IEAGHG Meeting Report 2017-TR12
November 2017

2nd International Workshop on Offshore Geologic CO_2 Storage

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The International Workshop on Offshore Geologic CO2 Storage was organised by the Bureau of Economic Geology (BEG) Gulf Coast Carbon Center (GCCC) at the University of Texas in Austin and IEAGHG, in co-operation with Lamar University and the South African National Energy Development Institute (SANEDI). The organisers acknowledge the financial support provided by the Carbon Sequestration Leadership Forum (CSLF), Lamar University, the City of Beaumont, and GCCC for this meeting and the hospitality provided by the hosts at Lamar University, Beaumont.

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This report was prepared by Tim Dixon, Katherine Romanak and Grace Womack

An International Steering Committee was formed to develop the technical programme for this workshop. The steering committee members were:

- Tim Dixon, IEAGHG (Chair)
- Katherine Romanak, BEG (Co-Chair, Host)
- Susan Hovorka, BEG (Host)
- Tip Meckel, BEG (Host)
- Paul Latiolais, Lamar University (Host)
- Anthony Surridge / Noel Kamrajh, SANEDI
- Lars Ingolf Eide, Research Council of Norway
- Traci Rodosta, US DOE NETL
- John Litynski, US DOE
- Di Zhou, China Academy of Sciences
- Filip Neele, TNO
- Paulo Negrais Seabra- Independent Consultant (formerly Petrobras)
- Ryozo Tanaka, RITE
- Owain Tucker, Shell
- Philip Ringrose, Statoil
- Michael Carpenter, Gassnova
- Thonda Harvey, Lamar University (Host)

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Further information or copies of the report can be obtained by contacting IEAGHG at:

IEAGHG, Pure Offices, Cheltenham Office Park
Hatherley Lane, Cheltenham,
GLOS., GL51 6SH, UK Tel: +44 (0)1242 802911 E-mail: mail@ieaghg.org Internet: www.ieaghg.org

International Workshop on Offshore Geologic CO_2 Storage

Meeting Report

Date and location:
19-20 June 2017, Lamar University, Beaumont, Texas, USA

Hosted by:
Bureau of Economic Geology, Gulf Coast Carbon Center, and Lamar University, Beaumont.

Sponsored or supported by:
Gulf Coast Carbon Center at The University of Texas at Austin's Bureau of Economic Geology,
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City of Beaumont, Texas

Report Contents:

Executive Summary

The 2nd International Workshop on Offshore Geologic CO_2 Storage was held in Beaumont Texas, 19-20 June, hosted by Lamar University and the Bureau of Economic Geology (BEG). The workshop was well-supported by the local community and attracted 50 attendees from 9 countries to discuss developments for offshore CO_2 transport and geological storage.

This second workshop built on the conclusions and recommendations from the first workshop in 2016 by continuing the theme of 'how to do', and including sessions on how to find storage, monitoring developments, CO_2-EOR potential offshore, and infrastructure options, with presentations from Norway, the UK, the Netherlands, Australia, South Africa and Japan. New to all attendees were presentations on the US Department of Energy (DOE) -supported US projects looking at offshore storage in sedimentary basins in the Gulf of Mexico, the Atlantic and in basalts in the northern Pacific. Conclusions and recommendations were agreed, these had a certain focus on infrastructure issues with the aim of engaging with operators of offshore infrastructure to make them aware of the opportunities from CCS and CO_2-EOR.

The conclusions include:

How to find storage:

- Storage site selection methods are becoming mature.
- Examples from different regions show some similarities in methods for adapting to regional geologic conditions, optimizing CO_2 source distribution, and developing national goals and policies.
- A conservative approach to project development favors assessing multiple sinks and multiple sources, so that the elimination of one site does not derail the whole project.
- Case studies from South Africa and Australia indicate the importance of systematic project refinement including down-selecting potential storage sites.
- Project risk is significantly lowered in cases where dense subsurface data sets are available, injectivity is known, and sinks are in proximity to sources.

Monitoring:

- Monitoring plans are successfully passing through negotiation with regulators.
- Pragmatism in balancing risk reduction with cost management is illustrated in cases from Peterhead, ROAD, Sleipner and Snohvit.
- Environmental monitoring by autonomous underwater vehicle (AUV) reduces cost and reduces human safety issues.
- Multiple approaches to overburden and water column monitoring are demonstrated.
- The ability to characterize and monitor the overburden in time-lapse is being developed.
- The sensitivity of data and the density of data needed to demonstrate no leakage are beginning to be considered.

EOR:

CO_2 - EOR continues to be considered as a prospective part of storage, for example in the Norwegian and UK North Sea, the Gulf of Mexico, and basins globally. Information and analysis continues to increase (see major summary by CSLF CO_2 - EOR task force, due 2017).

Infrastructure:

- Timing and cost issues arise with re-use of infrastructure offshore.
- Subsea solutions for adding CO_2-EOR to existing platforms are in development. The components exist, but there is still a need to qualify their use with CO_2.
- Many options exist for infrastructure, both new and reused, and the choices will be site specific.

The recommendations include:

- For research purposes, some wells could be made to release CO_2 in order to test monitoring and re-completion techniques.
- Utilize lessons learned from USA's re-use of wells for CO_2-EOR.
- Develop tools for assessing the viability of infrastructure.
- Communication with owners of offshore infrastructure the potential for structures to be used for CO_2 storage.
- Communication with institutions such as governments on infrastructure so opportunities for development and re-use are not lost.
- The importance of offshore CCS for developing countries needs to be communicated to bodies such as the Green Climate Fund using the good example in South Africa.
- Subsea solutions are coming for adding CO_2-EOR to existing platforms. Components exist, but they need to be need to be qualified for use with CO_2.

The workshop concluded with a field trip to look at all the elements of an integrated CCS project: a large CO_2 source at the Air Products capture project in Port Arthur: CO_2 transport options including, ship, barge, rail, Denbury's Green pipeline and CO_2 hub potential at Howard Energy Partners' GT-Omniport; and the geology of a potential storage site offshore. All of these components exist in close proximity in this part of south eastern Texas. The workshop concluded with meeting local dignitaries for an appreciation of the local industrial heritage at the Museum of the Gulf Cost in nearby Port Arthur. Beaumont was the location for 'Spindletop', the first large-scale oil find in the region which prompted the Gulf Coast oil boom and creation of many famous companies such as Texaco and Gulf Oil, and the resultant high density of refineries still to this day in the area. Initial feedback from international attendees was that the combination of the workshop and such a relevant field trip was extremely interesting for all.

The workshop came about to address a recommendation from the CSLF on offshore CCS, and with great timing the previous week the US DOE had issued an opportunity for funding for an offshore CCS partnership, which will enable progress to be continued in developing offshore CCS in the USA.

The presentations are available at http://www.beg.utexas.edu/gccc/goi.php .

Welcome and Objectives

Sue Hovorka, Paul Latiolais, Tim Dixon and Katherine Romanak welcomed attendees. Tim recapped how the offshore workshop series was born out of a CSLF Task Force on Offshore Geologic CO_2 Storage. He also reviewed the outcomes of the first workshop in 2016. The 2015 report of the CSLF Task Force on Offshore Geologic CO_2 Storage concluded:

> *"There is a growing wealth of research, development and practical experiences that are relevant to CO_2 storage offshore, but this expertise is familiar only to a few specific countries around the world. However there is also significant global potential for offshore CO_2 storage, and countries who are not yet active but may become interested in offshore storage, would benefit from knowledge sharing from these existing experiences and expertise. Such international knowledge sharing would be facilitated by international workshops and by international collaborative projects." (CSLF Ministerial Nov 2015: CSLF-T-2015-06)*

The aims of the first workshop were to initiate a discussion about the various aspects of offshore transport and storage to build an international community of parties interested in 'how to do' offshore storage. Its objectives were:

1. To facilitate countries to understand what is required, to share best practice and learnings from experiences
2. To identify their specific issues, challenges, opportunities, etc.
3. To identify synergies, common gaps and goals, and to recommend actions and next steps and opportunities for project collaboration

This 1st workshop was reported and published as IEAGHG 2016/TR2 (May 2016).

