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IEAGHG Meeting Report 2020-TR02 April 2020

4th International Workshop on Offshore Geologic CO_2 Storage

International Workshop on Offshore Geologic CO_2 Storage

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This report was prepared by Alex Bump and Katherine Romanak of BEG, and Tim Dixon of IEAGHG, with input from the presenters.

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

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- Katherine Romanak, BEG (Co-chair)
- Guttorm Alendal, UIB (Host)
- Susan Hovorka, BEG
- Tip Meckel, BEG
- Noel Kamrajh and Tony Surridge, SANEDI
- Filip Neele, TNO
- Paulo Negrais Seabra- Independent Consultant (formerly Petrobras)
- Ryozo Tanaka, RITE
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International Workshop on Offshore Geologic CO_2 Storage

Meeting Report

4th International Workshop on Offshore Geologic CO_2 Storage

Date and location:
11-12th February, 2020 at the University of Bergen

Hosted by:
The University of Bergen

In conjunction with:
The STEMM-CCS Project Open Science Meeting

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The University of Bergen
Gulf Coast Carbon Center at The University of Texas at Austin's Bureau of Economic Geology (BEG),
Carbon Sequestration Leadership Forum (CSLF)
IEA Greenhouse Gas R&D Programme (IEAGHG)
STEMM-CCS Project

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Executive Summary

The 4th International Workshop on Offshore Geologic CO_2 Storage was held 11-12 February 2020, hosted by the University of Bergen in conjunction with the EU-Funded STEMM-CCS project in Norway. The workshop addressed how to develop CCS projects with offshore storage and built on the recommendations and topics raised at the previous workshops. The aim of the workshop series is to facilitate sharing of knowledge and experiences among those who are doing offshore CO_2 storage and those who are interested, and to facilitate international collaboration on projects. Over 150 attendees from 18 countries participated in this 4th workshop.

The agenda included sessions on infrastructure, project updates, emerging country needs and progress, deep subsurface monitoring and modelling (shallow monitoring was covered by the STEMM-CCS portion of the workshop), regulatory frameworks and brainstorming toward an international project. Each session included discussion, and the workshop concluded by agreeing overall conclusions and recommendations. There were also twenty poster presentations for the Offshore Workshop.

Notable points arising from the presentations and discussions included the development of the Northern Lights integrated CCS project. This project is leading the way towards developing CCS hubs with industrial sources such as cement and waste incineration. We heard at the workshop that additional projects are now planning similar hubs with phased sources which brought up the notion that oversized transport infrastructure should be built to accommodate expansion of CO2 volumes over time. Also of note were discussions around the approved provisional application to the 2009 CCS Export Amendment within the London Protocol which now makes it possible for CO2 to be transported internationally for offshore storage. The group was the first international group to visit the future site of the Northern Lights CO2 storage hub. Key conclusions and recommendations were agreed.

Key conclusions included:

- Many offshore projects are now being planned, and many of these are considering hubs with phase-in of sources, hence needing to oversize transport infrastructure at the start, and recognising that now CO_2 can be exported internationally with new provisions to the London Protocol.
- There are benefits to CCS deployment in learning from hydrocarbon knowledge, including significant cost reductions, especially with examples from Northern Lights.
- Based on industry project perspectives, it was emphasised that MMV costs can be reduced by MMV strategies being risk-based and with a 'tiered' approach.
- A technical aspect from several projects was around depleted fields having the challenge of pressure drop from well head to reservoir, hence needing management of CO_2 temperature
- Inspection of legacy wells at various sites show very few wells leaking thus leakage from legacy wells may be less of a problem than first thought.

Recommendations included:

- Continue information sharing, such as with these workshops, the exchange of experiences, and getting more developing countries to these meetings.
- Regulatory authorities should consider re-use of infrastructure before requiring decommissioning.

- There is great potential for offshore CCS, and a need to communicate this to governments and other stakeholders.
- As Nationally Determined Contributions (NDCs) under the Paris Agreement get updated, more countries will need to include CCS. So it's important to make countries aware of their own potential for offshore CO_2 storage, or potential for export to neighbouring countries with offshore CO_2 storage.
- The CCS community would benefit from having offshore sites to practice and learn from, e.g. a well or a fault in an existing field that can be tested and investigated, similar to an offshore equivalent of CAMI site in Alberta.
- More knowledge is needed of the role of the overburden in retaining stored CO2
- Projects should consider oversizing transport to accommodate addition of CO2 sources over time.
- There is a need for more sponsorship for delegates from developing countries to attend these meetings
- Baby steps should be taken towards developing offshore projects, analogous to testing capture technologies
- Change the language to be more positive, e.g. “containment” instead of “leakage”
- Focus on the benefits of CCS rather than the risks
- Educate regulators and legislators on CCS—benefits, appropriate boundaries, clarification/framework needed
- Communicate how CCS impacts SDGs
- Distinguish between short term and long term regulatory needs
- Use experience to inspire funders to go big: e.g. look for a big platform akin to the international space station.
- Create an investment-friendly framework for CCS to de-risk investment.

In conjunction with the workshop, the STEMM-CCS open science meeting shared key results, technological developments and experiences from four years of intensive research into the environmental monitoring of offshore CO_2 storage.

Many thanks to the University of Bergen and the STEMM-CCS project for hosting and sponsoring and to CLIMIT for sponsoring. Thanks to the Carbon Sequestration Leadership Forum for their support, and to SANEDI for enabling this support.

Presentations related to the 4th International Workshop on Offshore Geologic CO_2 Storage can be found at http://www.beg.utexas.edu/gccc/4th-international-offshore-workshop-stem-ccs

The presentations relating to the STEMM-CCS portion of this workshop are not reported herein but presentations can be found here: http://www.stemm-ccs.eu/OSM-IOW-presentations

Welcome

A welcome was given by Gunn Mangerud (Dean for Climate & Energy Transition at University of Bergen), Katherine Romanak (BEG at University of Texas) and Tim Dixon (IEAGHG). These international workshops on offshore CCS arose from a recommendation by the CSLF Task Force on Offshore Storage in 2015. The workshop series was then initiated by the University of Texas Bureau of Economic Geology (BEG) and organised jointly with IEAGHG. Reports of each workshop are published by IEAGHG. This fourth workshop addressed and built on the recommendations from the third workshop, continuing the theme of 'How to do'. It was observed that recommendations from the third workshop had been acted upon by IEAGHG, BEG and others.

Session on Infrastructure

Phil Ringrose (Equinor): Use of existing infrastructure and knowledge base by Northern Lights

The Northern Lights Project is focused on sequestering industrial CO_2 emissions (cement, steel production, etc.) into saline aquifers. Many potential capture projects explicitly do NOT want their CO_2 to benefit the oil industry, which discourages potential uses for EOR. Arguably however, it is the CCS industry that will benefit most from the oil industry in terms of applicable learnings and cost savings.

