion into the Permanent School Fund. In 2024, the GLO released 13 additional tracts, signalling significant growth, ongoing development, and more to look forward to in the future.

CarbonNet Pelican Project - Scott Bailey & Vic Fitzgerald, Govt of Victoria

Australia faces significant emission reduction goals, aiming for net-zero by 2045. Looking particularly at Victoria, key contributors to emissions include electricity, oil and gas, and mining. They have achieved a 30% reduction in emissions since 2005 and plan to phase out coal-fired power in the 2030s, while boosting renewable energy. Additionally, Victoria is exploring opportunities for CCUS in depleted oil and gas fields, as well as saline aquifers. Near-term decarbonization targets include low-carbon hydrogen, ammonia, and urea production, while long-term goals focus on achieving negative emissions and importing CO_2.

The CarbonNet project is a key offset project being explored for Victoria and the Gippsland region. The project will use a 100-kilometer pipeline to reach the Pelican reservoir, which is located 10km offshore. It will store up to 168 million tons of CO_2, ramping up to 6 million tons per year. The project has completed its front-end engineering design (FEED) and is conducting geotechnical studies and market sounding to engage potential stakeholders.

The project focuses on decarbonizing existing industries and creating jobs while addressing the economic impact of shutting down coal plants in the Gippsland region. Future goals include further developing the permits for CO_2 storage, a regional biostratagraphical study, working on environmental impacts, and more.

Taiwan - Cheryl Yang, ITRI

Taiwan is creating a legal and business environment in response to the 2023 Climate Change Response Act. Taiwan's Ministry of Environment is working on national carbon management regulations, including carbon trading and carbon fees for entities emitting more than 25,000 tons of CO_2 annually.

Storage resource estimations of potential saline aquifer formations were made using the DOE's CO_2 Screen Tool and has identified offshore formations as promising areas for CO_2 storage, particularly in the Taishi Basin. However, potential conflicts with wind farms in this region will be examined. Two CCS test sites are planned: one at the TPC Taichung power plant and another at the CPC Tiehchenshan gas field. Both are targeting saline aquifers, and although there are some CO_2 source uncertainties, injection and monitoring wells at both locations are planned for next year in 2025.

Pre-feasibility studies have identified the most geologically preferred areas and there are plans for further studies in some of those regions. There are further research ongoing with the Industrial Technology Research Institute such as fiber optic sensing for monitoring applications. Although no wells have been drilled yet, near-surface DAS monitoring at the TPC site is ongoing, providing valuable insights for future developments.

South Korea - Eunsoo Jung, KCCUS

South Korea's Carbon Neutrality Pledge for 2050, made in 2020, has reached key milestones, including the enactment of the Carbon Neutrality Framework Act in 2021 and the CCUS Act in 2024. They have outlined two scenarios for carbon neutrality by 2050 and have a short-term goal of reducing CO_2 emissions by 11.2 million tons by 2030. The CCUS Act integrates regulations across industries to promote a cohesive approach to CCUS.

The government is advancing the East Sea CCS Project, an integrated demonstration targeting CO_2 capture from industry and power plants for injection into a depleted gas field, with plans to begin injection by 2028 and scale up to 1.2 million tons per year. Additionally, South Korea is exploring transborder CCS with partnerships in Australia, Malaysia, and Indonesia to overcome storage capacity limitations.

The CCU Mega Project aims to develop a business model by demonstrating the integration of CO_2 emitters with CCU producers and demanders. Led by a consortium of various entities, the project plans to process over 4,000 tons of CO_2 annually starting in 2026. Additionally, the Korea CCUS Association, consisting of 80 members from government, industries, and institutions, plays a crucial role in supporting policy-making, R&D, and fostering connections with both domestic and international stakeholders.

Petrobras' CCUS projects in the offshore scenario, Brazil - Andrea Pontual de Oliveira Wydmann, Petrobras

Petrobras currently produces 2.17 million barrels of oil per day, with 78% of this production coming from offshore pre-salt reservoirs. These reservoirs offer opportunities for low-carbon production, using advanced separation and injection technologies to capture and reinject CO_2 into the reservoirs from offshore platforms.

In 2023, they have successfully reinjected 13 million tons of CO_2, which made up 25% of global CCS injections, with a goal of reaching 80 million tons by 2025. The company aims to decarbonize its offshore operations through post-combustion CCS from the natural gas used to generate power on ships, with plans to connect FPSOs (Floating Production Storage and Offloading units) to Brazil's predominantly renewable electric grid. Petrobras is also exploring onshore CCS, viewing hubs as a future business model to provide storage and transportation services for other industries, particularly in Brazil's industrialized southeastern region.

An R&D project in Rio de Janeiro will test CO_2 injection into saline aquifers, helping shape Brazil's upcoming CCS regulations. This project aims to evaluate different monitoring technologies for injected CO_2 and support regulatory development. The pilot will capture around 100,000 tons of CO_2 per year, transport it via a 68 km pipeline, and inject it into an onshore well with three monitoring wells.

Malaysia - Haylay Tsegab Gebretsadik, Universiti Teknologi PETRONAS, Malaysia

Malaysia is one of the signatories of the Paris Climate Agreement and has significant gas fields with high CO_2 content, making it an ideal candidate for CCS. The goal is for Malaysia to become a CCS hub in the region, with several maturing fields which can be used as depleted reservoir sites for CO_2 storage.

The Kasawari field, discovered in 2011, is located in Central Luconia and is estimated to contain approximately 3 trillion cubic feet of recoverable gas, with a substantial portion being CO_2. It has many subsurface characteristics that make it suitable for CCS, and this depleted field is estimated to be able to store about 80 MT over 25 years at a rate up to 3.7 MTPA, contributing to the country's aim of achieving net-zero carbon emissions by 2050.

The Kasawari CCS Project is set to become the world's largest offshore CCS project upon its commencement in 2025. Ongoing partnerships with PETRONAS, ADNOC, Storegga, and other international entities aim to develop CCS and establish a regional hub. Moving forward, they will explore saline aquifers for CO_2 storage and address technical barriers, economic constraints, as well as regulatory and policy issues.

Woodside, Australia - John Fox, Woodside

Woodside has committed to investing $5 billion by 2030 in new energy products and lower carbon services. The investment strategy focuses on facilitating the energy transition, with Woodside serving as Australia's largest natural gas producer and the 15th largest LNG exporter globally. Efforts include investments in technology and collaborations aimed at enhancing CCS capabilities, a recent partnership with OCI in Blue Energy, and more.

Woodside's CCS initiatives in Australia currently involve 5 offshore CCS projects, providing access to over 11 million acres of pore space. These projects involve various partnerships to drive technology development. The five projects are the Sea CCS/Bass Strait project awarded in 2024, the Exmouth CCS awarded in 2024, the Bonaparte Basin awarded in 2022, the Angel CCS project awarded in 2022, and the Browse Basin awarded in 2022.

The Angel Project, located offshore in northwest Australia, was highlighted as a particularly promising site, projected to inject up to 5 million tons of CO_2 annually. Favorable geological features, including a four-way closure and proven seals, support safe CO_2 storage, and the depleted gas field offers extensive reservoir data. With minimal legacy wells in the area, this project represents a significant opportunity for Australia.

Bayu-Undan, Timor Leste - Tim Dixon, IEAGHG

Timor-Leste, a relatively new island nation established in 2002, is located north of Australia and has relied on the Bayu-Undan gas field as a significant income source for the past 20 years. However, production is set to cease early next year due to depleting reserves.

The gas field is connected to mainland Australia at Darwin by a 500-kilometer pipeline, where Santos operates the facility that processes gas for liquefied natural gas (LNG) production. Once production ceases, the plan is to capture CO_2 from other sources and transport it back to Timor-Leste for storage using the same pipeline. This initiative is crucial for Timor-Leste as the country seeks new income streams following the decline in its natural gas production.

Many institutions are helping develop and support this project. They are in the capacity development stage, and the oil company, Timor Gap, is moving toward joint operation of the gas field with Santos and has signed a memorandum of understanding with a Korean company to potentially source CO_2 from Korea. The ongoing efforts focus on building commercial contracts with CO_2 suppliers to strengthen the carbon capture and storage initiatives in Timor-Leste.

Discussion/Questions 1

A question from the audience regarding penalties and incentives highlighted that these vary by country, but Article 6 of the Paris Agreement can provide a framework for countries to establish cooperative approaches that encourage climate action through internationally transferred mitigation.