The 2nd workshop's aim was to address and build on the recommendations and topics raised at the first workshop to take offshore storage forward. Continuing the theme of 'how to do', the objectives were to take a technical 'deeper-dive' into key topics such as: 1) how to find storage offshore; 2) technical aspects and experiences of offshore monitoring; 3) CO_2-EOR offshore; 4) infrastructure developments and decisions; 5) U.S. developments in offshore storage assessment, and to produce conclusions and recommendations.

The workshop concluded with a field trip organised by Tip Meckel, to show all the aspects of an integrated CCS project with offshore storage that were available in the local area.

Session 1. How to find storage offshore – mapping and screening for good sites: Chair, Sue Hovorka

South Africa from Zero to Pilot Project and Offshore Assessment. Noel Kamrajh, SANDEI

Noel Kamrajh discussed the South African Energy Chain where coal dominates followed by oil and natural gas. As most CO_2 is produced in a concentrated location and by coal-fired power plants, South Africa wants to use CCS as a clean fossil fuel transition technology.

There is a mandate to use CCS as part of a long term mitigation scenario. The Cabinet has endorsed the CCS Road map as of May 2012. A Pilot CO_2 Storage Project is planned for the Zululand on-shore basin, which aims to be a proof of concept, increase South African technical capacity, raise awareness about the importance of CCS, and develop the South African regulatory environment. Determination of CCS Potential in South Africa was completed in 2004, the Carbon Atlas in 2012, and the pilot CO_2 storage project is planned for 2017. In 2025, 100 thousand tonnes of CO_2 are planned for an integrated demonstration project. In 2035, commercial operation is planned for storage of millions of tonnes of CO_2. Respectful stakeholder engagement is crucial to the success of this process as community and tribal leaders in the area can raise concerns and suggestions.

Specifically, in the offshore environment, the atlas showed a 150 gigatonne capacity with 98% offshore. The need is present for 4 gigatonnes for 100 years. A modified Steven Bachu (2003) methodology was used to screen and rank the potential storage basin. The result of this analysis showed that the Bredasdorp sub-basin ranked highest, followed by the Orange and Durban-Zululand basin. According to the CCS Roadmap's objectives to implement commercially scaled CCS, the Durban Basin is the most viable. This is due to existing pipeline infrastructure and routes.

Discussion:

Stakeholder engagement is a very formalized process. In the stakeholder engagement for the Zululand Project, there was a team of 4 full-time representatives. They took a multilevel approach with national government support. Tribal lands controlled by local authorities had direct engagement. Local community support was garnered with field trips to demonstrate lack of impact. There was not much resistance, but there are cautious tribal administrators. There is now full support from local chiefs, but not complete support from administrations.

Deep Saline Formation storage screening in Petrel Australia – Owain Tucker, Shell

Owain Tucker laid out Shell's steps to refining the geological evaluation for CCS: the terms 'Play, Lead, Prospect' were defined.

Owain explained the steps to their site prospecting plan where they reinterpreted stratigraphic correlations using chronostratigraphic approach rather than lithostratigraphic. This approach gives a more accurate picture of heterogeneity in the reservoir and indicates if the strata of interest is continuous. This is why it is necessary to dig deeper for a better understanding. By combining the latest seismic and chronostratigraphy, two delta systems were found to be separated in time.

The next step was to update depth and thickness maps, using velocity models. Doing this allowed Shell to discover that deviations in the contour depth maps were picking up an artefact. As a third step, the major faults, polygonal fault density in Wangarlu Fm, and pockmarks were mapped. Generally, polygonal faults are thought to be sealing and pockmarks are thought to be leaking types. But Owain encourages geologists to understand these faults through sampling them and steering clear of the pockmarks until the system is understood.

The area of interest is then constrained by the integrated data from 2D and 3D seismic, well and legacy data. The recommendations are to assess the capacity and mechanical properties of the AOI and use Common Risk Segments to narrow it down.

Discussion:

What are the CO_2 sources near Darwin and when would Shell make the investment? This discussion point was raised because it is important to have nearby sources that could potentially be retrofitted and easily have pipelines run to and from. However, the storage site cannot and should not be next to the Petrel field. Shell would make the decision to invest in a CCS site in the area of interest if a business case existed as was the case with Goldeneye.

Australia CarbonNet Stage 3 – Nick Hoffman, CarbonNet

One benefit of offshore storage is the relative lack of disturbance to the general public, with the exception of marine industries such as the fishing industry. Offshore CCS activities must be demonstrated not to interfere with such industries. Source-to-sink matching is the crucial step because safe storage is not always proximal to the capture plant. Location is a big reason why offshore works. There are good offshore geological basins and good data. Partnering with industry is a great strategy because whilst governments sometimes mandate transparency, often you must be in the petroleum industry to get the data, so we need to emphasize a working relationship with industry.

The Lessons from the Gippsland Project: We should take a portfolio approach: multiple options so that one single failure does not kill a whole project. In the early stages, scale of capacity must be understood: if you want to store 100s million tonnes for a commercial project down the line, ensure that your early plans consider this capacity. Essentially, do not use a single site, one capture method, one engagement method philosophy. Seek the low hanging fruit for commercial viability.

The CarbonNet project realizes that a challenge to private sector investment is storage certainty. Government has a role in substantially reducing uncertainty. With government investment of $20 million (AUS Dollars) to date, CarbonNet has identified and peer-reviewed potential storage sites appropriate for 25 to 125 million tonnes of CO_2. CarbonNet has calculated the 3D probability distributions for potential plume paths and is ready for a Declaration of Identified Storage Formation. This creates a bankable asset in resource development terms. Though the CarbonNet project is a relatively shallow-water project, this represents the future where CCS will move into the most cost-effective areas offshore.

Ultimately, gaining public acceptance from commercial fishing, oil and gas industry, and local governments and communities is key to submitting the Environmental Plan for regulatory approval. Additionally, environmental baseline technology validation is funded by the Commonwealth Education Investment Fund to validate technologies and build community and regulatory confidence. Through this effort, the CarbonNet Project will transition to the private sector by 2020.

Discussion:

What will be the pressure effects of injection and will fluid extraction be required? The petroleum industry has been producing here for 50 years; pressure depletion now extends-over hundreds of kilometers. It is unlikely that the pressure increase from injection at this one site will come up to pre-production limits. None of the faults shown in the 2D data should reactivate at the level of pressure. If multiple projects store 50 Gt CO_2, then it would be time to think about fluid extraction.

CO_2-storage screening for Norway – Niels Peter Christensen, Gassnova

Gassnova has three initiatives which are advancing CCS, and these integrates R&D, demonstration projects, and full scale carbon storage. Government buy-in along with international cooperation has made Norway an example for success in CCS.

There are challenges to bankable off-shore storage basins: Norway is not a large producer of CO_2. Their conventional opportunities are large depleted fields in the North Sea Basin: Smeaheia, Utsira South, Johansen. Transporting distances get too large as you go north. Prospects also fail because drilling an appraisal well is done at a large cost. Funding up front is thus a difficult process. However, industry was willing and Statoil was hired by the Ministry of Petroleum and Energy to bring three sites up to DG1 level. When evaluating these basins, good permeability and multimillion tonnes per year capacity was most important. The Utsira Formation was found not to have sufficient storage capacity available for the current project in un-licensed acreage. The Johansen Storage Complex was also rejected because of little industry experience with the storage formation and how the migration towards the Troll field would work. The Heimdal Formation had an active aquifer and hardly any pressure depletion. But the predicted lifetime is less than 10 years which would made the platform operations costs prohibitive in that time scale. Smeaheia has good data availability with indicates a tight structure and ample storage capacity beyond Norway's needs.