- Subsurface infrastructure—very substantial savings
- Well technology—substantial overlap
- Exploration databases and geologic knowledge—nearly priceless
- Reservoir technology—substantial overlap

Northern Lights is designed to take 1 tanker load of CO_2 at a time and inject it 110km away via 12" pipe, at an annual injection rate of up to 5Mt. With a view to future scale-up, an associated project has just drilled the Gladsheim well, which was a hydrocarbon exploration well, with a secondary CCS objective. The CCS data acquisition program was added to cover the outcome if no hydrocarbons were found, and good storage potential has now been confirmed. Here too, the CCS program benefitted from the hydrocarbon industry. Not only did oil exploration mainly pay for the well, but quantifying storage risks leverages a huge hydrocarbon industry knowledge base on fault seal, geomechanics, induced seismicity, etc.

Looking farther ahead, the vision for the development of CCS hubs is informed by decades of experience in hydrocarbons.

Discussion

Are there cost savings in CCS projects as compared to hydrocarbon projects, given the difference in CO_2 handling requirements vs CH_4 (or other explosive fluids)?

Costs are much cheaper for handling CO_2 than for explosive fluids, even accounting for the extra corrosion requirements of CO_2

Non-explosive fluids also allow the use of minimally manned (automated) facilities which also helps reduce costs

Russ Gilbert (Pale Blue Dot): How to develop storage near and around existing infrastructure

Economics favor developing storage near existing infrastructure but progress is needed in several areas to make that happen:

- Regulation: parallel storage and petroleum licenses.
- Business model: Needs to be developed with government.
- Value proposition: Storage is likely a low margin business with a very different risk/reward profile to oil and gas. We will need to minimize the cost base and maximize the injectivity and storage volume.

Most factors are double edged, with both positive and negative elements. For example, the Acorn CCS was given a cost challenge and makes a good case study. The re-use of existing infrastructure (pipelines plus onshore terminal) saved ~750M GBP. The use of legacy wells contributed further savings and both contributed to faster project development.

The pros and cons generally favor brownfield development for CCS storage. The critical risk is cost-effective mitigation of legacy well leakage risk.

Discussion

Was EOR considered for Acorn? Why or why not?

No, but almost certainly for political reasons. I don't see a downside personally, but additional hydrocarbon production would need to be de-carbonized.

So it could be cheaper if EOR were not involved?

Maybe but you still have to decarbonize hydrocarbon production which comes at a cost.

Filip Neele (TNO): Issues with reuse of existing fields infrastructure—lessons from Porthos project

There are many depleted gas fields in offshore Netherlands that could be used for CCS. In total there is ~1Gt of storage capacity in 100 fields. Use of these could also re-use existing infrastructure.

In the Netherlands, onshore CCS is delayed until CO_2 storage is demonstrated offshore. Offshore, CCS competes with windfarms and energy storage uses for existing fields. That said, the first gas fields are now being re-developed for CCS by the Porthos consortium.

The first phase of the Porthos development is the P18 cluster, 25km offshore, with about 35Mt capacity. Further phases are possible and they are looking at timelines for further development and ranking opportunities.

Regarding the re-use of infrastructure for offshore CCS, the key risk is managing pressure and temperature. Going from a high pressure pipeline to low pressure reservoir creates temperature drop, which is a safety risk that needs to be managed. Wellhead temperature should remain close to or above the freezing point, while bottom-hole temperature should remain above about 15C to avoid forming hydrates. Model experiments show that wells in depleted fields can have a minimum flow rate as a result of these temperature limits temperature limits (the exact number depends on tubing, reservoir,

etc.). That could limit the operational flexibility of the entire system. Shut-in transients must also be considered in design. Last, conformance monitoring needs to be defined and developed and may still be prone to false assessments.

Sarah Gasda (NORCE): Plugging and abandoning strategies for storage development

There is a huge density of wells in mature producing hydrocarbon basins. Most are designed for lifetime of less than 50 years. To take two examples, 50 years of drilling in the Norwegian continental shelf (CNS) has produced a stock of ~7000 wells. The Western Canada Sedimentary Basin (Alberta) has ~200,000 wells. The result is that there are likely to be 50-200 wells within the radius of influence of a typical injector.

All wells will be plugged and abandoned, but practices vary significantly and corrosion and mechanical fatigue create further uncertainty. We know that legacy wells often leak. Cased holes are more likely to leak and leakage tends to be from shallower zones than the production. However, monitoring shows that only ~5% of Alberta wells actually leak. A CNS study found 3 abandoned wells leaking biogenic CH4. Further study is needed to understand the prevalence of well leakage on the Norwegian continental shelf.

We would like to be able to predict leakage for CCS, either by downhole surveys or by measuring natural leakage. Study of abandoned producer from a CO_2 field shows the risk is the interfaces between steel, cement and rock, not the cement itself. The Alberta case study of 1100+ wells showed that even with 5% leaky wells, there is very little actual leakage (rates are low).

For CCS, we often ask how to cost effectively restore cap-rock integrity at P&A. If wells leak, the impact may be far more significant for public perception than for the environment.

Discussion

Historically it was believed that infrastructure reuse was extremely difficult. That's not what I'm hearing today. What is your view?

I don't know any CCS wells that reuse old wells.

Many gas pipelines have a very tight tolerance for fluids that go through them. Many are in very good shape. As long as dry CO_2 goes into them, they are probably fine.

Goldeneye was going to reuse old wells with new tubing. It's viable at least in theory.

Session on Deep subsurface monitoring and modelling offshore CO_2 storage

Martin Landro (NTNU): Geophysical monitoring in the overburden, what can we detect?

Sleipner has created the chance to experiment with different geophysical monitoring tools in the overburden, including time-lapse electromagnetics (EM), seismic, gravity surveys. Seismic works best for shallower layers, but a simple mass balance predicts a gravity anomaly that may help with imaging injected CO_2 in deeper layers.

Other tools also show promise. Optical seismology is a rapidly evolving tool that shows clear detection of earthquakes and fishing vessels and may work for CCS. Electromagnetics, including Controlled Source Electromagnetics (CSEM) and magnetotellurics (MT) should work but is unproven as yet. CO_2 is a highly resistive fluid that should show up well.

Looking to learn from hydrocarbon experience, a gas blow-out February 4-14, 1989, emplaced gas in shallow reservoir, which is analogous to a leak from a CO_2 reservoir and a chance to try different detection tools:

- A gas chimney is visible on seismic beneath platform
- Two repeat seismic surveys show a shallow gas anomaly spreading and thinning with time
- OBS (Ocean Bottom Seismic) also showed frequent shallow seismic events during the leak
- A 1991 seismic survey shows fingering amplitude bloom ~1.5km radius around well

Shallow seismic using an electric source (bubble gun) offers high resolution mapping 50-100m below sea floor, which can complement deeper, lower resolution surveys. In conclusion, monitoring is best with a combination of methods and joint inversion.

Discussion

Were the 1989 micro seismic events a double-couple like typical earthquakes or something else?

Not earthquakes, just sands stressed by fluid migration, magnitude unknown but likely M<1. There was a clear signal at less than 500m. It's basically listening to gas migration, comparable to Groningen field with lots of small seismic events

Great example. How much methane escaped into shallow layers?