Another question from the audience inquired about what long-term liability looks like in different countries. However, this varies by country, and many are still in the process of developing their frameworks.

Sleipner, Snøhvit, Smeaheia, Northern Lights & Kalundborg, Norway and Denmark - Michael Schoemann, Equinor

Equinor reaffirmed its commitment to transitioning towards a net-zero emissions target by 2050, during their spring capital markets update. This strategy focuses on three pillars: accelerating growth in renewables, optimizing the oil and gas portfolio, and developing new markets and low-carbon solutions. Equinor has doubled its ambitions for CO_2 storage and sequestration, increasing the target from 15 million tons to 30-50 million tons per year, equivalent to Norway's yearly emissions. This presentation provided updates on several projects.

Sleipner, located in the southern North Sea, has been operational since the early 1990s. CO_2 sequestration was implemented due to the high CO_2 content of the gas, which could not be flared because of taxes. To date, approximately 20 million tons of CO_2 have been stored. Similarly, the Snøhvit gas field in the Barents Sea transports gas onshore, where CO_2 is removed at an LNG plant and then stored back in the Snøhvit field. Approximately 8 million tons of CO_2 have been stored there to date. The Northern Lights project was born from the Longship project to demonstrate a large-scale CCS value chain for sequestration. The project will be ready to receive CO_2 within the month and results confirm that the reservoir can receive at least 5 million tonnes CO_2 per annum.

There are also several future projects being developed. The Smeaheia project is currently preparing to drill 2 appraisal wells with a concept to be a hub with CO_2 transportation by ship. There is an ambition to mature the reservoir to inject up to 20 MTPA. The CO_2 Highway Europe involves a pipeline from France and Belgium which would supply CO_2 back to Smeaheia as the main hub. Lastly, the CO_2 storage Kalundborg onshore is being evaluated for storage potential.

PilotSTRATEGY - update on the design of the offshore CO_2 injection site in Portugal - Pedro Miguel Pereira, Universidade de Evora

The PilotSTRATEGY project is a five-year R&D effort ending in 2026 funded by the European Commission, aimed at scaling up CO_2 storage in several Western and Southern European countries. The project involves multiple institutions across seven countries and includes detailed studies for three pilot injection wells located in Portuguese, French, and Spanish regions, as well as enhancing the maturity of storage capacity in deep saline aquifers primarily in Poland and Greece.

The Q4-TV1 offshore study area is situated approximately 20 kilometers from the shoreline of Portugal, in the northern part of the Lusitanian basin. The focus is on assessing saline aquifers composed of lower Cretaceous siliciclastic deposits. The project encompasses a 250 square kilometer prospect, offering potential for scaling from pilot to commercial CO_2 injection operations. The presence of a legacy well and bounding faults near the reservoir structure introduces risks that require thorough evaluation, including leakage scenarios that will be addressed in future phases.

The recent development of a 3D static model helps infer rock properties and supports an optimization approach for well placement. The project's goal is to inject up to 16 megatons of CO_2 over a 30-year period, extending the simulation of the long-term dispersion of the CO_2 plume for 1,000 years after the injection period to ensure safety regarding the legacy well and surrounding faults. Initial plans include injecting up to 100 kilotons of CO_2 within three years, while exploring options for commercial storage.

Transporting CO_2 via ship for direct injection is also under consideration as a temporary solution during the pilot phase to increase operational flexibility until a pipeline network is developed for large storage volumes. This approach necessitates collaboration with local stakeholders, such as port authorities and municipalities. Key challenges identified include ensuring a reliable CO_2 source at the pilot scale, increasing public awareness of carbon capture and storage (CCS), and navigating the complex offshore regulatory framework, which differs from onshore regulations.

Porthos, The Netherlands - Willem-Jan Plug, EBN

The Porthos project, located offshore Rotterdam, aims to inject 2.5 megatons of CO_2 annually ifor 15 years. The project's total capacity is 37 Mtons over 50 years, with additional capacity in infrastructure for future developments.

Construction began in January 2024 after achieving Final Investment Decision (FID) on October 17, 2023. Key infrastructure includes a 30 km onshore pipeline, a compressor station, an artificial island for offshore operations, and a 22 km offshore pipeline to transport CO_2 under high pressure. Offshore pipeline installation is scheduled for mid-2025, with full operational readiness anticipated in the first half of 2026. They will first inject in gaseous conditions and after about 2 years continue in the denser phase.

The project faces unique challenges as it is the first of its kind for injection into depleted gas fields, requiring new legislation and technical solutions. Ongoing business development alongside project construction creates pressure to achieve rapid operations while keeping future options open.

Aramis, The Netherlands - Anneke Kleinpenning, Shell

The Aramis project aims to decarbonize industries in The Netherlands, Germany, Belgium, and others that can transport to the location by leveraging the infrastructure of the Porthos project, which includes an onshore pipeline and compression station. The Aramis line will connect multiple emitters to offshore storage sites and incorporate cryogenic CO_2 transport capabilities.

The storage capacity landscape in Europe indicates that achieving global climate goals by 2050 will require over 100 gigatons of storage capacity. In the Netherlands, about 20% of the total storage capacity is located in depleted fields, mostly in the North Sea. Challenges arise in transporting CO_2 from remote offshore sites which necessitate dense phase transport.

The Aramis transport line is designed to transport up to 22 MTPA and estimations show a storage capacity of around 600 Mtons over 30 years. While FEED started in late 2023, permitting processes may lead to potential delays, pushing operational readiness to 2029. The project will initially connect with two to three lounge storage sites and plans to accommodate up to 15-20 emitters.

Greensands, Denmark - Soren Reinhold Poulsen, INEOS Energy Denmark

The recent developments in Denmark's Greensands project have been significant. Following the completion of a pilot project, plans are underway to establish the first commercial project. In addition to this, ongoing port developments are in progress, and exploration licenses for CO_2 have been awarded. The Greensand project involves converting existing hydrocarbon producing reservoirs, which were previously inactive since 2018, into sites for CO_2 injection. Preliminary studies have established the feasibility of injecting CO_2 at high rates and monitoring its behavior within the reservoir.

The first commercial project aims to utilize multiple reservoirs with the potential to store up to 8 million tons of CO_2 over 10 to 15 years. Lessons learned from the pilot project, which involved transporting CO_2 from Belgium, have informed the design of the new commercial venture. The focus for the new commercial project will include biogenic CO_2 sourced from biogas producers in Denmark. A storage site application has been submitted for approval, with anticipation of project sanctioning by the end of the year. Plans for construction in 2025 include a modified bulk carrier which can transport around 5000 tCO2/trip with an opportunity for injection of 0.3-0.4 MTPA pending logistical set-up. They are aiming for the first injections to occur in early 2026.

UK Poseidon and Orion transport and storage projects - Nick Terrell, Carbon Catalyst

The Poseidon and Orion projects in the UK's North Sea aim to play a significant role in decarbonizing the industrial and power generation sectors in the UK. The current landscape of CCS deployment in the UK consists of three groups of projects with varying timelines and strategies. Track 1 and Track 2 projects involve more government funding in the business model while later projects like Poseidon and Orion move towards market-driven mechanisms as the government reduces its involvement.

An overview of Perenco, the operator of both projects, is a major player in the UK energy sector, responsible for about 10% of the country's domestic supply. The company operates numerous offshore fields and strategically important gas processing terminals. Poseidon is located 30 to 40 miles off the coast of East Anglia, focusing on decarbonizing East Anglia, London, and continental Europe, while Orion, located 80-90 miles north of Poseidon, targets the Humber region, the UK's largest industrial cluster, known for significant CO_2 emissions.

Poseidon, centered on the depleted Leman gas field, has an anticipated storage capacity of 935 million tons with a peak injection rate of 40 Mtpa over 38 years. The project's development includes extensive appraisal work to assess risks and prepare for a storage permit submission by 2027. The goal is to commence CO_2 injection by 2029, offering transport and storage services to various customers in the region and neighbouring countries.

The Orion project targets the emissions from the Humber industrial cluster, utilizes 2 legacy depleted gas fields for storage, and will implement infrastructure reuse to lower capital expenditures. The license for Orion was awarded in August 2023, and an appraisal work program is underway to characterize the storage facilities and develop the concept further, aiming for a storage permit by 2029 and first injection by 2031.

Prinos and The Mediterranean - Nikolas Rigas, EnEarth

The Prinos project aims to convert a legacy oil-producing asset in Greece, operational since the 1980s, into a CO_2 storage site. This site is significant as it represents the only oil-producing asset in Greece, and the project is designed to maintain jobs while transitioning to carbon storage.