This results in more questions: Is there a business case for importing CO_2? What kinds of transport options are possible? Will it be ship transport or reuse of infrastructure? The concept selection and FEED study will be completed in 2017 and the decision to move forward is due in May 2018.

Creating a business case with CO_2-EOR has resulted in projects to be found non-commercial due to these transport questions, expensive top-side modifications, and alternative flooding mechanisms. Statoil and Gassnova think that the need for CO_2 mitigation will create business potential in this sector.

EASiTool for storage capacity estimates – Seyyed Hosseini, BEG

The purpose of this talk was to give an introduction to the user-friendly tool the GCCC has been developing to evaluate CO_2 storage capacity. Most static method lack accuracy as compared to other dynamic methods (Numerical simulations or analytical tools). EASiTool (Enhanced Analytical Simulation Tool) uses analytical models, captures dynamic data, and can perform sensitivity analysis (e.g. using tornado charts).

EASiTool assumes homogeneous properties, constant injectivity, no structure, two phase flow of brine and CO_2, and pressure dependent fluid properties. It can use superposition for multi-well scenarios. Comparing the USGS model and EASiTool, one finds that there is a lot less capacity with constant injectivity over time because the EASiTool is considering pressure considerations.

Discussion:

Why doesn't a simple material balance work? Time frame analysis is a challenge to the material balance. Capacity will depend on permeability when the boundary conditions are closed.

Session 1 Discussion

This discussion evolved into a conversation about seal efficiency: How do you determine which seal is efficient if you don't have local data? The easy answer is to choose a basin where you know seals are good from good data. Otherwise, measure seal properties, involve capillary entry pressure and take core.

What do we mean by leak? But the public care when we say the word leak. Pockmarks should be explained as a natural process where fluid leaks. Scale needs to be understood; this is a large tank with a teaspoon of escaping CO_2. Our phrasing should reflect the nature of the situation: we want to prevent CO_2 from migrating out of the reservoir or caps. This is one of the reasons to go offshore.

Session 2: Technical deep-dive monitoring-- how much is needed, how much do regulators need, limits of Monitoring. Chair Tim Dixon

Projects have received permits for onshore and for offshore storage. So the regulations that exist are workable. The following session laid out the reality of this process for offshore.

Goldeneye monitoring for EU permit and cost reductions – Owain Tucker, Shell

The Peterhead CCS project had reached the point just prior to the final investment decision. The project had satisfied the UK and EU regulatory environment. According to the EU Directive, the monitoring plan must be incorporated into effective corrective methods and updating the risk assessments with the monitoring. The goal is to be able to transfer the projects back to the state. To do so you must show the conformance over time. Emphasize three points: leakage prevention, talk about how the continuous phase is heading towards a stable equilibrium, and show that no leakage paths are observed.

How do we build a plan that satisfies the EU constraints? Shell performs bow tie assessments. Determine where the most likely risks are. Test the technologies to screen them against leak-paths and find which for what scenario and rank for cost benefit. Employ autonomous technology to save money.

Discussion:

What is the comparison to the onshore QUEST project? QUEST must put effort into groundwater safety assurance as landowners want to know their water is safe. Offshore, Shell needs to satisfy the marine environmental regulators and the fishing industry that the project is not disturbing the marine environment. Shooting seismic is easier offshore.

ROAD monitoring for EU permit – Vincent Vandeweijer, TNO

The ROAD project is a demonstration of an integrated onshore capture, transport and offshore storage CCS project, with a planned capacity for 1.1 million tonnes of CO_2 per year stored at the P18-4 site offshore. The monitoring plan had to comply with the EU regulatory scheme and the emissions trading scheme. A focus was placed on corrective measures taken by industry to ensure conformance for when the project has to be handed over to the government.

The ROAD CCS project is technically relatively simple in comparison to many other CO_2 storage projects, with a single well penetrating the nearly depleted P18-4 gas reservoir and minimum equipment installed on the platform offshore. Vandeweijer summarized their risk-based approach with use of the stoplight analogy. There was consistency in the monitoring plan, the contingency plan and with the risk management and closure plans. The monitoring plan was developed through a deep understanding of the chosen reservoir and site. Site characterization was performed with geomechanical and geochemical modelling, dynamic flow analysis, well integrity investigations, and migration studies. The corrective measures proposed through understanding reservoir behavior could then for instance be developed to include the neighboring reservoir in the plan in case of migration of CO_2 through a fault. It is essential that this process has to be transparent and involve communication with the competent authority and stakeholders at every stage when selecting a corrective measure.

Environmental regulations of subsea geological storage of CO_2 in Norway–Lars Ingolf Eide on behalf of Norwegian Environmental Agency

The NEA has regarded CCS as a prospective measure for CO_2 reduction since it was first utilized in the Sleipner field in 1996. Carbon emissions are considered pollution, so in order to store CO_2, a permit is required from the Norwegian Environmental Agency (NEA) pursuant to the Pollution Control Act. An environmental impact assessment is required for CO_2 storage pursuant to the Petroleum Act. CO_2 storage was done on a commercial scale with a Norwegian regulatory scheme well before the EU Directive was adopted in Norway in 2014. The NEA revised the environmental permits for Sleipner and Snovit in 2016 to meet the EU CCS Directive requirements. In order to get permits to store CO_2 under the EU requirements a project has to satisfy both the NEA and Norwegian Petroleum Directorate. These permits describe the leakage scenarios and mapping natural resources which could be impacted. The monitoring programme and financial security and mechanisms must be defined for the project. The monitoring program verifies the predicted behavior of the CO_2 plume and triggers corrective measures should a leak be detected. The monitoring programme runs from day one until the State decides to cancel it. It includes continuous monitoring of pressure and temperature at the wellhead.

For Snovit this was a success story in how the monitoring programme works: using reservoir simulation models the operator could predict a steady rise in pressure. The operator concluded from pressure measurements that the injectivity was too low to continue with the plan and triggered corrective measures. The operator perforated the injector higher up in the well as a solution. The environmental and petroleum regulators were informed. The corrective measures ensured that there was no leakage to the seabed, and avoided the risk that the gas reservoir above the site could be contaminated by the injected CO_2.

For future work, monitoring methods need to be matured. While 4D seismic is state of the art, it may not be economically feasible to take on a survey at the preferred frequency. Other issues such as leaks below the order of million tonnes may be missed. The current methods do not satisfy the EU Emissions Trading System's (ETS) requirement to quantify leaks with a certain accuracy.

Finally, financial security is required by the EU directive so that all permit obligations will be met over the storage lifecycle. These ensure the monitoring programme, corrective measures, closure and transfer are supported. In Norway, the decision is made case-by-case through the collaboration of the Ministry of Climate and Environment and the Ministry of Petroleum and Energy.

Discussion:

Environmental Benefit-Cost Analysis. CO_2 is taxed at $50 per tonne. Gas sales project picks up the cost for capturing CO_2. No environmental financing done for this project. All permit applications are available to the public, which include the leakage scenario and mitigation plan.

Update on Developing Best Practices for offshore storage in the US. – Melissa Batum, BOEM

In 2010, the Presidential Interagency Task Force on Carbon Capture and Storage examined the existing U.S. regulatory framework and recommended the development of a comprehensive U.S. framework for leasing and regulating sub-seabed CO2 storage operations on the Outer Continental Shelf (OCS) that addresses the broad range of relevant issues and applies appropriate environmental protections. However, this comprehensive framework has yet to be established; therefore, the existing regulatory framework is shared across multiple Federal agencies, including the U.S. Department of the Interior (DOI) and the U.S. Environmental Protection Agency (EPA), and may have jurisdictional gaps.