Saga Petroleum estimated the total amount of gas that escaped to be between 200 and 370 million standard cubic metres.

Marcella Dean (Shell): Offshore monitoring for CCS—safe and effective monitoring at lower costs

There are several questions around monitoring of offshore CCS:

- How would an operator ensure safe long-term monitoring?
- What would marine monitoring look like?
- How to reduce cost?

We suggest risk-based measuring, monitoring, verification (MMV), which includes a base case plan, contingency plan, and a corrective measures plan. It's risk based, comprehensive, and adaptable. Pre-, syn-, and post-injection monitoring would allow an operator to build and calibrate a model, and demonstrate their ability to predict plume behavior and therefore minimize the need for further long-term monitoring.

A hypothetical example would include identification, assessment, mitigation, and monitoring of risks. It would start with a baseline and risk-based monitoring. Tiers of further monitoring would be triggered

by observations where needed. The focus would be on in-well technology and increasing value through MMV data integration and automated processing and interpretation.

At Goldeneye, 75% of all MMV costs were related to seismic imaging. A further 17% of the cost was a single stand-alone DAS VSP survey of 4 wells.

Future projects could include temperature monitoring via fiber optic cable outside the wellbore. There are large opportunities for machine learning and automated data interpretation and detection.

Discussion

There is lots of data coming!

Jen Roberts (University of Strathclyde): Pressure, faults, and CO_2 leakage

We need to understand pressure conditions in the overburden. Pressure seals may be an important site selection criterion. Pressure seals are defined here as a seal layer (the caprock or any unit in the overburden) with anomalously high pressure (as compared to the hydrostatic pressure). Encountering overpressure while drilling is common in hydrocarbon exploration, and the pressure seal could be highly effective, but has not been talked about much so far for CCS.

We looked at natural CO_2 seeps in Italy and tried to figure out factors in leakage. Overpressure in the overburden (often but not always the caprock) was strongly linked to CO_2 retention. Leaking reservoirs tended to be located within 10km of modern extensional fault systems that break surface, which is intriguing but not clear causation.

Understanding the overburden pressure conditions could be a useful site selection criteria and could potentially reduce monitoring requirement. Importantly: the data is available – pressure conditions are reported in/can be deduced from drilling records.

Discussion

You're worried about the caprock leaking but could it actually be a better seal? We may be underestimating how much sealing capability the overburden can offer.

General discussion

What's smallest amount of CO_2 you can detect?

Depends on where and with what method, how far you are from the leak, etc. On top of a leak with hi-res seismic, we can detect a few tons. With seismic methods small leaks can be clearly detected. If you are trying to track injected volumes, seismic is less sensitive.

All agree that 4D seismic is a good early detection tool but the cost is high. How big is the seismic cost compared to overall storage cost?

We need to do what's fit for purpose. We need to show that plume is where it's intended to be. It may not be important to show the exact edges, just that it's under the seal. You should always do a baseline survey such that you can do 4D if needed. The cost is small relative to the overall storage project.

Are there many examples of CCS with pressure seals? Perhaps the Southwest Hub?

The SW Hub quite unique because there is no seal in the overburden – and so there is no overburden overpressure. I don't know about others projects. Open to room? It's the topic of a PhD at Strathclyde that's about to be advertised!

I'm intrigued by the concept of cyclic monitoring. Is there potential for an engineered solution? That is could you increase pressure in overburden in response to a leak?

That idea has been suggested. I think there is work to be done in studying the role of pressure in overburden and underburden.

There's an example from Ekofisk field of injecting into a shallow shale. It created a M4.3 earthquake. I wouldn't recommend it! It's similar to fracking of unconventional reservoirs.

Session on Regulatory Frameworks

Tim Dixon (IEAGHG): London Protocol for CO_2 export resolution

The London Convention and Protocol is a good international treaty. It was agreed in 1972, has some 87 countries, and it stopped dumping of wastes in ocean. In 2006 an amendment was approved to permit offshore CO_2 geological storage and this came into force after 100 days. In 2009 an amendment was approved to allow export of CO_2 for offshore geological storage, however to come into force it requires ratification by 2/3rds of countries but only 6 have done so to date, which raises the question of how to allow the export of CO_2 while ratification is pending.

Norway and the Netherlands proposed a provisional application of the amendment. Despite opposition by one NGO, it was adopted by countries by consensus on 11 Oct 2019 and it means that countries can now legally import/export CO_2. The environmental protection was already in place through the London Protocol's guideline documents.

This ability to export is needed for Northern Lights to be able to receive CO_2 from across Europe and is the last significant international legal barrier to be removed for CCS.

Discussion

Is there any worry about a provisional application being used by other factions trying to get initiatives through? Is it an end-run around rules?

Any provisional application would still need approval by countries in plenary so it wouldn't be a back-door route. All countries want to do something about climate change and this was seen as a positive development. The provisional application text still encourages formal ratification of the 2009 amendment.

Martha Roggenkamp (University of Groningen): Legal aspects of re-use of infrastructure

There are two legal regimes:

- Legislation governing offshore removal (covered by international oil and gas law)
- Legislation governing new uses of the sea such as CCS

How to align legal the legal requirements oil and gas facilities with CCS is an open question. UNCLOS is the key overarching body of law. It requires removal of disused facilities but there is no clear definition of "disused." National laws on re-use and CCS are evolving and in various states.

The ALIGN project is looking at different scenarios for the repurposing of oil and gas facilities for CCS:

- CCS license awarded during hydrocarbon production—simplest scenario
- CCS license awarded after end of HC production—relatively simple
- Production ceases/license lapses before start of CCS—most complicated. Who is responsible for infrastructure during the lapse?

In the case of a time lapse, there is a question about whether all infrastructure can be reused or should some be removed. If it is not removed at the end of hydrocarbon production, how do you arrange for th future removal of remaining infrastructure. It is likely that the state is the one to step in during any gap between hydrocarbon production and CCS, although the willingness likely depends on the state involved and it opens a number of questions:

- Who maintains the facilities?
- Does the state appoint an interim operator? Maybe the permit specifies an operator of last resort?
- Who covers costs during interim?
- Is a CO_2 emissions permit required in the interim? Who holds it?

At present this is a complicated issue with no clear answers and it will require some change to current law.

Discussion

Were there any such legal issues with the Goldeneye project and reuse of their pipelines?

It isn't known if there were.

Pipeline legislation for CCS is less defined than hydrocarbons.

How long does an operator have to remove infrastructure?

There is no clear timeline. It depends on the state. For short periods (2-3 years), you might be able to rely on the decommissioning process to cover the gap.

Brian Hill (Crescent RI): Offshore best practice in the USA

Many parties are working on defining best practice for offshore CCS in the US. The SSEB, IOGCC are working on it, the BOEM is involved. Work by the BEG from ~2010 is widely quoted and they are active.