The project has gained recognition as a project of common interest by the European Union and has received government funding to support its development. Currently, there are nine emitters signed onto the project, which together total 5.4 million tons of CO_2 emissions. Notably, four of these emitters have also secured funding from the Innovation Fund, which has helped establish a value chain for emissions and storage. EnEarth applied for a storage license two years ago and submitted a conversion application in July 2024. The company expects to receive full storage licensing by the end of the year, with construction slated to begin in mid-2025 and operational readiness targeted for 2028-2029. The project anticipates a total sequestration capacity of up to 3 million tons of CO_2 per year, which will address approximately 10-30% of Greece's industrial emissions.

The project is alone in the East Mediterranean and faces both advantages and challenges being the sole storage solution. As EnEarth works towards establishing a regional hub for CO_2 storage, the company has formed technical service agreements with its parent company, which operates major gas fields throughout the Mediterranean. This hub is strategically positioned near major emitters in multiple countries in the Med. Looking to the future, they are working to create a "green zone" in the region.

NETL Offshore CO2 Storage Inventory - Julia Mulhern, NETL

The National Energy Technology Lab discussed ongoing initiatives to inventory offshore CCS projects and their characterizations and to provide data collection resources. The project is part of a broader mission to curate data and develop tools that advance CCS technologies.

The inventory encompasses actualized projects and various characterization studies accessible through the Energy Data Exchange which details various offshore projects. It is composed of an ArcGIS Spatial Layer (live on EDX), an interactive Web Map (live on EDX), and an Interactive Dashboard set to be published in January.

The work is ongoing and welcomes feedback to improve the inventory's accuracy and usefulness. The attributes included in the inventory have been expanded from previous versions, now featuring details about rock properties, porosity, permeability, and other relevant characteristics. This expansion aims to facilitate comparative analyses and enhance collaboration among stakeholders in the CCS community. Looking ahead, the dashboard will enhance the web map by providing live graphics and updates based on user interactions, thereby facilitating project comparisons and analog selection.

Inventory website:https://edx.netl.doe.gov/dataset/offshore-gcs-data-inventory

The data collection includes Web Apps, primarily for the U.S., featuring nine web maps sorted by data categories as well as a Data Gaps Assessment Report documenting the development process. Once again, contributions from the community are encouraged to include additional publicly available data in their resources.

Project Round Up- Global Progress - Nikki Clarke, IEAGHG

This presentation offers an overview of various global offshore CCS projects.

In Australia, the Cliff Head project is entering the FEED stage and has received Australia's first project license and additional licence area.

In China, the country has over 120 CCS demonstration projects, with its first offshore project Enping operational since June 2023, injecting 60,000 tons as of December 2023. They have a capacity of 30,000 tons per year and a total of 1.46 planned to be injected. Additionally, the Daya Bay project is a CCS cluster research project of up to 10 millions tons.

In Thailand, the Arhit gas field has completed the FEED study, advancing its first CCS project, aiming to start operations by 2027. Also, PTTEP has announced plans to study storage potential in the Northern Gulf of Thailand.

In Indonesia, a CCS project in the Sunda-Asri Basin is expected to reach a final investment decision by 2026.

In Japan, the Tomakomai project and other plans are in place to develop CCS technologies, with intentions to export CO_2 to neighboring countries.

In Bulgaria, the ANRAV Project is a complete CCS initiative involving cement transport and storage into depleted fields in the Black Sea.

In Denmark, the appraisal phase of the Bifrost Project has been completed, estimating 2-3 million tons per year with transportation planned via repurposed pipeline or direct injection.

In Ravenna, Italy, they have commenced a pilot-scale injection with CO_2 transported by a repurposed gas pipeline. Phase 2 of this project aspires to reach 4 MTPA by 2030.

In Norway, several active projects are under development, with new license rounds recently announced.

In the Netherlands, the Porthos and Aramis projects are advancing, and Shell has acquired new blocks for CO_2 storage in saline aquifers which would tie into the Aramis infrastructure.

In the United Kingdom, 14 companies were awarded 21 storage licenses last year and the Crown Estate has launched a comprehensive seabed resource initiative aimed at optimizing resource use. The CO_2 Transportation and Storage Task Force's industry review, published in August, offers recommendations to optimize the timeline for storage development. Track 1 funding licenses were granted to Liverpool Bay and the Endurance Field. They are both expected to reach their FIDs soon.

Discussion

Question: What's happening with the NETL maps displaying mid-ocean ridge basalt projects? Are these active projects or studies?

Answer: The data in the map includes any/all information available which includes rough estimations from general studies, characterization studies, etc, eventually there will be a filter available to allow users to sort between projects and/or studies.

Question: Why is CO_2 transport and injection in the gaseous phase preferred in the Portos project?

Answer: Gaseous injection was chosen due to low reservoir pressure. To avoid severe cooling at the wellbore, the injection begins in the gaseous phase and later, give or take 2 years, will transition to a dense phase.

Question: What work has been done on direct injection via shipping for the Poseidon project?

Answer: The team is actively exploring the potential for direct injection, but the focus is currently on infrastructural reuse and transferring CO_2 from ships to the wellhead.

Question: What well integrity challenges have been faced in the Porthos project due to downhole pressure and temperature regimes during CO_2 injection?

Answer: Two main challenges were highlighted: the possibility of forming hydrates near the wellbore and the risk of losing the bond between the cement and casing caused by cooling effects.

Session 3: Challenges and Solutions to Injecting CO_2 into Depleted Fields in the Offshore

Poseidon Project - UK's first well injection test - Nick Terrell, Carbon Catalyst

The Poseidon project is currently focusing on upcoming well injection tests at the Leman reservoir. This will be the first of its kind in the UK, involving the injection of CO_2 in both gaseous and dense phases into a highly depleted offshore gas reservoir. The project aims to collect data that will enhance understanding of CO_2 behavior and support the wider CCS sector.

Preparations are underway to inject approximately 5,000 to 6,000 tons of CO_2 over a 90-day period, starting late 2024. The data collected will be vital for assessing well, reservoir, and monitoring aspects. The project will also evaluate the potential for reusing existing gas production wells, the thermal effects of CO_2 on the wellbore, sustainable injection rates, and the impacts of CO_2 phase changes on the reservoir. New monitoring technologies, such as fiber optic systems, will be tested to gather real-world empirical data essential for model calibration.

The CO_2 will be supplied primarily from a facility in the Netherlands and transported via truck to a shipyard in Belgium before being loaded onto a supply vessel for delivery to the injection site. The target is 2 reservoirs within the Leman sandstone reservoir with both zones perforated and separated by a packer. The injection will begin with cold gaseous CO_2, progressing towards liquid CO_2, as understanding how these phases transition is key to optimizing the liquid phase injection process. This transition management is critical due to the reservoir's depleted state, which may cause liquid CO_2 to revert to gas once it enters the formation.

A comprehensive data collection strategy will involve various monitoring technologies, including pressure gauges, flow meters, DTS fiber optics for temperature, distributed acoustic sensing for seismic measurements, and more. Ensuring effective data management, visualization, storage, and real time decision making will be a crucial aspect of the operation.

Questions

The questions following the Poseidon project presentation were mainly focused on the complexities that arise with CO_2 phase changes. There are volume and temperature changes depending on the phase and require different methods of handling. Different phases have different costs and uncertainties associated with them that needs to be considered.

Question: Designs question, why are so many CO_2 tanks placed on the offshore asset?

Answer: The decision was made to have intermediate storage on the platform for better operational flexibility. This approach also accommodates the logistics of CO_2 supply in winter, when weather challenges arise.

Question: What fluid testing is being done, and are there any uncertainties related to fluid reactivity?

Answer: Compositional modelling has been done, but some uncertainties remain, particularly with fluid behavior during injection.

Question: Is seawater being used as a heating medium to warm cryogenic CO_2, or is it all electric steam?

Answer: The system relies on electric steam for heating.

Question: Will the collected data from this pilot project be published and shared with the wider industry?

Answer: The team plans to share the data, with some elements subject to UK data release guidelines.

Challenges of CO_2 injection into Depleted fields - Owain Tucker, Shell

Depleted fields present many advantages for CCS, notably the presence of existing infrastructure like wells, platforms, and proven seals that have securely held hydrocarbons for millions of years. Previous production activities also yield valuable data, helping to lower risks in new storage projects and saving time and resources by reusing assets. However, wells in these fields also pose challenges. This presentation focuses on well integrity, and phase behavior.