Under the Outer Continental Shelf Lands Act (OCSLA), the Department of the Interior (DOI), Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE) may authorize and regulate the development of mineral resources (including oil and gas) and certain other energy and marine related uses on the OCS. Under this authority with respect to CO2 EOR and GS, the DOI may permit the use and sequestration of CO2 for EOR activities (secondary and tertiary) on existing oil and gas leases on the OCS and authorize the sequestration of CO2 GS for certain types of projects. Although oil and gas EOR operations occur on the OCS, none to-date have used CO2.

The purpose of developing the Best Management Practice (BMPs) for CO2 offshore transportation and sub-seabed storage was to compile and evaluate relevant information to establish a benchmark that may support the DOI in the potential future development of informed policy and regulatory frameworks. The deliverables are a worldwide annotated literature database (built in EndNote) along with a BMPs with Data Gaps Analysis Report. The BMPs address the following:

1. Site Selection and Characterization
2. Risk Assessment
3. Project Planning and Execution
4. Monitoring
5. Mitigation
6. Inspection and Performance Assessment
7. Reporting Requirements
8. Emergency Response and Contingency
9. Decommissioning and Site Closure

Discussion:

Are there any regulations moving through congress? The current administration isn't keen to clarify or introduce offshore regulations. The Obama administration did have a Presidential Taskforce, but the introduced concepts were not formalized. An important comment: The pie chart from the literature review demonstrates how research dollars have been spent so far in academia and industry. The technical gaps found should be where the research dollars go next to encourage more pilot projects in the emerging industry.

Session 2 Discussion

The discussion spurred by this session touched on how a solid regulatory framework encourages industry to invest in these projects because uncertainty is minimized. In the EU and UK, there is an understanding that the regulatory environment is stable. The Peterhead project seems to be the exception because all the homework was done but the government cut the business case for the project last minute by removing the funding. Generally, however the regulators may change but the intent is stability. In the US, with changing parties, intent is unstable. There is not a guiding precedent in the regulatory scheme.

Another discussion was about long-term monitoring and funding in order to ensure a successful handover to government hands. Generally European, Canadian, and Australian governments expect industry to pay into funds that cover issues if the operator fails. This is a motivating purpose to the EU Directive's financial plan requirement.

The conclusion of this session was that it is a good thing the regulations are evolving to be site-specific rather than prescriptive. Despite Peterhead not launching, the good news was that the permitting process in Europe seems to be successful. Projects have been getting permits which is progress for the CCS industry.

Session 3. Technical deep-dive: Environmental and overburden monitoring – Chair, Katherine Romanak

Leak detection – Keisuke Uchimoto, RITE

Locating the CO_2 signal presents a significant challenge to monitoring in the marine environment. Uchimoto presented his evaluation of side-scan sonar (SSS) as a potential method for detection of CO_2 bubbles and a "bio-oceanogrpahic" geochemical method for detecting high partial pressure of CO_2 (pCO_2) in seawater. The goal is to attribute CO_2 anomalies to either leakage or natural variability.

SSS is an active sonar which can detect seafloor and water column features and objects on the vertical section perpendicular to the moving path. The blank in the center of the scanned image is the water column. Bubbles can be detected from aberrations in this blank. A bubble release experiment was performed to gain a fundamental knowledge of how SSS can be used for bubble detection. Questions to be answered include, 1) at what minimum leakage rate does SSS detect bubbles, and 2) what differences in between SSS bubble images scale with distance? The experiment concluded that while air bubbles at a low leakage rate of 250 ml/min were detectable, CO_2 emitted at a much higher leakage rate of 1500 ml/min provided a weaker signal but was detectable. Provided that bubbles come up straight (which isn't always the case), the distance between observation line and release point can be roughly estimated. So SSS has the potential to assist in finding a CO_2 leakage point.

Another challenge to CO_2 leak detection is the use of a constant value for background pCO_2 when there is high natural viability in this value. In the eastern part of Osaka bay in Japan, this environment exists. Uchimoto explained there is about a 1600 µatm range from winter to summer in the value of pCO_2. In August alone, the range is also too large to apply the background data seasonally. Uchimoto and his team showed that because there is a negative relationship between pCO_2 and dissolved oxygen as a result of photosynthesis, false negatives are prone to occur in O_2-rich water. False-positives are prone to occur in O_2-poor water. So using a constant pCO_2 value is incomplete. Uchimoto proposed using a threshold derived from the upper limit of a prediction interval of the regression line. False-negatives would not be concentrated in O_2-rich water and false positives would not be concentrated in O_2-poor water. Unchimoto points out that there is still room for these false-negative and false positives to occur in his updated threshold approach He asks us to consider if this is error is an inevitability for any threshold approach.

Discussion:

What are the costs and benefits of using SSS for a monitoring programme? Cost can vary, depending on the application. The benefit to using SSS versus hydrophones is that the operator has spatial control over SSS and can potentially detect bubbles over wide scales.

Gulf of Mexico (GOM) shallow overburden work – Tip Meckel, BEG

This talk focused on vertical resolution in the meter scale. The goal is to record vertical resolution in a refined way. Generally, the shallow interval has been ignored in conventional oil exploration; this p-cable tool overlaps. The p-cable system at the BEG consists of a 100m tow line with twelve 25m-long streamers spaced 12.5 meters apart.

The test zone for this system in the Gulf of Mexico were shallow salt structures. Dry wells were surveyed to determine if they were non-sealing. The primary observations were that this was a structurally complex area with evidence of charge. Potentially, it could be a good place to inject CO_2. This was because there was success imaging overburden in detail: they could resolve faults and complex stratigraphic heterogeneity. Additionally, there was identification of potentially leaking geo-systems pathways. This data could be integrated with the coring samples.

Discussion

The data changed the original geologic interpretation. Originally Tip thought that the salt formation wouldn't be a great seal because it is mobile. But with the data he now thinks the opposite is true. The salt formation migrates with the structure, so it is potentially sealing. There is a need more petroleum migration studies.

AUVs for environmental monitoring – Kim Swords- Sonardyne

Progress in the offshore monitoring, measurement, and verification for carbon capture and storage is using autonomy to drive cost savings. This is motivated by two challenges that are intertwined. The impact of CO_2 leakage is not easily detectable and the offshore environment is hostile. There is a need for lower cost, safe monitoring. Sonardyne are the technology lead for an Energy Technologies Institute (ETI) funded monitoring demonstration project. The ETI (http://www.eti.co.uk/) is a UK public-private partnership funded by industry and government departments to facilitate energy technologies needed in the UK.

The project uses an autonomous underwater vehicle (AUV) to perform wide-area surveys of the storage complex. Basic processing of the data is done on the AUV in real time and then sent to shore via satellite link at regular intervals through the survey. The system detects a leak using both active sonar and a suite of chemical sensors. CO_2 leaks in seawater are complex, in shallow water a plume of bubbles is generated which then dissolve back into the seawater, for instance a 10 L/min leak of CO_2 can be fully dissolved in the water column at 3 meters above the seabed. The project also used active sonar landers which are designed to monitor high risk areas, these can detect leak rates as low as 1L/min and larger leak areas at ranges of hundreds of meters. A passive sonar was also demonstrated which listened for the bubble's ringing and can provide a crude estimate of leak rate, but this technology is in the early stage of testing and can currently only detect the bearing to the leak. Detection performance was shown at around 65-m-range.

An interferometric synthetic aperture radar (InSAR) technique is used by geophysicists on land to measure deformation of the overburden for hydrocarbon reservoirs when extraction has progressed to a certain point. Traditional bathymetric sonar surveys are not suitable for this analysis. Sonardyne have designed and built and instrument that uses high accuracy pressure sensors (to measure z), together with acoustic measurements of ranges underwater (x,y) to calculate seabed settlement or heave. Different sensor packaging and sensors are available depending on shallow or deep water needs.