We are uncomfortable with the term "best practice" at the moment. The US has no offshore projects so the focus is on developing "available and leading practices," looking at existing practices and trying to identify the relevant components for CCS. These include:

- Oil and gas practices
- Onshore CCS practices that could be applied offshore
- Outreach and project management

We are now at stage of assembling "the kitchen sink," that is, a comprehensive set of available practices. We will look at what is most applicable to Offshore CCS and aim to refine the list into a set of leading practices. We are looking for conversation with industry to inform on what works and trying to create a traffic light coded matrix of leading practices. The initial roll-out of the project is coming and we will be calling for input!

We are not yet close to an offshore CCS project in the US. There is lots of space onshore for storage and utilization. Currently there is only a carrot and no stick to go offshore. 45Q is not enough to do it.

General Discussion

I like the concept of triggered monitoring, decision logic. Is there something similar already in the oil and gas industry to learn from?

Exception-based monitoring already exists for all kinds of facilities. MMV would also incorporate broader concerns, e.g. environmental baselines, etc.

In the US, OCLSA and MPRSA govern offshore CCS. They allow coal-fired power plant emissions to be sequestered but not from other sources. Do you see that changing?

That's something that will have to be addressed. SSEB doesn't lobby but can inform. Where are the emissions? When you look at coastal emissions (e.g. Houston, Port Arthur) there are lots of anthropogenic CO_2 sources that will need to go somewhere. Decommissioning of offshore production platforms is coming fast and going to force a conversation. SSEB provides a great deal of information to legislators and can help inform and educate.

Session on Project updates

Philip Ringrose (Equinor): Northern Lights

Northern Lights is proceeding well. The business development side is very positive—there are lots of emissions sources to potentially feed in. The next stage gate is coming in spring and we are aiming for an investment decision by the end of year.

The confirmation well just finished drilling in January with the objective to confirm reservoir extent/capacity and seal capacity. The well was drilled as a keeper, down-dip in a large fault block with a 2-degree dip. It is a relatively cheap, vertical well with subsea template and a total depth of 2865m. They performed a Formation Integrity Test (FIT) in the seal and are doing dynamic production tests now

in the reservoir**.** Logs show good reservoir permeability, pending dynamic confirmation, and we have confirmed no pressure communication with overlying sandstone, which is the Troll reservoir in neighboring fault block.

Paulo Negrais Seabra (former Petrobras): Lula project

To date, 15bn BOE recoverable has been discovered in the Santos Basin pre-salt play. Discoveries lie at 5000-7000m depth, in ~2000m of water. The natural CO_2 content in these fields varies from 1% to 80% and ANP (National Agency of Petroleum, Natural Gas and Biofuels) has required no venting of CO_2 a condition for development.

Lula is the largest pre-salt field and has ~10% CO_2 in the gas stream. You could call the Lula project a CO_2 EOR scheme but it's not the traditional type with a depleted field. Platform constraints require limited size and weight for separation system which led to the choice of a membrane system.

Nine FPSOs are working the pre-salt, separating CO_2 from gas. Between production start-up in 2013 and the end of 2018, 9.8Mt CO_2 were injected. Oil is transported by tanker to onshore refineries. Gas is constrained by limited pipelines and sometimes gets reinjected because it can't be flared.

Jiro Tanaka (JCCS): Tomakomai

Tomakomai is a demonstration project, next to a city with 130,000 people**.** CO_2 is sourced from a hydrogen production unit and injected offshore via 2 directional wells with a ~4km step-out. The project achieved its target of 300kt stored in late 2019 and stopped injecting at that point.

Injected CO_2 is monitored with Ocean Bottom Seismic (OBS) and heavily instrumented wells. The pre-injection Bottom Hole Pressure (BHP) was 9.3MPa and rose to only 10MPa during injection (with an engineering limit of 12MPa).Two repeat seismic surveys show a small plume with <30% saturation. No micro-seismicity has been detected that can be attributed to injection.

There was a natural M6.7 earthquake 30km away in Sept 2018 at 37km depth. No effect on bottom-hole pressure (BHP) or temperature (BHT) was detected at Tomakomai. The project was shut in at the time of the earthquake, but it caused an island wide power outage. Expert review found no causal relation between injection and the earthquake

At this point, the project has successfully concluded and the facilities will now enter a new phase.

Darin Damiani (US DOE): US storage resource assessments

Over the last 10 years the DOE's carbon storage program has invested about $1bnin onshore CCUS R&D. Recently the program has started to invest in offshore CCUS R&D to expand the CO_2 storage resource potential of the U.S. We are currently assessing offshore CO_2 storage potential using a regional approach similar to our onshore assessments. 5 projects supported by the storage program completed a preliminary assessment of the east coast and Gulf of Mexico (GoM), with $13.8M of DOE investment. And 2 other projects are currently underway to do a more detailed CO_2 storage assessments of the

GoM, with $16M of DOE investment. These projects are regionally split between the western (GoMCarb) and eastern portions (SECARB Offshore).

Based on preliminary work, the GoM looks to be a vast and nationally-significant CO_2 storage resource. The East Coast is not as data rich as the GoM but a first look at available data suggests CO_2 storage resources could be at the Gt scale.

In addition to the offshore assessment projects, we are also developing tools to aid in offshore storage site prospecting and cost estimation. The National Energy Technology Laboratory (NETL) is currently developing a multi-criteria, multi-GIS layer CCUS screening tool to identify sites/regions best suited for offshore CO_2 storage. The beta release is expected in April 2020. NETL is also developing a cost model for offshore CO_2 storage that is based on their existing and publically available tool for onshore storage. The offshore tool will be useful for considering the cost of an offshore storage pilot project, which is something we want to better understand for program budget planning.

Tip Meckel (UT BEG): GoMCarb Partnership

There are several large clusters of point-source emissions along the Gulf Coast. The largest is between Houston and Port Arthur with 40-50Mt/yr in point-source emissions within 50 miles of coast. Static characterization shows 172 Gt storage capacity in the near offshore on Texas-Louisiana Gulf Coast. We are working on more detailed characterization, loosely based on the SPE scheme. We currently have seismic data coverage along the entire Texas and western Louisiana coasts and are making progress on the mapping.

Mapped closures are generally <30m in height and the faults are generally small, with less than 25m of throw, so fault seal is a significant risk and one that we are working on.

Ultimately the vision is to aggregate onshore sources for storage offshore but existing offshore facilities are aging and we have lost about half of all offshore infrastructure in the last 10 years to decommissioning. The window of opportunity to re-use existing facilities is limited.

Mike Godec (ARI): SECARB Partnership

SECARB focuses on the eastern Gulf of Mexico, which has most of the EOR opportunity. We are looking at both storage and EOR opportunities. The plan is to

- Integrate data to find high quality prospects
- Develop concept for commercially viable projects
- Adapt simulation tools, etc.

The focus of Initial activity is to define what a good project looks like and understand (and shape) the regulation. We are working with OSU to buy a Mississippi Canyon 3D seismic survey and analyze amplitudes, looking for fields with EOR potential. We are looking at how to develop pipeline infrastructure and early project candidates that could build into something like Northern Lights.