We need to consider the interaction of legacy wells with the natural geologic system. Many old and abandoned exploration wells lack modern records, making it difficult to demonstrate subsurface isolation. Sidetracked wells may also create risks for CO_2 storage if their original wellbores (termed mother bores) weren't adequately isolated. Additionally, reusing infrastructure might sound attractive but requires an objective analysis: balancing the cost, effort and effort to maintain the facility integrity and the reliabilty required to continue operations (think "second hand car"). Platforms and wells experience corrosion, fatigue, wear, and geomechanical issues, complicating their reuse in new projects.

CO_2 injection differs from hydrocarbon production. From a safety perspective, the considerations made to accommodate the risks associated with hydrocarbons are different from that for CO_2. Additionally, CO_2 undergoes phase changes (gas, liquid, supercritical) in the operating range – contrast this to methane which is in the supercritical region. These transitions can introduce risks, such as extreme cold temperatures that could lead to freezing or hydrate formation in the wellbore. Special care with injection pressure and temperature is essential, especially in ultra-depleted gas fields with very low pressures, to maintain well integrity. There are three broad categories of depleted fields, hydrostatic, moderately depleted, and significantly depleted.

Fields with moderate depletion or strong aquifers, such as Goldeneye, are good candidates for CO_2 storage owing to their tendency to repressurize more easily, and the presence of residual oil or gas which offers added compressibility for storage (compared to water filled pores). In ultra-depleted fields, however, CO_2 injection is more complex, necessitating special measures like temperature management to prevent hydrate and water ice formation.

Regulatory requirements for depleted fields focus heavily on well integrity, where maintaining thorough records is essential for future operations. When reusing fields, it's critical to ensure future decommissioned wells won't compromise the storage formation. Effective pressure management balances the need to prevent well damage with the goal of maximizing storage capacity.

Questions

Question: Does it matter that some portions of a depleted field were not within the supercritical depth and temperature range, especially since they were managing pressure artificially.

Answer: It doesn't significantly matter if the storage formation is shallower than preferred. The only impact is that less CO_2 can be stored because of the lower volume at shallow depths. Note that in shallow areas, the rock strength becomes a factor, as weaker rocks are more susceptible to pressure changes.

Storage in depleted fields - Discussion led by Susan Hovorka, GCCC

The discussion aimed to gauge the audience's perspectives toward CO_2 storage in depleted fields, highlighting both the advantages and disadvantages. A quick poll assessed favorability, with responses ranging from very favorable, to considering it, to negative. Between the in person and online comments, 23 voted very favorable, 15 voted in consideration, and 3 voted negative.

Among the online voters, Europeans leaned towards very favorable while Canadians and Americans leaned towards consideration. In person, most votes leaned towards very favorable and were largely represented by Americans. Representatives from Australia, Malaysia, and Nigeria each voted in high favorability. There was some discussion surrounding what depletion means because oftentimes it's described in terms of economic viability, not the resource.

Next, the advantages and disadvantages of using depleted fields for CO_2 storage were discussed.

Key advantages included: 1) known site with established capacity and pressure response, 2) proven seal with a well-understood closure on the trap, and 3) existing infrastructure such as wells, platforms, and pipelines. Most participants favored the first option — the known site.

Expanding on how using a known site reduces project risks, attendees highlighted several benefits: the injectivity and storage capacity are already understood, eliminating the need to gather porosity or permeability data which can save on exploration costs. Instead of relying on analogue data, real site data is available, and the reservoir's response is well-known. Attendees also noted that even if it's not a specific site, working within a familiar basin in general, like the Gulf of Mexico, offers advantages.

Beyond the technical/geological advantages, attendees also pointed out that existing infrastructure may lead to less community opposition and fewer permitting challenges, as communities are already accustomed to such projects. Moreover, communities often rely on these resources, so when oil and gas production declines, the storage resource can provide a new revenue stream. Additionally, depleted fields come with established leases and defined trap acreage, adding to their appeal for CO_2 storage projects.

Key disadvantages of using depleted fields that were discussed included: 1) Existing (legacy) infrastructure, 2) Pressure depletion and phase behaviors, 3) closure preserves CO_2 mobility (i.e. minimal dissolution and capillary trapping), 4a) existing hydrocarbons posing as an environmental risk, and 4b) existing hydrocarbons limiting monitoring. In a poll, option 1 received 16 votes, option 2 received 8 votes, option 3 received 2 votes, option 4a received 7 votes, and option 4b received 4 votes.

Further discussion among attendees highlighted concerns about the assumption that porosity and permeability remain constant over time. Examples from Europe and the Gulf of Mexico (GoM) demonstrated that reservoir characteristics can change during injection compared to the conditions during original production. Additionally, if a reservoir is left idle after production and before reinjection, its properties will change. Online comments pointed out that tail-end gas production is highly dependent on gas prices, and aligning the timing between the end of production and the start of injection is critical. Also, unlike some large sites in the North Sea, many depleted fields in the GoM are relatively small and will not be viable for CO_2 storage.

Additional comments on the disadvantages of using depleted fields included concerns over CO_2 displacing methane and weak residual trapping. Some noted that the disadvantages in the U.S. differ from those in Europe due to varying regulatory environments, not just geology and compartmentalization. There were also concerns about old wells, aging infrastructure, and volume of wells that have sidetracks. From a European perspective, it was noted that Norway is targeting saline aquifers since many of its fields are less mature, while the Netherlands is focused mostly on depleted fields. The UK, on the other hand, has a mix of options—depleted fields in the south and aquifer potential in the north—so it is pursuing both avenues, with challenges that are ultimately specific to each storage site.

Session 4: Shipping & Direct Injection

Shore to shore & underwater CO_2 Transport - Dhruv Boruah, Oceanways

Oceanways introduces a new solution for underwater CO_2 using a more flexible transport model. The presentation highlighted the limitations of traditional pipeline and shipping methods for CO2 transport. Pipelines, while effective, are expensive, slow to build (taking over seven years), and face regulatory and logistical challenges, with significant CAPEX and OPEX demands. Shipping offers flexibility but comes with high costs and operational issues, including weather and legal restrictions, such as the Jones Act in the U.S.

Oceanways proposes breaking pipelines into smaller segments and using standard ISO gas tanks to transport CO_2 underwater. Their concept involves a cradle to hold these gas tanks, which are transported by an underwater vehicle resembling a drone. This scalable system allows for flexibility in transporting CO_2 based on capture capacity, storage options, and distance. Each tank holds around 500 tonnes, and the system can be adjusted to meet different project needs.

Oceanways estimates that it can build the necessary underwater vehicles in about 14 months at a cost of around $30 million. A fleet of 40 vehicles could transport up to 2.5 million tons of CO_2 annually through multiple trips. However, the docking system remains a key challenge. They've identified the "sweet spot" for their model to be transporting between 500,000 and 2.5 million tons per annum over distances of 0 to 113 miles.

The company proposes a "transport as a service" model, charging $12 per ton of CO_2 transported, with pricing adjusted based on project specifics and the availability of tax credits like 45Q. Future goals include establishing a pilot test site in Corpus Christi, Louisiana, or the North Sea.

Shipping and offshore direct injection of CO_2 in geologic storage - Haije Stigter, Carbon Collectors

Carbon Collectors offer an alternative to pipelines for CO_2 transport. The presentation highlighted that while CO_2 capture projects are advancing, storage infrastructure is lagging, and while pipeline projects like Porthos and Aramis are planned, they face delays due to high capital requirements and the need for committed customers.

Carbon Collectors' solution, a "virtual pipeline," uses barges, tugs, and an offshore mooring system to transport CO_2 to offshore storage sites, offering a quicker alternative to pipelines. Their system does not require emitters to invest in additional storage facilities, as the barges themselves act as intermediate storage at the emitter sites. They transport CO_2 at 40 bars and 5°C, offering advantages such as avoiding the need to heat CO_2 upon injection into the reservoir. The CO_2 is compressed, conditioned, and liquefied before transport. Once it reaches the offshore storage site, it is injected through an offshore mooring and injection system.

The system is flexible, allowing scaling based on the amount of CO_2 captured, with minimal additional infrastructure needed. It has received regulatory approval and is ready for deployment, with operations anticipated to begin within 24 to 30 months after contract signing. While an offshore mooring system will need to be constructed, other infrastructure such as receiving terminals, subsea flow lines, and subsea wells are not necessary, making it a streamlined and efficient solution for CO_2 transport.