Discussion:

Where does development need to be? Areas for on-going development include (a) gaining more operational experience with the AUV-based system which should include some repeated baseline surveys of a test site at different times, this data would feed into (b) improving and refining chemical detection algorithms operating over short temporal scales and driving better understanding of background variation.

What is the drift in pressure sensors? Drift can occur in pressure sensors for a wide variety of reasons, but is typically due to 'aging' of part of the sensing mechanism. Drift in measurement needs to be clearly discriminated from real seabed movement. As such various characterization and mathematical processes can be employed to maximize accuracy of measurement over long durations.

Session 3 Discussion

In the first part of the discussion on leakage with bubble detection, gas exchange at the surface was considered as an explanation of pCO_2 variability at the Tomakomai project. Questions arose as to whether CO_2 or O_2 was leaving the system faster by mixing in the atmosphere. The regulator asked that a threshold be determined based on only one year of background data which was not enough data to capture environmental variability. Additionally, it was proposed that stoichiometric relationships might be more complex in the ocean.

Does shallow faulting in the Gulf of Mexico condemn a site? Can we demonstrate that these areas have been stable? Whereas detailed information can show faults and might spook regulators, this information also creates a greater understanding of the risks about the site. Many gas reservoirs are found by faults, so faults can be a real benefit because they keep things from moving onshore. Active faults don't condemn a site because you're seeing how they are lighting up their leak points. Strong clues about the feature can be gathered from UHR3D seismic, thus there is more certainty about charging the basin offshore than onshore.

Session 4. Changing the game for CO_2-EOR offshore: Chair, Ryozo Tanaka

The Primary goal of this session is to figure out how to encourage more offshore CO_2EOR.

CSLF CO_2-EOR Task Force update – Lars Ingolf Eide, RCN

The CSLF CO_2-EOR Task Force was created to highlight the main differences between onshore and offshore CO_2-EOR and identify the issues that differentiate CO_2-EOR and pure offshore CO_2 storage. Finally, identifying technical solutions that would benefit both storage and EOR was done.

The Lula Project in Brazil is a model for future projects. The reservoir is well-suited for miscible gas EOR. There was extensive reservoir characterization. There was a robust and flexible development strategy. The project used a water alternating gas (WAG) solution with two WAG injectors and one CO_2 injector.

Approaches for enabling offshore CO_2-EOR include using late-life oilfield infrastructure, focusing on the residual oil zone (ROZ), and understanding issues specific to CO_2-EOR. Subsea systems could save expenses like retrofits or weight issues, effectively reducing CAPEX and OPEX for CO_2-EOR projects. The next generation of EOR technology would incorporate mobility control due to the large scale of well spacing offshore.

However, CO_2 supply chain issues are the main barrier. There are few remaining technical barriers, but political and commercial barriers remain firm.

When designing a monitoring verification and accounting (MVA) programme offshore, it is important to consider the different risk profiles. Additionally, without an established regulatory environment, demonstrating CO_2 storage from a CO_2-EOR project meets similar challenges to the onshore environment. Transitional requirements need to be created.

Establishing CO_2 utilization, storage and pipeline systems for oil fields in shallow and deep waters of the Gulf of Mexico–Vello Kuuskraa, ARI

Large oil fields in the Eastern and East Central Gulf of Mexico offshore offer opportunities for utilizing and storing CO_2 while increasing domestic oil production and federal revenue. There is a time urgency on implementing shallow water pipeline systems for EOR, as most of the 29 sites will be abandoned by 2025. The three-pipeline system needed would require 1.7 Billion USD, but if these fields are plugged the costs increase dramatically. The CO_2 transport from Louisiana and Mississippi would cost 4 USD per barrel, delivering 40 million metric tonnes per year. The US Federal Government would receive 40 Billion USD of royalty revenues based on the technical recoverability in these fields and 80 USD per Barrel.

There is less of a time urgency on the deep water three-pipeline system to feed 63 larger oil fields: 18 of the large deep water oil fields have produced 93% of their original reserves. This system would transport 57 million tonnes of CO_2 at a capital cost of 4.1 billion USD. The sources are from onshore Louisiana, Mississippi, and Alabama. The federal government would receive nearly 64 billion USD of royalty revenue, assuming all the technically recoverable oil would be developed.

Discussion

This evaluation was just for the transport costs. It doesn't cover capture cost. Discussion centered on incentivizing capture in order to get 80 USD per tonne. In shallow waters, recovery efficiencies are better but decline in deeper waters.

US EOR learnings from onshore for offshore – Sue Hovorka, BEG

Hovorka suspects the screening tree used onshore can directly be applied to offshore. However, to get CO_2-EOR offshore, you need a patient investor that understands the time dependencies of permitting and infrastructure. There is competition with CO_2 as a flooding fluid because of US incentives for tertiary recovery. But offshore, using compressors is energy intensive and heavy.

Discussion:

The challenge in the US is to convince the government that CCUS is sequestration. Industry has been hinting they want carbon neutral fossil fuel production which is where CO_2-EOR plays a role.

North Sea technical and economic potential – Stuart Haszeldine, SCCCS. Presented by Owain Tucker, Shell

This work is based on a multi-company study led by SCCS looking at CO_2-EOR potential for the North Sea. There are currently at least three fields using gas-EOR in the North Sea, and from public data it appears that there are around twenty oil fields that have potential for CO_2-EOR. CCS and CO_2-EOR offshore could both benefit from acceleration and be profitable and environmentally important. With CO_2-EOR offshore, there is an economic multiplier effect of 7x, which is a higher multiplier than wind (3.3x) and straight CCS (2.6x) [i.e. for every £1 invested by government the multiplier is the total economic activity stimulated]. Various analyses have looked at a range of economic assumptions and concluded that EOR is economic at $60/barrel. Storage through CO_2-EOR is more secure because of forced interaction with residual oil and water, and so it is more rapidly secure than straight storage in an aquifer. CO_2 accounting has issues: evaluators can choose where to draw boundaries. But if you continue to pump CO_2 in, in due time you would create a net carbon storage process. Accelerating storage can be accomplished via the virtuous circle: additional income streams for CO_2-EOR create a self-reinforcing loop (investment after investment). This would create a transition to sustainable operations offshore in the North Sea.

Discussion: How does the virtual cycle work when we consider a material balance?

In many wells, you're displacing water in addition to oil. That is how you can inject more CO_2 than the oil that came out.

Session 4 Discussion

With regard to the life cycle for EOR, can we prove that the direct and indirect emissions are negated by stored CO_2? What are the boundaries for the assessment? The DOE have commissioned a study that evaluates the life cycle of EOR from cradle to grave starting with the capture point and including all the way to burning oil produced even to gasoline. The result in the mass balance is the stored CO_2 and that is very dependent on the storage strategy. Different WAG ratios may vary that outcome. Discussion here centered on whether operators can recycle the CO_2. Vanessa Nunez pointed out that they have no choice often but to consider most of it as stored because only a small amount of CO_2 is recoverable.

Session 5. Infrastructure developments: Chair, Tip Meckel

CO_2 Transport and storage infrastructure development – challenges and possible way forward, Thomas Berly, IEA

Since the Paris Agreement, CCS is gaining momentum. Because EOR technology is proven, many countries are considering projects. But currently CCS is not on track for the 2 degree scenario at the currently verifiable 0.066 Gt of CO_2 stored. There needs to be a massive, internationally coordinated ramp up of CCS to meet the 2 degree scenario. CCS is critical for supplying 32% of the additional emissions reductions to meet the 'well-below' 2 degree scenario compared to 2.7 degree scenario. . Technically, this is a possible target when couple with a supportive regulatory environment and economic incentives, but it is a massive task. We cannot assume that storage costs will always go down. We must reset our understanding of capacity as being a function of achievable injectivity and economics. The problem must be framed correctly: we need to store a minimum million tonnes per year per some cost. We can do this by government and industry coming together to create enablers. There needs to be an independent appraisal entity with an understanding and acceptance of failure along with the right level of accountability. The CCS narrative needs to be refined. Time is running out: we have ten years to sort this.