Gry Møl Mortensen (SGU): NORDICCS/BASRECCS

NORDICCS was a 4 year project, looking to boost deployment of CCS in the five Nordic countries. It ran from 2011 through 2015, with a budget of 6,2M euro. The main outcomes were:

- A storage atlas (available online https://data.geus.dk/nordiccs/map.xhtml)
- A roadmap to deployment of CCS
- A theoretical capacity assessment of 86Gt in the most prospective deep saline aquifers, and up to 9000Gt in the Icelandic basalts.

BASRECCS is a current network looking at CCS in the Baltic Sea region. The objective is to help enable at least one full-scale CCS project by 2030 and a network of projects by 2040. The plan is to put on an annual Baltic carbon forum, work with EU strategy and build presence in the region.

Filip Neele (TNO): Porthos and ATHOS Projects

Porthos is a consortium out of Port of Rotterdam authority, with Gasunie and EBN. The aim is to develop open access CO_2 transport and storage infrastructure (capture is separated). Four suppliers are currently interested, including Shell, XOM, Air Liquide, and Air Products. 54km of pipeline (33km onshore and 21 offshore) link the terminal with the P-18 gas field, the initial storage target, with about 35 Mt capacity. The plan is to inject 2-4Mt per year. Work is ongoing on permits and a FEED study. Coming milestones are:

- 2020 in-principal FID
- 2021 actual FID
- Aim to be operational 2023

Longer term, there is a vision of Phase 2 and 3 with expanding footprint to include industrial Ruhr CO_2 sources and a wider range of offshore depleted gas fields for storage.

ATHOS is a similar project, but based in Amsterdam and formed of a partnership of EBN, Gasunie, the port of Amsterdam and Tata steel, the major CO_2 emitter in the Amsterdam area. The goal is to realize an open access, large-scale network for CCUS that sequesters 1.5-7.5Mt/yr. The plan is for permitting 2020-2022, FID for construction in 2023 and the start of injection in 2027. At present, bids have just been requested from offshore operators for storage, with awards due at the end of 2020.

Tony Espie (BP): Net Zero Teesside Project UK

Net Zero Teesside is the most advanced of five prospective hubs that together have the potential to substantially decarbonize industry in the UK. The configuration of the Net Zero Teesside hub comprises a gas-fired power station with CCS (a world first) together with a range of industrial CO_2 sources. There are over 50 industrial CO_2 sources in Teesside area, generating 3.1Mtpa of CO_2.

OGCI chose Teesside over 50 other locations. It was a compact site, with strong local support and a variety of CO_2 streams. The plan is to scale up injection in three phases: Ph1: 3Mtpa, Ph2: 5Mtpa, Ph3: 10 Mtpa .

The pipeline is designed for 10Mtpa, running to storage site offshore. The site is the Endurance saline aquifer site that was partially appraised in the previous White Rose project. The concept select phase is now concluding preparatory to entering the concept optimize phase.

The Endurance site is located 160km south-east of Teesside. It is a 4-way dip closure with a salt seal. Modelling suggests >400Mt capacity and the appraisal well shows good injectivity. We anticipate the need to extract water for pressure management when injection ramps up from 4Mtpa to 5. Options for the discharge of hypersaline brine are being evaluated.

The next project stage gate is expected in Q2, 2020 which will lead into optimizing the design. A FEED study is anticipated in 4Q 2020, with FID around 4Q 2021, drilling beginning in 2023 and first injection in 2025.

Russ Gilbert (Pale Blue Dot): Acorn

Acorn is a project to store CO_2 offshore, north of Aberdeen in the UK CNS. The first target will be the Captain Sandstone, which is already licensed with a capacity of ~150Mt. The second phase will target the Mey Sands, which are yet to be licensed but have a much larger capacity at ~450Mt. CO_2 supplies are anticipated from 4 sources:

- St Fergus equipment emissions (0.3Mtpa)
- St Fergus H2 SMR (0.5Mtpa)
- Grangemouth refinery (~5Mtpa)
- Peterhead shipping (~10Mtpa)

The project is funded by BEIS, INEA and Shell, Total, Chrysaor, with a 50/50 government /industry split. A FEED will run from late 2020 to the end of 2021, with FID due at the end of 2021 and first injection in 4Q 2024. The project will likely use a single subsea well, but a range of options are under review. Critically, it needs the UK government to come up with a commercial model.

Andrew Ross (CSIRO): Carbon Net

Carbon Net is a feasibility study of commercial-scale CCS in Gippsland, funded by the Australian and Victorian governments. The vision is to create a region of negative emissions and new low emissions industries that build on the local history of CCUS.

The project as completed concept and feasibility studies and is now in development phase, looking to secure investors and customers for CCS service. There is not yet a timeline to FID.

The Pelican storage site has been identified as the target, with 125Mt capacity. Injection is anticipated at 5Mtpa into a 4-way dip closure located 8km offshore. 3D seismic was acquired in 2018 and an appraisal well was completed January 2020. The well was drilled to 1523m TD and took 89m of core. An injection test up to 10kbpd was successful with water. After testing, the well was P&A'd to reduce long term liability.

The next steps in the project are around updating models and permitting.

General Discussion

Regarding the Acorn project, what is the license for the Captain Sandstone?

There is no permit to inject yet. We have a license to explore the area and 4 years to submit an application to exploit which would lead to an injection permit.

What is the next step on BASRECCS?

Seeking funding.

Tomakomi—What is the local community support for the project and what was the impact of the earthquake?

There was an extensive outreach program, with an annual forum for residents and a site tour. The main public concerns have been around safety. There was an uptick in attendance post-earthquake. Fisherman are a key group for Tomakomai. Stakeholders will depend on local sites.

GoM—when do you foresee an investment decision?

The driver is 45Q. Half a dozen companies are considering investment. All are confidential but the timelines are probably similar because the deadline for the start of construction is 2023 in order to qualify for tax credits.

Session on Emerging Country Reports

Andrew Jupiter (UWI): Trinidad and Tobago

Trinidad and Tobago is a country of 1.3M people and a long history in oil and gas. It has been involved with oil since 1857 and commercially producing oil since 1908. Trinidad is the #1 exporter of ammonia from a single source, with 11 plants in operation. It has 4 LNG trains and is the #1 exporter of methanol from a single source, with 7 plants. It is also #3 in emissions/capita.

Trinidad and Tobago is committed to supporting CCS. We started with COP 23 and 24 and are working on promotion of CCS in the country. We held a CCS symposium in Trinidad with 23 institutions, including industry, NGOs, government, and academia. We are looking at a number of ways forward including:

- Joint industry/academic partnerships
- Forming international partnerships (including a recently signed MoU with University of Texas)
- Funding by international agencies (world bank, GCF)
- Creating a storage atlas

We very much want to be involved in CCS.