Questions

Question: Can Oceanways elaborate on the regulatory aspects of surface and underwater transport, and how these might impact short-term implementation?

Answer: Surface transport has extensive regulatory frameworks while underwater transport is currently unregulated. Oceanways is working with entities like DNV, the U.S. Coast Guard, and UK's Maritime and Coastguard Agency to ensure compliance for their pilots. Additionally, they plan to conduct some pilots in private waters and use a support vessel for the first year of operations. Their phased approach aims to build confidence among stakeholders.

Question: Has this been built for military purposes?

Answer: Yes, smaller versions of the technology have been used for military purposes, but the larger-scale version designed to transport CO_2 has not yet been built for military use.

Question: What is the maximum depth for the vehicles (Oceanways)?

Answer: The design currently targets depths of 100 to 150 meters. However, the early phase focuses on shallower areas like Corpus Christi and the North Sea. The depth rating will increase as the project progresses, balancing cost and operational needs.

Question: How do your systems (to Carbon Collectors and Oceanways) manage temperature changes and the CO_2 phase behavior during transport and injection?

Answers:

Carbon Collectors: They transport CO_2 at 40 bars and 5°C. During offloading, pressure and temperature drop to around -10°C, and the CO_2 is injected at 80 to 120 bars depending on reservoir back pressure. Their system ensures limited thermal expansion and avoids extreme low temperatures.

Oceanways: His team is still working on understanding temperature control and prefers to hand over the CO_2 to the operator who manages storage and injection.

Question: What is the timeline for the full operational deployment of this concept?

Answer: It depends on storage development, particularly the need for operators to surrender production licenses and obtain storage permits, which can take up to two years. Once the permit is secured, operations could begin within 24 months, with scaling up thereafter.

Day 2

Session 5: Public Engagement

Gulf of Mexico: Local stakeholders' perspective - Sue Hovorka TXLA CMC

The Texas Louisiana Carbon Management Community (TXLA CMC) is a collaboration among six universities—UT Austin (UT), Louisiana State University (LSU), Lamar University (Lamar), University of Houston (UH), Texas A&M Corpus Christi (TAMUCC), and Texas A&M Kingsville (TAMUK)—focused on advancing carbon capture and storage (CCS) initiatives through community outreach. The team has varying expertise in science, engineering, workforce development, business, and social sciences.

A key goal of the project is making CCS more relatable to the general public, especially for those who prefer personal interactions over technical data. Universities play a crucial role in providing trusted information, fostering partnerships, and maintaining a local presence in these communities. The goal is to educate the public about CCS through trusted, local outreach efforts and initiatives like student engagement, legislative partnerships, and interactive tools such as a comic book and a game designed for middle school students. Additionally, using the university's connections and the 'phonebook' of subscribers, parties interested in CCS can network with other interested parties in the region.

Lamar University highlighted its local STEM outreach programs, which include engineering camps for middle and high school students, as well as CCS education initiatives for teachers. They also emphasized partnerships with local industries to provide students with real-world experiences. Community concerns about property values and health and safety issues related to new carbon pipelines were addressed, with Lamar proposing a collaboration with ExxonMobil to install CO_2 monitoring stations. These stations would offer emergency notifications to residents, helping to alleviate concerns and ensure public safety.

IRA Prevailing Wage and Apprenticeship Requirements - Melvin White MRSW

The Managing Resources and Services in the Workplace (MRSW) management was established in 1999 as a social venture, focused on developing underserved communities. Today, under the Bipartisan Infrastructure Law, applicants must develop community benefits plans, an area where MRSW management has been active since its founding. The company operates registered apprenticeship and pre-apprenticeship programs, ensuring compliance with these plans, particularly under the Inflation Reduction Act, which enforces strict penalties for non-compliance.

Regarding apprenticeship requirements, one out of every four workers on a project must be a registered apprentice. The program integrates classroom education with on-the-job training to develop a skilled workforce while helping companies meet compliance obligations. MRSW management offers consulting services to assist companies in creating and maintaining community benefit plans, registering apprentices, and adhering to federal regulations. These efforts promote workforce development and provide financial incentives for compliance, benefiting both workers and companies. Continued collaborative efforts among universities, community colleges, and companies to support the energy transition and labor force development are crucial to transforming communities and building the future workforce.

Social science research application in UK offshore energy transition projects' - baseline survey results - Darrick Evensen, University of Edinburgh

The study in this presentation explored public perceptions of CCS in the UK, highlighting a need for targeted communication as CCS projects gain traction. Conducted by three Scottish universities in collaboration with the British Geological Survey, the research analyzed opinions from a national sample of 4,109 individuals, alongside a localized subset of 1,016 respondents in the Humber region, where CCS projects are beginning to develop. This allowed for a comparative analysis and the establishment of baseline perceptions.

Initial findings revealed that public knowledge of CCS remains low, with more than half of respondents unfamiliar with the concept. Despite this, general support for CCS was relatively high, with many respondents indicating they either somewhat support it or remain uncertain. CO_2 leakage and consumer costs were identified as top concerns from both the national and Humberside samples.

Those with no knowledge of CCS showed greater concern about CO_2 leakage and minor ground tremors. Conversely, those more familiar with CCS ranked minor tremors as their lowest concern and expressed higher worry that CCS might reduce emissions without decreasing fossil fuel reliance and might distract from other climate mitigations. These latter concerns were also more prevalent among left-leaning individuals and female responders. Additionally, people with some knowledge recognized at a higher percentage that CCS was important for emissions reduction.

Analysis of the open-ended responses revealed that most participants expressed general uncertainties and a desire for more information, rather than approaching the subject with a preconceived mindset. More information may alleviate certain concerns, but could also raise new ones, such as the possibility of CCS distracting climate policy from other mitigation options. Overall, the findings highlight a strong need for well-targeted, clear communication to address misunderstandings and enhance public awareness.

Social science research application in UK offshore energy transition projects' - MOET - Elizabeth Gabe-Thomas, PML & Hazel Napier, BGS

"Managing the Environmental Sustainability of the Offshore Energy Transition" (MOET) is a UK-based project funded by the Natural Environment Research Council. MOET involves collaboration between the British Geological Survey, Plymouth Marine Laboratory, and the

National Oceanography Centre. The goal is to create the UK's first comprehensive study on the environmental and social impacts of the offshore energy transition infrastructures, focusing on wind farms, carbon dioxide storage, and hydrogen. One of the main objectives is to explore how these technologies interact, identifying synergies while minimizing conflicts between different infrastructures. Key themes emerging from engagements with different stakeholders include the co-location of different technologies, cumulative impacts, and the need for better understanding of public perceptions and regional nuances.

The social science part of the project takes two approaches: an ecosystem service approach and a mental models approach. The former examines the impact of offshore technologies on marine ecosystems and their services, such as food provision, environmental regulation, and cultural services. The latter focuses on understanding how the public and stakeholders perceive these technologies, aiming to improve communication about the risks and benefits.

Stakeholders highlighted "Not In My Backyard" as a key concern, suggesting offshore technologies might be more acceptable than onshore, though this may differ from public opinion. Other concerns include CO_2 leakage, job losses, and reliable future-proof energy. The project will continue to explore and address these key social issues, keeping in mind that stakeholder feedback may differ from public opinion.

Questions

Question: In MOET work, there were 3 case study areas mentioned. Does the information gathered vary between the areas?

Answer: The data has not yet been collected, but based on the literature, differences are expected. For example, in Teesside, there is a history of energy work, which could influence results. A national survey will be conducted to compare broader public opinions with those from specific case studies.

Question: Regarding the 3 technologies being studied in MOET (geologic hydrogen storage, geologic carbon storage, and wind energy), will the survey ask participants to rank or favor the technologies? And how will you approach the question of co-location of these technologies?

Answer: The survey is still in development, but the plan is to explore differences in public perceptions across the technologies. Co-location of the technologies will also be examined, and designing the survey to present these ideas clearly to respondents is a challenge, but it's a goal.

Question to Darrick Evensen: Do you think there's a statistically significant difference in attitudes between people who have heard of CCS and those who haven't? Is there value in working with a "blank slate" of people who know nothing about CCS?

Answer: Yes, there are statistically significant differences. The group with some prior knowledge showed stronger support for CCS and had different concerns and perceptions of its benefits. However, the causality is unclear whether the knowledge came first or if people learned about CCS because they were already interested. Future studies will explore this further.