Discussion:

Where is the disconnect between the IEA and governments? Governments do not seem to have the IEA's urgency. We need to reinforce the importance of CCS daily. Governments might sing the song we want to hear, but the initiatives are isolated. Additionally, there are some in industry saying they want to achieve zero emissions through means other than CCS. This is where the narrative for CCS must be refined.

Smart Technology for CO_2 handling subsea – Lars Ingolf Eide on behalf of Aker Solutions

The main challenges to CO_2 handling at the subsea level is the lack of a supply chain. Facilities are also not designed for CO_2 handling, which would result in loss of production while retrofitting. This is where subsea processing starts to look attractive. All the building blocks are available and have been qualified for subsea use. An additional benefit is the recoverability in cost from EOR's limited operational time frame.

Aker Solution's zero emission offshore power concept involves producing CO_2 locally for EOR from "short travelled" gas combusted with pure O_2. The power can be used to electrify offshore installations, reducing offshore emissions. Excess power could be sold to the grid. After its use, CO_2 is permanently stored.

Discussion:

Offshore EOR could extend the field life perhaps by 60 years. The platforms were not originally designed for this 60 years. Would the costs of maintenance be prohibitive? For many, the cost of decommissioning was more expensive than doing EOR. In the Gulf of Mexico, the platforms were designed to last a long time.

Re-use of hydrocarbon wells – Gert-Jan Heerens, TNO

Reuse of hydrocarbon wells is not a bad option due to the scale of investment in well construction. But there are challenges. Transparency with the regulatory agencies is very important. Industry and scientific data are not consistent about whether wells will leak over time, with estimates ranging from 0 to 60% of wells will fail over 20 years. In order to create better seals, TNO is using natural formations instead of cement plugs for abandonment. Natural salt formations can potentially collapse to seal breaches. Additionally, bentonite is a material that is better at sealing than cement. For CCS applying the resealing with the natural formation at the end of the injection might be a good selling point. It is important to realize that anything man-made will degrade. So, industry must connect with regulators over this issue. Additionally, using geo-mechanical models, leak paths can be predicted using a Well Integration Forecast System. A project to forecast future well integrity for reuse and P&A is under development comprising prediction of steel & cement degradation in subsurface conditions embedded in a probabilistic integrity forecast model.

Discussion:

We need be transparent about well leakage. If the regulators know what is behind well seals, then they can accept alternatives and solutions. Some bubbles came up in Rotterdam and getting the wells closed was a long process. If we are transparent, we'll have buy-in from the community. This is transferrable to the CCS community.

Session 5 Discussion

Our understanding of the leakage caused by infrastructure is inadequate. In the case of Deep Water Horizon, no one knew how the fluid flow would behave. There is not a research scenario by which we can understand the entire spectrum of negative effects of failure, from tiny leaks that accumulate over time to catastrophic leaks. Fluid flow model are needed in addition to a better understanding of the physics. Could tracers be contained in cements to identify small breaches? LSU has practice wells--can we create failure cases there?

Thomas of IEA stated that massive upscaling of CCS must happen: 1) what is the role for developing countries 2) UNFCCC GCF should be a main driver in starting CCS, but GCF doesn't understand the role of CCS. Does the IEA help the GCF understand this? Yes, developing countries should be involved to meet these scenarios. Non OECD countries are key and must be a part of CCS ramp up. The IEA interacts with the World Bank and Asian Development bank to put CCS on the map and create funding opportunities. But we need to do better.

No CCS without the ‘S’: storage first. Is there any role for utilization without storage just to get the engine running? This is a big debate. But IEA knows we need to put CO_2 away. That is the option. If utilization is a catalyst, we do see the validity. But we need to demonstrate the environmental opportunity of utilization.

Thomas mentioned cost of offshore CCS is going to rise; why wouldn't we see costs get lower when we get better at it. Industry has shown this isn't the case. Will the cost of projects rise? There is a high unit cost for storage projects that are too small. There is a need for larger projects. The first entry into any basin holds all the risks. Over-engineering decreases with experience. However, once you have the first stage completed, you might have to extract water to double capacity. So costs can rise there. The message was doom and gloom, but it should have been costs go down over time. But don't assume they won't go up twenty years down the line.

Session 6. US developments in offshore storage assessment: Chair, Lars Ingolf Eide

Mid-Atlantic Assessment – Neeraj Gupta, Battelle

Neeraj Gupta presented a summary of work from the Mid-Atlantic consortium of companies that are digitizing data and pinpointing places of interest for future work in CCS. The first step was to conduct a regional assessment of geologic CO_2 storage resources in the Mid-Atlantic U.S. Offshore area. Data was compiled from the Delaware Geological survey. The consortium digitized over 1 million feet of log data. For future work, risk factors and storage resource calculations should be performed.

Southeast Atlantic Offshore – Jack Pashin (Oklahoma State University) & Jim Knapp (University of South Carolina)

The data came from the oil exploration in the 70s. Two basins in the South and Mid-Atlantic planning areas were identified: The Carolina Trough and Blake Plateau Basin. There was missing well control data except for some exploration wells. Porosities are favorably at millidarcy scales.

Near-offshore storage on the inner shelf of the Gulf of Mexico – Tip Meckel, BEG

The planning area stretches from easternmost part of Texas coast to central Louisiana. There is interest in studying the giant petroleum fields as analogs for storage. They had plenty of data but had more of an issue in identifying the right structure for storage use. So they are studying depleted oil and gas reservoirs, evaluating saline formations, and engaging the public and other stakeholders. There is complex geology and core has either degraded or been taken away for study. It will take time to process all of the data from this site.

Discussion:

It is imperative to understand how the petroleum systems work so we might be able to engineer a system to mimic it.

Deep ocean basalt formations mineral carbonation – Dave Goldberg, Columbia University

The CarbonSAFE project is a pre-feasibility study offshore in the Pacific Northwest born out of previous on shore carbonation studies in basalt formations in the Columbia River and Iceland

Basalt Formation. Those projects have shown that in situ mineralization occurs quickly. The CarbonSAFE study is taking place in the Cascadia basin, roughly 100 miles offshore, making use of data, core, and infrastructure from six international Ocean Discovery Program (IODP) well completions that exist in this ocean basalt formation. Prior forced gradient tracer experiments have led to some understanding of the hydrology of the system. Knowledge gaps exist in understanding the lateral porosity and permeability structure near the site. The project will collect site-specific lab data on the chemical reactivity of the basalt, and in the future, take advantage of the NEPTUNE network of sensors and power sources for real time monitoring. Potential CO_2 sources nearby include the power plants and manufacturing sectors in Oregon, Washington, and British Columbia, and potentially, the Alberta oil sand industry.. Existing pipeline structures with established right of ways exist through parts of this region. Challenges to sourcing the CO_2 may arise from limits on non-coal-fired sources and issues related to ocean disposal across international lines.

Session 6 Discussion

We're always drawn to locations with data. The places that accumulated oil and gas are a tiny fraction of the volume of area. There are more options but we don't have data. When you compare what's around that field, you have a lot of space. Can you extrapolate the data? Is it an indication of what else was there? Look at existing gas fields and characterize the setting and column heights. Some involve faults; others do not. When you look at them as a population, sub populations aren't behaving differently. Gives confidence that faults in the system don’t serve to limit accumulations sides. You don't see that fault-dominated fields are smaller than others.