Se Won Chang (CCS Research Center in Kongju National University): Korea

We have a long history in CCS. We started in 2002 with capture technology first and started work on geologic characterization since 2010. We ran small-scale demonstration projects of CO_2 capture and geologic storage separately. CO_2 capture project operated 2 power plants of ~10MW capacity from 2010 to present. CO_2 geologic storage project have tried to inject CO_2 onshore and offshore. An earthquake in Pohang (M5.4) in December 2017 stopped the projects for 1.5 year to regain public acceptance. We finished the injection test of 100 tons of CO_2 offshore successfully in 2017, but could not finish the injection of CO_2 onshore by 2017.

Our forward plan is:

- 2021-2023: promotion of CCS; site selection for offshore large-scale geological storage
- 2024-2030: large-scale demonstration project (0.3-1Mt/yr) planned

The evaluation of Gunsan basin will be underway and there will be a FEED study on a 150MW power plant capture system. We are also planning a medium-scale CCS demo using the exhausted gas reservoir in the East Sea (Ulleung basin). The budget for the site selection and the characterization for large-scale CCS 2021-2023 was already approved by the government. However, we are now looking for more funding for the integrated large-scale demonstration project of offshore geologic storage 2024-2030.

Discussion

How did you handle public perception post-earthquake?

It was a real problem. We had 2 projects underway, including injection tests. There was some damage to cities from earthquakes. We canceled operations and launched a study of the earthquake's effects on the storage site. We concluded that there was no impact, but we realize now that public perception is very important. We will weight it more heavily in future projects.

Chi Wen Liao (ITRI): Taiwan (presented by Katherine Romanak)

The storage potential is mostly in western Taiwan, as are most of the power and industrial emissions. There is 2.8Gt of capacity in onshore gas fields and 68Gt in the offshore. Two capture pilot projects are in operation or construction

- 1.9MW and 500kW calcium looping pilot trials in eastern Taiwan
- Small-scale solar assisted capture on a coal-fired power plant

Taiwain Power Company has drilled a 3km appraisal nearshore well, which is actually located onshore very close to the coastline, and is conducting baseline data collection.

Public and community outreach is currently work in progress. A Forum was held on Feb 6 2020 to understand stakeholder concerns and create dialog. We need alternatives to onshore CO_2 storage, including trans-boundary transport and the possibility of regional offshore storage hub. Public communications and outreach are important as is international engagement to continue supporting this work.

Tim Dixon (IEAGHG): Global CCS summary

These are really thoughts rather than a comprehensive global summary. The GCCSI 2018 map shows 18-19 large-scale projects now in operation, including 4 offshore. The countries involved are moving ahead. The question is about other countries. Is there information needed to progress toward a CCS decision? Sue Hovorka did a survey in 2016 for the first Offshore Workshop that identified storage capacity and storage risk management as the highest priorities. Those topics now dominate these conferences, along with transport but the first question for new countries is generally suitability of their geology and the potential for local storage. IEAGHG consequently produced a report to help such countries (IEAGHG 2016-TR6).

Many countries are now looking at offshore CCS (see slide of map by Medford 2019) and there is lots of potential for offshore storage (see slide of map by Ringrose and Meckel 2019) . The Paris agreement set voluntary commitments, to be updated every 5 years. The first update is due in 2020. Only 10 countries had CCS in their plans in the first round but it is likely that many more will be looking at it now and including it in their updates. There is also great interest in the COP Side events from developing countries wanting to learn about CCS

We are making progress but the information needs continue. Currently the focus is on capacity building through international knowledge sharing workshops, funded by the World Bank, ADB, GCF, and CTCN. Do we encourage more of that or something else?

Discussion

What do you think about the jobs side? Does it create employment and benefit for developing countries?

I see desire for it. It's part of the concept of a "just transition", for example in Poland, the coal workforce is worried about losing jobs in transition to low carbon, so there is lots of interest from trade unions. There is work by IIASA that predicts some 44000 new jobs in the US power sector with CCS and there are other examples. High employment is attractive to many countries for politics and economic growth.

What would you do about political uncertainty? Political transitions often stop projects

It is a challenge. I don't know if we have an answer. Large multi-nationals have strong interest now though and have a longer timeline than governments. They are under increasing shareholder pressure and interested in actually doing, which is making a difference. It's encouraging.

Session to Wrap up

Katherine Romanak led a discussion on working towards an international collaborative project. Noting that these workshops share experiences, identify key areas of interest, clarify concepts and build a community of trust. However a strategic and higher level of learning is needed through international collaboration in operational projects. We should consider how to build knowledge sharing and technology transfer into such projects. Some onshore projects have done this well. It was observed that there are contractual challenges to be overcome, but that researchers can be project incubators.

The following overall conclusions and recommendations were agreed for the whole workshop:

Conclusions

Insights and trends

- We are moving from decarbonizing just the oil and gas industry to decarbonizing broader energy systems and industries
- CO_2 can now be exported
- More offshore projects are being planned
- Many projects are considering hubs with phased sources – hence a need to oversize the transport network at the start, as Northern Lights is doing
- There is much more predictive power from ocean models and they are improving all the time

Learning from the oil industry and re-using infrastructure

- There are many benefits, including cost reductions, for CCS deployment in learning from hydrocarbon knowledge
- Depleted fields have the challenge of dealing with a pressure drop from well head to reservoir, which creates a need for the management of CO_2 temperature
- Are there other (perhaps better) uses for old/abandoned offshore facilities that should be investigated?

Monitoring

- MMV costs can be reduced by being risk-based and tiered/triggered monitoring and intervention
    - We should leverage the opportunities of fibre optic monitoring technology
    - Advanced monitoring tools are now available and continuing to develop
- Leakage from legacy wells may be less of a problem than anticipated
    - Shales can help reduce the risk
- We have limited knowledge of the role of the overburden in retaining stored CO_2

Key Recommendations

- We should continue knowledge sharing
- Governments should consider re-use of infrastructure before decommissioning
- Encourage projects to consider oversizing transport infrastructure to accommodate future CO2 sources
- Future NDCs will need CCS. We should make countries aware of their own potential and the potential for export to neighbouring countries
- We should get more Developing Countries to these meetings.
- In terms of collaboration on projects, we should find offshore sites to practice and learn from:
    - E.g. find a well or a fault in an existing field that we can investigate and learn from
    - We should look for incremental steps toward developing offshore projects, analogous to testing capture technologies
    - We should enable for ambassadors to go and participate in other projects, to observe and share learnings.