Question: There should be more public engagement efforts, such as billboards and ads about CCS, similar to what has been done in some regions, like Beaumont.

Answer: No specific answer was provided, but Katherine Romanak added that there has been a CO_2 pipeline through Jefferson County for the last 8–10 years without negative feedback, highlighting the importance of public awareness.

Session 6: Managing Risk of Potential Leakage Pathways & Products (CO_2, brine, other) in the Offshore

Environmental monitoring and risk perspective, Global scene setting - Katherine Romanak, GCCC

An overview was provided on environmental monitoring and risk management related to carbon storage, focusing on balancing the risks of CO_2 in the atmosphere versus potential leakage from storage. The importance of helping stakeholders understand these risks was emphasized. While environmental monitoring can be complex and extensive, a more focused, "parsimonious" approach is advocated—monitoring only what's necessary to minimize complexity and costs while achieving regulatory goals for greenhouse gas accounting and environmental protection.

Monitoring challenges include determining the necessary level of monitoring, avoiding false positives, and ensuring stakeholders' confidence. Though baselines are often mentioned, climate change and natural fluctuations make environmental baselines unreliable. Effective attribution of CO_2 anomalies is crucial. Ratio-based approaches based on respiration show success in the terrestrial environment, while bubbles and chimneys are good indicators of leakage in the offshore environment.

Progress has been made with attribution being included into the EU CCS Directive and commercial projects adopting need-based monitoring tools. In conclusion, routine environmental monitoring should be reduced, intensifying efforts only when there's a clear reason or suspicion of leakage. The importance of having a plan in place to address stakeholder concerns transparently and effectively was stressed, and project developers were encouraged to focus on attribution strategies in their environmental plans.

Well remediation or 'do nothing' - a risk perspective - George Ormerod, Risktec

Risktec's five-step approach to managing well risks involves identifying wells, screening for exposure to brine, CO_2, or pressure, assessing well integrity, analyzing the highest risks, and evaluating options for risk reduction. The importance of a proportional approach was emphasized, where simpler cases may require qualitative methods, and more complex or high-risk situations need deeper quantitative analysis.

Legacy wells, both inside and outside licensed areas, need to be identified as they could pose risks to CO_2 storage due to potential leaks. Screening methods eliminate wells that do not pose a threat, such as those lacking reservoir presence, not connected to pressure zones, or outside the predicted CO_2 migration and pressure increase areas. For wells that pass the initial screening, a more detailed analysis is conducted to assess potential containment or integrity issues, such as the condition of plugs or the reservoir's driving force.

The use of bowtie diagrams was introduced to visually represent threats, barriers, and consequences and show where controls can be introduced. Then quantitative estimations of risk levels are scored based on engineering judgments, but uncertainties often exist and should not be considered highly precise. The final decision-making process involves balancing the cost and practicality of remediation with the potential risks, including environmental and reputational impacts. Ultimately, the goal is to apply appropriate tools to mitigate risks and present clear results to stakeholders.

Quantitative assessment of potential CO_2 leakage volumes in the Dutch North Sea - Al Moghadam, Filip Neele, TNO

This presentation from TNO explored the quantitative assessment of potential CO_2 leakage volumes, focusing on the behavior of CO_2 leakage from wells. TNO developed CREST, a staged finite element well integrity tool, to create hydro-thermo-mechanical models that simulate potential scenarios throughout a well's lifecycle. Currently, CREST only considers a simplified leakage pathway across the caprock and into the overburden.

A case study inspired by a depleted North Sea gas field, where current regulations in the Netherlands limit pressure to hydrostatic, examined leakage scenarios at varying pressures. Mechanical modeling showed that the cement sheath around the well's casing can change with pressure and temperature, affecting permeability. Injecting below hydrostatic pressure prevented significant leakage; however, when pressure was increased, the worst-case leakage could reach a few thousand tons per year, though more realistic projections showed 2,700 tons of leakage over 5 years. Additionally, the presence of creep, where softer rocks such as cap rocks begin to move, can reduce leakage estimates by up to three orders of magnitude.

Another case study with a legacy well explores an aquifer injection where the pressure is above hydrostatic. Similarly, leakage scenarios were run under different pressures and it once again showed that creep effects reduced leakage estimates by orders of magnitude. These findings underscore the need for adaptable pressure management and provide leakage estimates for regulators to determine acceptable thresholds. By understanding these dynamics, operators can make informed decisions on pressure limits, optimizing storage efficiency while addressing leakage concerns.

Update on recent HR3D survey and activity in the GOM - Tip Meckel, GCCC

High Resolution 3D Seismic Surveys (HR3D) offers higher resolution compared to traditional seismic surveys, enabling more detailed imaging of the subsurface such as gas accumulations, which are critical for CCS monitoring. The GCCC, with funding from the DOE, has deployed this multiple times in the GOM and internationally. This presentation provides an update to the survey conducted near Galveston, TX, in shallow waters. These surveys aim to assess potential CO_2 leakage paths and monitoring of the overburden above possible injection sites.

A 2013 survey near a salt dome at San Luis Pass detected a gas chimney and other shallow gas anomalies using HR3D, providing a useful analog for studying potential CO_2 migration into the shallow subsurface. A follow-up survey in 2024 at the same site assessed changes over time, revealing little change in the gas features, suggesting a static system. This observation provides insights into fluid retention in shallow stratigraphy, which is important for CCS projects. The HR3D surveys demonstrate the technology's applicability for pre-injection characterization and 4D monitoring of CO_2 storage sites, capable of detecting small subsurface features and providing valuable data. There will be another opportunity to gather more data in the next year. The presentation concluded by emphasizing HR3D's potential to enhance monitoring and safety in CCS projects, with plans for future surveys aimed at refining the technology and exploring its application at additional CO_2 storage sites.

Discussion

Questions to Al from TNO asked about how the cement hydration was modeled, noting its impact on mechanical properties. Al responded that it was modeled in CREST, and affirmed the importance of cement hydration in estimating the stress state after cement sets, emphasizing the role of defects in well leakage, particularly at the cement-casing interface. Another question inquired if microannulus formation was inevitable, and if not, how it would be detected in legacy wells. Al responded that while it is not inevitable, it is common due to factors such as formation properties and shrinkage during cement hydration if the cement pulls from the well.

The session touched on the growing regulatory burden on CCS projects. Participants agreed that while data on the storage complex is essential, it is one of the most understood components, and adding complex tools to characterize this is prohibitive for CCS development. More emphasis should be placed on what data is missing for robust monitoring approaches.

Another question asked all participants if there was any consideration for reusing marginal wells for monitoring and how the metallurgy was selected for their projects. It was noted that while it is theoretically possible, it often proves more cost-effective to drill new wells due to concerns over the integrity of older wells and the impact of CO_2 on metals. Discussion about metals led to a conversation revolving around the incident at the ADM project in Illinois. CO_2 had migrated outside the permitted storage area due to corrosion in a monitoring well, moving into a formation still 5,000 feet below the surface. The migration to this unpermitted formation was sensationalized, with headlines suggesting leakage at the surface, which was not the case.

This case exemplifies the added risk of implementing monitoring wells that add a migration pathway without any added data. It was highlighted that the design duplicated a previous one intended to gather and validate data, which may not align with current best practices for commercial projects. Additionally, the well was perforated in two zones, the storage zone and above the first confining layer, and the CO_2 leaked through the tubing. The tubing metallurgy may become a topic for more investigation, but the corrosion was attributed to formation fluids, not the CO_2 itself. The upper packer prevented any further vertical migration.

Another aspect of this incident highlights the regulatory language used in the permits. The violation of this incident comes from the lack of permit approval in the upper injection zone, but there were no material violations concerning safety objectives. Distinguishing between specific injection and confining intervals vs. the entire complex in the permit may be needed. Expanding a confining zone in the permit could include additional legacy wells within the AOR through specific intervals, which may be a risk worth considering. It was noted that in the EU, the permit is for the storage complex which is the broader geological domains and secondary containment formations, offering more flexibility in monitoring and containment.

Lessons learned emphasize selecting monitoring tools that add value without increasing risk, such as avoiding monitoring wells within the storage interval, refraining from perforating wells in multiple intervals, exercising caution in metallurgy choices, and including multiple zones in permits to mitigate risks of violating permits if CO_2 migrates into unplanned zones.