Session 7. Conclusions and Recommendations. Chaired by Tim Dixon, Susan Hovorka, Katherine Romanak, Tip Meckel

The attendees agreed the following as the main conclusions and priority recommendations from the workshop.

Conclusions (separated into themes)

How to find storage:

- Site selection methods are becoming mature.
- Examples from different regions show some similarities as well as methods for adapting to regional geologic conditions, source distribution, and national goals and policies.
- Case studies at South Africa and Australia show methods of systematic refinement and down-selecting.
- Lowering risk for projects includes favoring denser data about the subsurface, known injectivity, and proximity of sink to source.
- A conservative approach favors assessing multiple sinks and multiple sources, so that one no-go does not derail the whole project.
- Use current best geologic practices – ie chronostratigraphic instead of lithostratigraphic to understand if target reservoir strata are continuous.

- Projects should not only be based on geological characteristics – the project needs to be large enough to be a business case.

Monitoring:

- A deep dive into monitoring plans shows that these plans are now successfully passing through negotiation with regulators.
- Pragmatism in balancing risk reduction with cost management is illustrated in cases from Peterhead, ROAD, and Norway, although different monitoring approaches are still seen.
- AUV environmental monitoring reduces cost and reduces human safety issues.
- Multiple approaches to overburden and water column monitoring are demonstrated.
- Overburden monitoring gives the ability to characterize and monitor in time-lapse.
- Sensitivity of data and density of data to demonstrate no leakage are beginning to be considered.

EOR:

- CO_2-EOR continues to be a prospective part of storage in Norwegian and UK North Sea, GoM, and basins globally. Information and analysis continues to increase (see major summary by CSLF task force).
- The business case that would allow EOR to be profitable remains elusive. There is competition for capital – onshore first in USA, or other potential energy projects or alternative ways of recovery; delay in payback.
- There are timing and cost issues with re-use of infrastructure offshore – e.g. Norway
- Access to CO_2 will stimulate EOR projects.

Infrastructure:

- Policy approach will shift from individual projects to infrastructure, e.g. Alberta Carbon Trunk Line.
- What are the economies of scale for infrastructure and how can cost be reduced?
- Subsea solutions are coming for adding CO_2-EOR to existing platforms. Components exist, but they need to be qualified for use with CO_2.
- Salt and shale ductility, and bentonite plugs can be used for sealing P&A wells.
- Many options exist for new and reused infrastructure and will be very site specific.
- There is a need for clear regulation in US offshore.

Recommendations:

- Design wells to release CO_2 for research purposes.
- Learn from the USA's experience in re-use of wells for CO_2-EOR.
- Tools are needed for assessing infrastructure.
- More communication with offshore infrastructure owners is needed.
- More communication with institutions such as governments is needed on infrastructure.
- Communicate the importance of CCS for developing countries to entities such as the Green Climate Fund showing the good example in South Africa.
- Address data gaps.
- Qualify subsea system components for use with CO_2.

The presentations are available at [http://www.beg.utexas.edu/gccc/goi.php .](http://www.beg.utexas.edu/gccc/goi.php)

Field Trip

A field trip was organized and led by Tip Meckel to look at the potential for "CO_2 Recovery and Storage on the Gulf Coast", covering the entire CCS chain.

The first stop was to look at a transport facility, GT-Omniport, in the centre of the Port Arthur energy complex, operated by Howard Energy Partners. This has direct access to major transportation means, including shipping, rail, highway and pipelines (including Denbury's Green Line). This facility has the potential to be a CO_2 transport hub. Thank you to Howard Energy Partners for providing lunch.

The second stop was a CO_2 source, the Air Products CO_2 capture facility at the Valero Refinery in Port Arthur. This plant has been capturing CO_2 since 2013, reaching 3.5 million tonnes of CO_2 to date, and sending it 150 km to Denbury's onshore EOR field at Hastings (monitored by BEG).

The third stop was the Sea Rim State park on the coast to look at the depositional environment that creates the potential storage sites close offshore, and the offshore infrastructure potential.

The fourth stop was the Museum of the Gulf Coast. This was to appreciate the industrial history and legacy of the area, which is rich and long in hydrocarbon production and refining, and to hear from local dignitaries. Beaumont was the location for 'Spindletop', the first large-scale oil find in the region which prompted the Gulf Coast oil boom and creation of many famous companies such as Texaco and Gulf Oil, and the resultant high density of refineries still to this day in the area. Many thanks to Jeff Hayes for providing dinner.

Initial feedback from international attendees was that the combination of the workshop and such a relevant field trip covering the entire CCS chain in one locality was extremely interesting for all.

Appendix 1 – Agenda, Steering Committee, and Attendees

2nd International Workshop on Offshore Geologic CO_2 Storage

DAY 1 SUNDAY, JUNE 18, 2017

7:00–8:30pm	*Reception at MCM Eleganté Hotel, Veranda Room (located between the front desk and Starbuck's on the first floor), 2355 I-10 South Beaumont, Texas 77705* *Menu: Light hors d'oeuvres, coffee, tea, water, and a cash bar. Kitchen will remain open until 10:00pm for anyone desiring a late meal*

DAY 2 MONDAY, JUNE 19, 2017

8:10am	Welcome. Sue Hovorka, BEG, Paul Latiolais, Lamar University, Katherine Romanak, BEG, Tim Dixon, IEAGHG

Session 1. How to find storage offshore – mapping and screening for good sites: Chair, Sue Hovorka

8:30am	South Africa from zero to pilot project and offshore assessment – Noel Kamrajh, SANEDI
8:50am	Australia CarbonNet Stage 3 – Nick Hoffman, CarbonNet
9:10am	CO_2-storage screening for Norway – Niels Peter Christensen, Gassnova
9:30am	Deep Saline Formation storage screening in Petrel Australia – Owain Tucker, Shell
9:50am	EASiTool for storage capacity estimates – Seyyed Hosseini, BEG
10:00am	Discussion
10:30am	Coffee and posters

Session 2. Technical Deep-dive Monitoring – How much is needed, how much do regulators need, limits of Monitoring: Chair, Tim Dixon

10:50am	Goldeneye monitoring for EU permit and cost reductions – Owain Tucker, Shell
11:10am	ROAD monitoring for EU permit – Vincent Vandeweijer, TNO
11:30am	Environmental regulations of subsea geological storage of CO_2 in Norway–Lars Ingolf Eide on behalf of Norwegian Environmental Directorate
11:50am	Update on Developing Best Practices for offshore storage in the US. – Melissa Batum, BOEM
12:10pm	Discussion
12:30pm	Lunch

Session 3. Technical Deep-dive Environmental and overburden monitoring – Chair, Katherine Romanak

1:30pm	Leak detection – Keisuke Uchimoto, RITE
1:50pm	GoM shallow overburden work – Tip Meckel, BEG
2:10pm	AUVs for environmental monitoring – Kim Swords- Sonardyne
2:30pm	Discussion
2:50pm	Coffee and posters

DAY 2 MONDAY, JUNE 19, 2017 (CONTINUED)

Session 4. Changing the Game for CO_2-EOR Offshore: Chair, Paulo Negrais Seabra

3:10pm	CSLF CO_2-EOR Task Force update – Lars Ingolf Eide, RCN
3:30pm	North Sea technical and economic potential – Stuart Haszeldine, SCCCS
3:50pm	Establishing CO_2 Utilization, Storage and Pipeline Systems for Oil Fields in Shallow and Deep Waters of the Gulf of Mexico–Vello Kuuskraa, ARI
4:10pm	US EOR learnings from onshore for offshore – Sue Hovorka, BEG
4:30pm	Discussion
5:00pm	End
7:00pm	*Optional: Group dinner at Suga's Please bring $50 cash and you will be given a receipt*