    - Could we create and offshore equivalent of CAMI site in Alberta for international collaboration?
- Communication
    - We should change the language to be more positive, e.g. “containment” instead of “leakage”
    - Be open about risks, but focus on the benefits of CCS and weight benefits against risks.
    - We should communicate on how CCS interacts with SDGs
    - We should educate regulators and legislators on CCS—benefits, appropriate boundaries, clarification and framework are needed
- We should develop roadmaps for the implementation of CCS and work backward to identify the work that needs to be done.
    - Perhaps do it for individual countries?
    - Storage hubs for multiple countries/emitters may require multi-country road maps
- We should use the experience to inspire funders to go big!
    - Create an inspiring name/acronym
    - Look for a big platform (akin to the International Space Station)
- We should work to create an investment-friendly framework for CCS (i.e., de-risk investment)

Appendix 1

Workshop Programme including posters

(note Offshore Workshop held jointly with STEMM-CCS Open Science meeting, hence joint programme)

STEMM-CCS Open Science Meeting

and

4th International Workshop on Offshore Geologic CO_2 Storage

11-12 February 2020

Hosted by the University of Bergen

With thanks to our co-sponsors:

Organised by:

With support from:

STEMM-CCS Open Science Meeting &

4th International Workshop on Offshore Geologic CO_2 Storage

Acknowledgements

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Conference Programme

Tuesday 11 February 2020

08:30	Registration
09:00	Welcome from University of Bergen – Pro-Rector Margareth Hagen
09:05	Welcome from STEMM-CCS and the Offshore Workshop – Doug Connelly (STEMM-CCS), Katherine Romanak and Tim Dixon (Offshore Workshop)
09:15	CCUS activities in Bergen – Dean Gunn Mangerud, University of Bergen
Session 1. Technological and Engineering challenges *Chair: Matt Mowlem, NOC*	
09:30	STEMM-CCS: Pushing the boundaries – Doug Connelly, National Oceanography Centre
09:45	**Invited talk**: Enabling a CO_2 release experiment in the North Sea – Kevin Saw, National Oceanography Centre
10:00	An Overview of the Design, Build and Testing of the CO_2 Injection Rig – Allan Spencer, Cellula Robotics
10:15	Shallow subsurface coring with a robotic seafloor drill – Oliver Peppe, British Geological Society
10:30	Development and deployment of a suite of autonomous in situ carbonate sensors for the STEMM-CCS gas release experiment – Samuel Monk, National Oceanography Centre
10:45	pH optodes for CO_2 leakage detection – Sergey Borisov, TU Graz
11:00	Coffee & Posters
Session 2. Infrastructure *Chair: Paulo Negrais Seabra*	
11:20	Use of existing infrastructure and knowledge base by Northern Lights – Philip Ringrose, Equinor
11:35	How to develop storage near and around existing infrastructure – Russ Gilbert, Pale Blue Dot
11:50	Issue with re-use of depleted fields infrastructure – lessons from Porthos project – Filip Neele, TNO
12:05	Plugging and abandoning well strategies for storage development – Sarah Gasda, NORCE Norwegian Research Centre / University of Bergen
12:20	Discussion
12:30	Lunch & Posters

Session 3: Understanding complexity *Chair: Christian Berndt, GEOMAR*	
13:30	**Invited talk**: What is sufficient for a "baseline"? – Jerry Blackford, Plymouth Marine Laboratory
13:45	Water column environmental baseline assessment for offshore CCS sites: analysis of field data from the Goldeneye storage complex – Mario Esposito, GEOMAR
14:00	The pH distribution in and around a CO_2 vent – Dirk der Beer, Max Planck Institute
14:15	**Invited talk**: Geophysical approaches to fluid flow in the subsurface and water column – Jon Bull, University of Southampton
14:30	Underground CO_2 storage assurance - The assessment of onshore geological analogues of fluid-escape systems – Panoche Hills, California – Ben Callow, University of Southampton
14:45	Elastic and hydromechanical properties of fractured sandstone reservoirs during and after CO_2 storage – Ismael Falcon Suarez, National Oceanography Centre
15:00	Relating geophysical properties from control source electromagnetic and seismic data at a fluid escape structure in the Northern North Sea – Naima Yilo, University of Southampton
15:15	Coffee & Posters
Session 4: Deep Subsurface Monitoring and modelling offshore CO_2 storage *Chair: Philip Ringrose, Equinor*	
15:30	Geophysical monitoring in the overburden, what can we detect? – Martin Landro, NTNU
15:45	Offshore monitoring for CCS – safe and effective monitoring at lower costs – Marcella Dean, Shell
16:00	Pressure, faults, and CO_2 leakage – Jen Roberts, University of Strathclyde
16:15	Discussion
Session 5: Regulatory Frameworks *Chair: Owain Tucker, Shell*	
16:30	Whose fault is it when a well leaks, review of regs in different CCS countries – Ingvild Ombudstvedt, IOM Law
16:40	London Protocol CO_2 Export Resolution – Tim Dixon, IEAGHG
16:50	Legal aspects of re-use of infrastructure – Martha Roggenkamp, University of Groningen
17:00	Offshore best practice in the USA – Brian Hill, CrescentRI
17:15	Discussion
17:30	Meeting close

Wednesday 12 February

Session 6: Detection, Quantification & Qualification *Chair: Guttorm Alendal, University of Bergen*	
09:00	**Invited talk**: Making containment verification cost effective: new methods for autonomous observation of offshore CCS reservoir integrity – Matt Mowlem, National Oceanography Centre
09:15	Lab on chip carbonate sensors for quantification and mapping of a plume of dissolved CO_2 – Allison Schaap, National Oceanography Centre
09:30	Utility of tracers for CO_2 leakage detection and quantification in the marine environment – Rachael James, University of Southampton
09:45	The migration of carbon dioxide within shallow sediments at the STEMM-CCS release site: analysis of AUV-mounted Chirp sub-bottom profiling data – Ben Roche, University of Southampton
10:00	Leakage monitoring and quantification by tracing and modelling dissolved CO_2 plumes at the Goldeneye CO_2 release experiment – Jonas Gros, GEOMAR
10:15	The Cseep method as a monitoring tool to detect and quantify CO_2 seepage – Abdirahman Omar, NORCE Norwegian Research Centre
10:30	Modelling of leakage scenarios to determine impact and anomaly criteria for detection – Marius Dewar, Plymouth Marine Laboratory
10:45	Coffee & Posters
Session 7: Project Updates *Chair: Tip Meckel, Gulf Coast Carbon Center, Bureau of Economic Geology*	
11:15	Northern Lights project – Philip Ringrose, Equinor
11:21	Lula – Paulo Negrais Seabra, former Petrobras
11:27	Tomakomai – Jiro Tanaka, JCCS
11:33	US storage resource assessments – Darin Damiani, US DOE
11:39	GoMCARB Partnership -Tip Meckel, UTBEG
11:45	SECARB Offshore Partnership – Mike Godec, ARI
11:51	South Africa offshore feasibility study – KB Trivedi, PetroSA
11:57	NORDICCS/BASRECCS – Gry Mol Mortensen, SGU
12:03	Porthos and Athos Projects - Filip Neele, TNO
12:09	Net Zero Teesside Project UK – Philippe Legrand, BP
12:15	Acorn – Russ Gilbert, Pale Blue Dot
12:21	Discussion