Session 7: Interactive Session - Evaluating Well Risk – led by Susan Hovorka, GCCC and Amanda Ardill, Shell

This interactive session divided attendees into groups to rank risk levels for 4 different completions in 3 different locations. Location 1 is inside the CO_2 Plume at the 30 year mark, location 2 has elevated pressure in the brine at the 30 year mark as well as a legacy well, and location 3 will see migration in 100 years.

Multiple groups noted completions with a severed wellhead as an issue as it complicates re-entry and there may be a need to re-enter the well and improve the cement barrier to ensure proper sealing. There were also concerns about the lack of cement across the injection zone in some of the completion designs, which poses risks for CO_2 migration. Additionally, the designs with two barriers were seen as more preferable.

Typically, if the wells were in the location to see migration in 100 years, they were not of much concern for remediation with only some of the riskier ones being considered for monitoring. In the elevated pressure in brine locations, some proposed phased remediation, with some suggesting monitoring the CO_2 plume before deciding on full remediation. If the wells were in the plume, and for some even in the elevated brine region, proper re-entry and improving barriers (such as additional cement plugs) was seen as necessary to ensure long-term integrity during CO_2 injection and storage.

There was a noted difference in perspective between regulators (focusing on integrity) and operators (balancing cost with necessary safety measures), with many suggesting a risk-based approach to well remediation.

Session 8: Regulatory factors to consider

Overview - Tim Dixon, IEAGHG

In this segment, recent regulatory developments in CCS were discussed, with a focus on updates from the past year related to the London Convention and London Protocol. These international frameworks are crucial for managing offshore environmental protection, especially in the context of CCS projects.

The London Protocol prohibits dumping of all wastes, with a few exemptions, and has been amended to allow CO_2 geological storage. Guidelines were adapted to focus on CO_2-specific conditions, providing a framework for regulating offshore CO_2 storage and addressing concerns about CO_2 stream composition. The final language for carbon dioxide streams allowed for dumping uses the term "overwhelmingly" to describe the necessary CO_2 content. There is an action list of substances not allowed in the CO_2 stream.

Some developments include the collaboration of Japan and Australia to share knowledge and discuss learned experiences on offshore permitting experiences using the CO_2 Specific Guidelines. There is growing interest in transboundary CO_2 storage, particularly in Southeast Asia. The London Protocol restricts waste export, but an amendment now allows CO_2 export for storage if bilateral agreements between countries are in place. In cases involving transboundary sub-seabed formations, the CO_2 Specific Guidelines stipulate that the contracting party where the injection takes place is responsible for implementation. Additionally, in cases like what is developing between Australia exporting CO_2 to Timor-Leste, it is up to Australia to demonstrate to the London Protocol and IMO that Timor-Leste has the regulations that meet the requirements. The situation is developing, and will be important to watch.

Countries like Norway, the Netherlands, Denmark, and others have applied for the provisional application of CO_2 export. Bilateral agreements for projects like Northern Lights and Greensands are underway. Additionally, UNFCCC Paris Agreement Article 6.2 and 6.4 created frameworks for an international carbon market. Overall, there is a need to adapt to the increasing complexity of CCS projects, especially transboundary operations, making ongoing collaborations and studies essential.

Update from BOEM - Melissa Batum, BOEM

The Bureau of Ocean Energy Management (BOEM) oversees the outer continental shelf (OCS) of more than 3.2 billion acres, beginning 3-9 nautical miles from the U.S. shore. Responsibilities encompass conventional energy (oil and gas), renewable energy, marine minerals, and carbon sequestration. The 2021 amendment to the Outer Continental Shelf Lands Act (OCSLA) granted BOEM the authority to regulate carbon sequestration within the OCS. Ongoing work involves joint rulemaking between BOEM and the Bureau of Safety and Environmental Enforcement (BSEE) for this emerging program.

BOEM is tasked with managing the entire lifecycle of offshore activities, including pre-lease assessments, site characterization, leasing, operating, monitoring, closure, and more. The processes established for carbon sequestration align with existing protocols for oil and gas and renewable energy, involving significant collaboration and iterative efforts between BOEM and BSEE throughout all stages of a project. Stakeholder input is integral to the decision-making process, ensuring compliance with environmental laws such as the National Environmental Policy Act.

To identify optimal carbon storage locations, BOEM is conducting regional storage assessments, initially focusing on the Gulf of Mexico and Atlantic regions. Research is being conducted to evaluate environmental impacts and best practices for carbon storage operations, building on prior studies. Challenges related to pressure management, sound impacts on marine environments, and cumulative environmental effects are being addressed to ensure the program's success. Considerations are also being made for multiple projects in the same region, taking into account potential impacts on pressure and geology.

Questions

Question: Who is the final decision maker for applications?

Answer: The decision maker varies based on the scale of the project. For large-scale programs like the oil and gas program, the Secretary of the Interior is the final decision maker for the National 5-year plan. For regional projects, the decision-making authority can move down to the regional director, with input from higher levels. At the site-specific level, decisions may be made by a BSEE regional office. The decision-making process is tiered, starting with broad national/regional analysis and becoming more specific at the site or project level.

Question: How well do BOEM and BSEE currently work together, and will any institutional changes be needed to ensure close collaboration on carbon sequestration projects?

Answer: They are already deep in collaboration, especially through renewable energy and with carbon sequestration, will likely require even more integration due to the iterative process of monitoring and managing projects over long periods.

Development of Australia's National Action List for offshore CCS - Linda Stalker, Andrew Ross, CSIRO

Australia's National Action List (NAL) is designed to ensure compliance with the London Protocol, which governs the regulation of CO_2 storage and environmental protection. CSIRO is contributing technical expertise to help establish guidelines for incidental associated substances (IAS) in CO_2 streams. The NAL focuses primarily on environmental and human health impacts, rather than operational concerns, and will set upper-level limits for specific substances that could pose risks during carbon storage operations in case of a leakage or accident.

To develop the interim NAL, data were gathered from various CCS projects and standards like ISO 27913. Emissions data were analyzed pre- and post-capture to assess concentrations of IAS in CO_2 streams. Understanding how incidental substances are captured, compressed, and conditioned throughout the CCS value chain allowed for the establishment of safety and environmental health benchmarks.

The next step was to use short-term exposure limits (STELs) for various compounds and apply safety factors to ensure conservative estimates for potential health risks. For instance, permissible levels of carbon monoxide in a CO_2 stream were adjusted for possible expansion in the event of containment failure. The interim NAL also compares the concentrations of substances across different stages of capture and storage and also makes considerations for different CO_2 phases. Additionally, IAS without STELs are included that relate to infrastructure integrity, subsurface reactivity, and efficiency.

Looking ahead, the transition from the interim NAL to a full version will include both upper and lower limits for IAS. This full version will adopt a "traffic light" system to guide the industry in maintaining safe levels of incidental substances. Development of the full NAL will also incorporate feedback received during an open consultation period with industry stakeholders, with the finalized version expected to be released next year.

Update from the working group on CO_2 standards, ICM Forum, European Commission - Filip Neele, TNO

This presentation centered on the ongoing work of the Industrial Carbon Management (ICM) Forum, a stakeholder consultation platform created by the European Commission to facilitate the development of CCS in Europe. The Forum has four working groups focusing on CO_2 infrastructure, CO_2 standards, public perception, and carbon capture and utilization. The working group dedicated to CO_2 standards is aiming to gather knowledge on CO_2 stream compositions and their impurities while assessing their impact on CCS projects.

There is growing complexity of CCS infrastructure in Europe with various projects developing different CO_2 specifications. A key challenge will be ensuring compatibility between these projects, especially as they begin to link through shared infrastructure such as pipelines and shipping routes. While this working group does not intend to establish a Europe-wide standard for CO_2 composition, it aims to clarify the reasons behind differing specifications and provide stakeholders, particularly emitters wishing to connect to these projects, with valuable insights.

The group's work is divided into several work streams. One focuses on reviewing current CO_2 standards by gathering existing and proposed specifications and analyzing the differences. Another work stream examines the future layout of CCS infrastructure in Europe, considering transport corridors and the possible dominance of the stricter specifications from ship-based projects. A third stream explores long-term goals, including the need for interoperable networks and multimodal transport chains, especially for cross-border cooperation. The final work stream will make recommendations and conclusions on the findings. Preliminary results will be presented at the ICM Forum in October, with the goal of publishing a final report by the end of the year. While final results are not yet available, there is hope to deliver a report of similar quality to the previous year's work.