DAY 3 TUESDAY, JUNE 20, 2017

8:10am	Introduction for the day, field trip and logistics – Tip Meckel

Session 5. Infrastructure developments: Chair, Tip Meckel

8:20am	CO_2 Transport and Storage infrastructure development – challenges and possible way forward, Thomas Berly, IEA
8:40am	Smart Technology for CO_2 handling subsea – Lars Ingolf Eide on behalf of Aker Solutions
9:00am	Re-use of hydrocarbon wells – Gert-Jan Heerens, TNO
9:20am	Discussion on new versus re-use of existing infrastructure – Tip Meckel to chair
10:00am	Coffee and posters

Session 6. Panel discussion on US developments in offshore storage assessment: Chair, Lars Ingolf Eide

10:30am	Mid-Atlantic Assessment – Neeraj Gupta, Battelle
10:40am	Southeast Atlantic Offshore – Jack Pashin (Oklahoma State University) & Jim Knapp (University of South Carolina)
10:50am	Near-offshore storage on the inner shelf of the Gulf of Mexico – Tip Meckel, BEG
11:00am	Deep ocean basalt formations mineral carbonation – Dave Goldberg, Columbia University
11:10am	Discussion
11:30am	**Session 7. Conclusions and recommendations: Chairs, Susan Hovorka, Tip Meckel, Tim Dixon, Katherine Romanak**
12:00pm	End
12:00–7:00pm	**Field trip** incorporating aspects of the full CCS chain: 1) Air Products capture facility, 2) Midstream transport terminal including rail, vessel and pipeline transport, 3) modern analogues of storage formations at the Texas coast, and 4) Museum of the Gulf Coast, Port Arthur Texas. Lunch and dinner will be provided. The bus will return to the hotel after the event.

We thank Bart Owens of GT-Omniport for generously providing lunch at their facilities on the field trip Tuesday afternoon. We offer our sincere thanks to Jeff Hayes of Port Arthur for his support for the dinner on Tuesday night. The event could not have been possible without the thoughtful involvement of Tom Neal, the Director at the Museum of the Gulf Coast - thank you!

POSTERS

Title	Presenter / Author	Affiliation
Use of high-resolution 3D marine seismic for characterization and monitoring of offshore CCS sites	Tip Meckel	Gulf Coast Carbon Center, The University of Texas Bureau of Economic Geology
CO_2 Storage Potential of the MAFLA Shelf, Eastern Gulf of Mexico	Jack C. Pashin	Boone Pickens School of Geology, Oklahoma State University
Public and stakeholder understandings of offshore CO_2 storage and implications for monitoring: The case of the Tomakomai CCS Demonstration Project	Leslie Mabon	School of Applied Social Studies, Robert Gordon University, Scotland
Long Term Prediction of CO_2 flow Behavior by Field Scale Flow Simulation Model	Yutaka Tanaka, Daiji Tanase, Takayasu Honda	Japan CCS Co., Ltd.
Carbon Dioxide (CO_2) Project in the Brillante Field.- Sustainable EOR Project	Heron Gachuz Muro	Pemex Exploration & Production
Tomakomai CCS Demonstration Project - Environmental Impact Assessment and Leakage detection	Jun Kita	Applied Biology Group, Marine Ecology Research Institute
CO_2 storage options and CCS development in The Netherlands	Filip Neele	TNO
Brazil Country Update	Paulo Negrais Seabra	Independent Consultant, formerly Petrobras
Use of natural and artificial tracers to detect and quantify CO_2 leakages at the seafloor from marine CO_2 storage sites	Anita Flohr	National Oceanography Centre, University of Southampton, UK, Carbon
Carbon Sequestration in the Southeastern United States: Past, Present, and Future	Camelia C. Knapp	School of the Earth, Ocean, and Environment/Earth Sciences and Resources Institute, University of South Carolina
EASiTool : An Enhanced Analytical Simulation Tool for Storage Capacity Estimation	Seyyed Hosseini	Gulf Coast Carbon Center, The University of Texas Bureau of Economic Geology

INTERNATIONAL STEERING COMMITTEE

Tim Dixon, IEAGHG (Chair)

Katherine Romanak, BEG (Co-Chair, Host)

Susan Hovorka, BEG (Host)

Tip Meckel, BEG (Host)

Paul Latiolais Lamar (Host)

Thonda Harvey Lamar (Host)

Anthony Surridge, SANEDI

Noel Kamrajh, SANEDI

Lars Ingolf Eide, Research Council of Norway

Traci Rodosta, US DOE NETL

John Litynski US DOE

Di Zhou, China Academy of Sciences

Filip Neele, TNO

Paulo Negrais Seabra, Independent Consultant, formerly Petrobras

Ryozo Tanaka, RITE

Owain Tucker, Shell

Philip Ringrose, Statoil

Michael Carpenter, Gassnova

ATTENDEES

Name	Company
David Adelman	University of Texas at Austin School of Law
Melissa Batum	Bureau of Ocean Energy Management
Thomas Berly	International Energy Agency (IEA)
Patti Berry	Southern States Energy Board
Alain Bonneville	Pacific Northwest National Laboratory
Kristen Carpenter	Louisiana State University
Niels Peter Christensen	Gassnova SF
Lydia Cumming	Battelle
Tim Dixon	IEAGHG
Hui Du	Louisiana State University
Lars Ingolf Eide	Research Council of Norway
Anita Flohr	National Oceanography Centre, University of Southampton, UK
Heron Gachuz Muro	Pemex
Ramon Gil Egui	UT-Austin, BEG
David Goldberg	Columbia University
Arne Graue	University of Bergen
Neeraj Gupta	Battelle
Stuart Haszeldine	University of Edinburgh
Gert-Jan Heerens	TNO
Brian Hill	Southern States Energy Board
Nick Hoffman	The CarbonNet Project
Seyyed Hosseini	UT-Austin, BEG
Susan Hovorka	UT-Austin, BEG
Carlos Jenkins	SME
Noel Kamrajh	Sanedi
Camelia Knapp	University of South Carolina
James (Jim) Knapp	University of South Carolina
Vello Kuuskraa	Advanced Resources International
Chi-Wen Liao	Industrial Technology Research Institute
Shangmin Lin	Deloitte
Tip Meckel	UT-Austin, BEG

ATTENDEES (CONTINUED)

Name	Company
Robert Mitchell	Global CCS Institute
Paulo Negrais Seabra	Independent consultant
Vanessa Nunez-Lopez	UT-Austin, BEG
Hilary Olson	UT-Austin, BEG
Jeffrey Palmer	ExxonMobil Exploration
Jack Pashin	Oklahoma State University
Mileva Radonjic	LSU
Traci Rodosta	DOE-NETL
Katherine Romanak	UT-Austin, BEG
Babak Shafei	AquaNRG Consulting Inc.
Chung Shih	Leidos
Jeff Summers	U.S. Department of Energy
Alex Sun	UT-Austin, BEG
Kim Swords	Sonardyne
Ryozo Tanaka	RITE
Gary Teletzke	ExxonMobil Upstream Research
Burt Thomas	DOE NETL
Ramon Trevino	UT-Austin, BEG
Owain Tucker	Shell
Peter Tutton	University of Texas
Keisuke Uchimoto	Research Institute of Innovative Technology for the Earth
Betsy Valente	U.S. EPA
Vincent Vandeweijer	The Netherlands
Robert Wenger	ExxonMobil
Joshua White	Lawrence Livermore National Laboratory
Neil Wildgust	Energy & Environmental Research Center
Grace Womack	Drexel University
Michael Young	UT-Austin, BEG
Sophia Zabaras	Shell
Di Zhou	UK-China (Guangdong) CCUS Centre

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IEA Greenhouse Gas R&D Programme

Pure Offices, Cheltenham Office Park, Hatherley Lane,
Cheltenham, Glos. GL51 6SH, UK

Tel: +44 1242 802911

mail@ieaghg.org
www.ieaghg.org