12:35	Lunch & Posters
Session 8: Emerging CCS country needs and progress *Chair: Katherine Romanak, University of Texas*	
14:00	Trinidad & Tobago – Lorraine Sobers, UWI
14:10	Korea – Se Won Chang, CCS Research Center in Kongju National University
14:20	Taiwan – Katherine Romanak, BEG
14:30	Discussion - Global Sum up – Tim Dixon, IEAGHG
Session 9: Synthesis – the end products *Chair: Doug Connelly, National Oceanography Centre*	
14:45	**Invited talk:** Beyond STEMM-CCS: Implications for offshore CCS and marine CO_2 monitoring – Chris Pearce, National Oceanography Centre
15:00	The STEMM-CCS online monitoring and decision support tool – Anna Lichtschlag, National Oceanography Centre
15:15	**Invited talk:** Industry perspective on results of STEMM-CCS project – Marcella Dean, Shell
15:30	STEMM-CCS: informing regulatory bodies and policy makers – Doug Connelly, National Oceanography Centre
15:40	Panel discussion on implications and application of STEMM-CCS outcomes – Chair: Vikki Gunn, Seascape Consultants
16:00	Coffee & Posters
Session 10: Wrap up *Chair: Katherine Romanak and Tim Dixon*	
16:15	Brainstorming towards an international collaborative project and funding
	Conclusions and recommendations
17:00	Closing remarks – Doug Connelly (STEMM-CCS), Katherine Romanak and Tim Dixon (Offshore Workshop)
17:05	Meeting close
19:00	Dinner at the Grand Hotel Terminus, Zander Kaaes gate 6, 5015 Bergen

Poster presentations

Poster title	First author
Deployment of benthic chambers at the Goldeneye CO_2-release field experiment: Lessons learned for CCS leak detection.	Jonas Gros, GEOMAR
Aquatic Eddy Covariance, a Highly Sensitive Tool for the Quantification of a Release of Dissolved Inorganic Carbon at the Seafloor	Dirk Koopmans, Max Planck Institute, Bremen
Deviations from environmental baseline: indication of CO_2 leakage from real-time measurements	María Martinez Cabanas, GEOMAR
Passive acoustic quantification at the STEMM-CCS release site - application of beam forming techniques	Jianghui Li, University of Southampton
Reactive transport modelling insights into CO_2 migration through sub-vertical fluid flow structures.	Hector Marin-Moreno, National Oceanography Centre
A novel set-up for combined imaging and flow-through experiments with sediment cores	Elke Kossel, GEOMAR
Effect of CO_2 saturated seawater injection on transport properties of the sealing formations	Sourav Sahoo, National Oceanography Centre
Above the pipe – Geometry and formation processes of cold seeps in sands and sandstone derived from UAV-based analyses of an Early Eocene methane seep system, near Varna, Bulgaria.	Christoph Böttner, GEOMAR
Ocean-bottom seismic experiment for characterization of a gas chimney beneath the actively seeping Lunde pockmark, Vestnesa Ridge, W-Svalbard Margin	Sunny Singhroha, Center for Arctic Gas Hydrates, Environment and Climate
4D time-lapse seismic interpretation of gas chimneys, Vestnesa Ridge offshore W-Svalbard	Malin Waage, Center for Arctic Gas Hydrates, Environment and Climate
Subsurface fluid flow quantification in a gas chimney using modeling of 4D seismic data	Sunny Singhroha, Center for Arctic Gas Hydrates, Environment and Climate
High resolution subsurface characterisation at Scanner Pockmark region using broadband seabed seismic data	Farid Jedari-Eyvazi, University of Southampton
Fracture characterisation using shear-wave splitting analysis of azimuthal anisotropy in the Scanner Pockmark area, North Sea	Adam Robinson, University of Southampton
P-wave velocity anisotropy in the Scanner Pockmark area, northern North Sea	Gaye Bayracki, National Oceanography Centre
Sediment porosity at the Scanner Pockmark in the North Sea from controlled source electromagnetic data	Romina Gehrmann, University of Southampton
Applications of a Machine Learning Extrapolating Technique in CCS Monitoring	Kristian Gundersen, University of Bergen
Biogeochemical consequences of a short-term CO_2 leak in the water column: field experiment and modelling	Evgeniy Yakushev, NIVA
Predictions of Relative Permeability of Water-CO_2 Flow at Pore Scale by LBM	Amin Zarareh, Heriot Watt University
The Effects of Numerical Schemes on the Predictions of Permeability of a Berea Sample by Direct Numerical Simulation	Nidal Saab, Heriot Watt University

Simulation and Prediction of CO_2 leakage from STEMM-CCS field experiments	Umer Saleem, Heriot Watt University
Greenhouse gas emissions from marine decommissioned hydrocarbon wells: leakage detection, monitoring and mitigation strategies	Christoph Böttner, GEOMAR
Operation and decommissioning of storage facilities for CCS activities in Brazil.	Romario de Carvalho Nunes, University of São Paulo
Prospectivity of noble gas tracers in CCS monitoring schemes	Anja Sundal, University of Oslo
Impact potential of hypersaline brines released into the marine environment as part of reservoir pressure management.	Jerry Blackford, Plymouth Marine Laboratory
Scope and key findings from the ACT4storage project	Ann Blomberg, Norwegian Geotechnical Institute
An integrated geomechanical workflow for storage integrity screening	Thibault Candela, TNO
Carbon dioxide capture, transport, and storage and its definition competences in Brazil.	Israel Lacerda de Araújo, Imperial College London
Induced-seismicity geomechanics for controlled CO_2 storage in the North Sea	Joonsang Park, Norwegian Geotechnical Institute
Modeling and Monitoring of Offshore CO_2 Leakage for the GoMCarb Project	C.M. Oldenburg, Lawrence Berkeley National Laboratory
Legal Aspects for CCS in Depleted Oil & Gas Fields in Brazil: a case of study	Raíssa Moreira Lima, University of São Paulo
CO_2 Storage Resource Assessment and Development Roadmap for Mid-Atlantic Offshore Region of USA	Neeraj Gupta, Battelle
Where to Store the Carbon? Adapting Petroleum Exploration Tools to Identify and High-grade CCS Sites	Alex Bump, University of Texas-BEG
Does CO_2 concentration in seawater continue to rise during CO_2 leakage?	Keisuke Uchimoto, Geological Carbon Dioxide Storage Technology Research Association / RITE
Carbon Storage and its property rights	Isabela Morbach Machado de Silva University of São Paulo
Dynamic changes in fault permeability – How can experimental work provide support for fault seal integrity?	Elin Skurtveit, Norwegian Geotechnical Institute
Regional identification of seal bypass systems for CO_2 storage: A case study from the Northern North Sea	C. Lloyd, University of Manchester
World's First Carbon Sequestration Project in Salt Caverns Built Offshore in Ultra Deep Waters in Brazil	Pedro V. M Costa, University of São Paulo
Potential of Carbon Storage in the offshore Santos Basin, Brazil: geological & economic possibilities.	Mariana Ciotta, University of São Paulo
Solid Carbon - A Negative Emission Technology Investigation of Carbon Capture and Geological Storage in the Deep Ocean Cascadia Basin Basalt	Martin Scherwath, Ocean Networks Canada
Cross-border CO2 transportation for storage lowers public support for CCS	Christine Merk, Kiel Institute for the World Economy

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