CO_2 streams - Adriaan Kodde, Shell

The presentation focused on CO_2 specifications in the context of transport and storage hubs, highlighting the complexities that arise when CO_2 is aggregated from multiple capture sources. Transport and storage systems have strict limits on impurities, but these impurities vary across sources. Additionally, the responsibility of cleaning the stream lies with the capture plant where it is more economical.

While hydrocarbon pipelines have well-understood uniform corrosion mechanisms, CCS systems face unique challenges that can cause rapid failure due to different corrosion mechanisms, such as stress corrosion cracking and material degradation under low temperatures. CCS hubs that utilize various transport modes require CO_2 compositions that are compatible across these systems, complicating the overall process.

One critical concern discussed was the potential for reactions between impurities which can form highly corrosive acids in CO_2 streams. Research insights indicate that acid drop-out from CO_2 streams through oxidation/hydration of sulphur species poses a significant risk. These reactions are further exacerbated by temperature changes, especially around compression stages in the transport process. A key concern is that high corrosion rates cannot be controlled or timely detected.

Additionally, the importance of addressing dust in CO_2 transport pipelines, particularly in sandstone storage formations, was highlighted. Dust particles can clog reservoirs and impede injection processes, leading to costly issues. Remedial actions to restore CO2 injections include acid stimulation, and installation of dust filters upstream the injection well to mitigate challenges of dust particle clogs.

Questions

Question: Based on feedback from industry, did you adjust BTEX levels?

Answer (Linda Stalker): Industry feedback suggested decoupling the BTEX group to assess individual compounds, focusing particularly on benzene due to its significant health concerns, while noting that others in the group have less impact. Feedback also included setting lower threshold values below which there would be no concern, while higher levels could trigger enhanced monitoring or additional actions, along with addressing the potential reactions between contaminants.

Question: Are you splitting component limits between projects using pipelines versus those using shipping?

Answer (Linda Stalker): Stalker confirmed that they are working on documenting the history of projects and how their specifications change, especially in hub and cluster projects where new participants may introduce different specifications. Specifications might tighten as hubs aim to minimize challenges, pushing responsibility back to capture facilities.

Question: There is strict impurity criteria for operations (e.g., NH_3 limits) that are different than that for health, how is this being addressed?

Answer (Linda Stalker): They try to make clear their work is on environmental and human health impacts, not operation, which may often be stricter than environmental or health limits.

Question: Have you looked at the interaction between components e.g., the increased respiratory rates when CO_2 is inhaled:

Answer (Linda Stalker): The study has not looked at such specific physiological effects yet, but the interaction between different components will be examined further in the full NAL.

Question: Is it difficult for existing hubs and clusters to change CO_2 standards?

Answer (Adriaan Kodde): Yes, plans and infrastructure are based on an initial specification. While new insights might justify reopening discussions, it's not easy to make changes.

Question: To lessen burden on emitters, would a port cleanup option be more effective than imposing shipping specifications on pipeline network users?

Answer (Adriaan Kodde): That is a concern, especially regarding sulfur limits. The challenge lies in how liquefaction units typically do not remove sulfur. A port cleanup might be cost-effective depending on the cost of the unit, but every step in CO_2 separation also results in the loss of some CO_2.

Question: After making a future EU-wide CO_2 standard, would it apply to both new and existing hubs and clusters or just new?

Answer (Filip Neele): Not sure if such a standard would emerge, but if EU-wide standards were developed, it would likely emerge organically as projects merge and connect. He wasn't sure whether a strict specification would eventually be enforced or if multiple specifications would coexist across different regions.

Session 9: Closing Wrap-up

Conclusions:

The workshop underscored the broad diversity among CCS projects globally, highlighting differences in country of origin, business models, and stages of operation, with a notable increase in activity in Asia. The development of CO_2 transport by ship and barge was also emphasized, utilizing various pressure and temperature models to accommodate different project needs. Interest in using depleted fields varied, influenced by factors such as scale, maturity, and national priorities, with increased storage pressure identified as a way to boost capacity—illustrated by Northern Lights regulations that prevent exceeding original reservoir pressure.

There was consensus against placing monitoring wells directly in CO_2 plumes, advocating instead for selecting monitoring tools whose benefits outweigh the risks. Discussions of CO_2 phase changes, with a particular focus on assessing risks and impacts at various stages of each project, was insightful. Addressing microannuli around wells was deemed critical. Public outreach was also emphasized, given persistent misconceptions and a lack of understanding of CCS among the general public. Local advertising on billboards in Port Arthur, newspaper adverts, and ads on Spotify exemplify these efforts. There was a consensus during the well management exercise that a deferred corrective action approach— monitoring and then taking appropriate measures—was the preferred strategy for managing pressurized brine and long-term migration locations.

The EU is leading efforts on CO_2 specifications with managing impurities within CO_2 streams. Feedback highlighted that as DAC plants scale up, managing oxygen content in CO_2 streams will become a significant challenge for specifications, as large-scale operations lack the dilution potential of smaller plants. The importance of sharing lessons learned across projects was emphasized, with the US's experience serving as one example that could inform the EU's efforts on CO_2 specifications. Additionally, clearer definitions and communication regarding the quantification of leakage amounts and subsequent consequences, as well as the distinction between a storage complex/zone and a confining complex/zone, are essential to clarify what constitutes a leakage. One key takeaway is that hydrocarbon leaks associated with oil spills are not comparable in this context; researchers had to create controlled, manufactured conditions to study CO_2 release effectively.

Recommendations:

It was suggested that regulatory frameworks and language used in permits (US specific) account for confining systems composed of multiple zones that ensure robust containment. It is advisable to avoid placing monitoring wells directly in the plume and to refrain from perforating multiple intervals. There was a call for large-scale public awareness campaigns to demystify CCS technologies and address public concerns, potentially through engaging and accessible initiatives.

For future project roundups, key focus areas include: transferable lessons learned, insights from projects nearing operational stages regarding the management of timing for transport, capture, and storage, and an overview of the outreach processes of projects.

Also, there was an ask to release semi-annual or quarterly project summary.

Day 3: Field trip

On the third day of the workshop the group were treated to an excellent field trip organised by Tip Meckel of the Gulf Coast Carbon Centre. This included the full CCS value chain, from CO_2 sources at the local refineries (including Air Products CO_2 capture facility), ExxonMobil's Green Line CO_2 trunk pipeline, Baker Hughes well- and caprock-inspection tools, and the shore and offshore geology at the Sea Rim State Park.

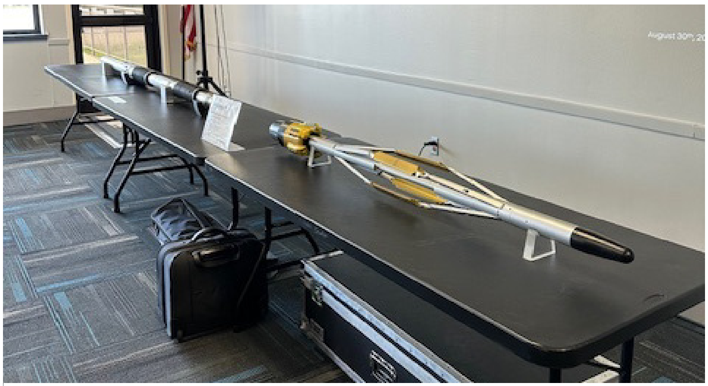
Tip provided an interactive lesson in the regional geology which has created the numerous storage formations. Tip made a key point, the last time the Offshore Workshop was held here was in 2017. Then geological storage in the area was just a concept promoted by Tip and colleagues, now seven years later there are many storage leases formally agreed both offshore and onshore, and numerous projects in development (and new LNG plant being built). What progress! "What starts here changes the world", to quote the University of Texas slogan.

In addition, the group considered regional ecosystem aspects and benefits with a talk by John DeFillipo of the National Wildlife Federation, including IEAGHG and GCCCs work on demonstrating neutral impacts of CCS on avian populations, all very relevant with the large number of potential CCS projects and offshore wind projects in this migration hotspot.

ExxonMobil's Green Pipeline at the Beaumont ump station

Tip Meckel (GCCC) explaining Gulf of Mexico stratigraphy and why its suitable for CO_2 geological storage

John DeFillipo of the NWF explaining the ecosystems of the Gulf Coast and how they might be impacted by the energy transition



A selection of logging tools as demonstrated by Baker Hughes (Proxima and RCX Straddle Packer Microfrac)

Attendees of the 7Th International Workshop at the ExxonMobil Green Pipeline – Beaumont pump station

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