IEAGHG Meeting Report 2018-TR02
August 2018

3rd International Workshop on Offshore Geologic CO_2 Storage

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The Research Council of Norway

CLIMIT

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carbon sequestration leadership forum

sanedi South African National Energy Development Institute

Statoil

Norwegian Ministry of Petroleum and Energy

IEA GREENHOUSE GAS R&D PROGRAMME

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DISCLAIMER

IEAGHG supports and operates a number of international research networks and workshops. This report presents the results of a workshop. The report was prepared by IEAGHG and the Bureau of Economic Geology as a record of the events of that workshop.

The 3rd International Workshop on Offshore Geologic CO_2 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 The Research Council of Norway. The organisers acknowledge the financial support provided by The Research Council of Norway, Statoil, the Norwegian Ministry of Petroleum and Energy, Statoil, and the Carbon Sequestration Leadership Forum (CSLF) with SANEDI, and the hospitality provided by the hosts at The Research Council of Norway, Oslo.

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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)
- Lars Ingolf Eide, The Research Council of Norway (Host)
- Åse Slagtern, The Research Council of Norway (Host)
- Susan Hovorka, BEG
- Tip Meckel, BEG
- Noel Kamrajh, SANEDI
- 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
- Mark Ackiewicz / Traci Rodosta, US DOE

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3rd International Workshop
3-4 May, 2018
Research Council of Norway
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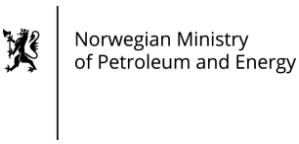

Meeting Report

Date and location:
3-4 May 2018, The Research Council of Norway, Oslo

Hosted by:
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Statoil

Report Contents:

Executive Summary

The 3rd International Workshop on Offshore Geologic CO_2 Storage took place on 3-4 May, organised by the Bureau of Economic Geology (BEG) in collaboration with IEAGHG and others, and hosted by the Research Council of Norway in Oslo, with support from SANEDI and CSLF.

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 60 attendees from 8 countries participated in this 3rd workshop.

The agenda included: How to learn from learnings?; Value Chains for Offshore; Infrastructure re-use; Monitoring offshore CO_2 storage/EOR; Offshore CO_2 storage resource assessment; Project updates; Standards and Regulatory Frameworks; and Brainstorming towards an international collaborative project.

Notable points arising from the presentations and discussions were the first 4D seismic images of the CO_2 plume at Tomakomai, the potential funding opportunities for developing countries from the Green Climate Fund and other sources, value chain opportunities being created by the new 45Q extension in the USA and by hydrogen in EU, Japan and Australia, and a new appreciation by many of the issues to be considered in the re-use of infrastructure. Key conclusions and recommendations were agreed.

Key conclusions included:

Value chains:

- There is a new interest in the EU and Japan for value chains combining hydrogen production and CCS.
- 45Q tax credits may be significant to stimulate projects.

Infrastructure:

- Re-use of infrastructure is not necessarily easy. Reuse of pipelines is more likely than with platforms.
- More R&D on legacy wells is needed, specifically how to deal with the challenges presented by legacy wells. Different standards exist in time, region, and purpose.

Monitoring

- The benefits of permanent reservoir monitoring outweigh the extra cost, but coverage is inflexible with this method.
- Different monitoring methods should inform each other, including methods for determining trigger points. This type of complementary monitoring is crucial.
- Marine environment baselines – very complex but we are learning more.

- AUVs are proving successful for long term surveillance, both temporal and spatial, and for public assurance.
- The workflow is to find anomaly and then attribute its source.
- HR4D seismic can be used for characterisation of shallow leakage structures and for monitoring the plume during injection.
- Microseismic techniques require background data.

Resource assessment

- Don't spend too much time on refining broad static assessments – leap from regional to more local assessments including dynamic capacities, and to well injectivity basis.
- Society of Petroleum Engineers are developing and releasing a Geologic Storage Resources Management System (SRMS) this year.
- Resource quantification will be more important as projects mature.

Projects

- Norway has plans for full-scale CCS.
- USA is developing robust offshore R&D programmes.
- Japan and Brazil have matured projects emerging.
- 4D seismic imaging is very encouraging at Tomakomai. First imaging of CO_2 at 60,000t at 1km depth.

Regulatory frameworks

- Regulations should adapt to learnings.
- ISO certification is useful for building trust in a project and useful for communication with different stakeholders.
- London Protocol: scope still needs clarifications. Projects can help test applicability. Not one-size-fits-all, but case by case assessment.
- Key message from Tomakomai: additional techniques needed.

Brainstorming Criteria for International Collaborative Project – (the what and the how, not the where)

- Objective is to share learning by doing from the real projects.
- Need roadmaps on where to find information on CCS
- Can we learn from the International Space Station or the International Ocean Discovery Program, for CCS.
- The ACT initiative could be used for projects, not just for R&D (ACT - Accelerating CCS Technologies, an EU ERA NET Cofund).
- Develop ACT to be the operationalisation of Mission Innovation
- Could Oil and Gas Climate Initiative (OGCI) fund a real project?

Funding

- Some major international funders are keener on non-fossil fuel technologies.
- The value of CCS needs better and more advocacy to funders.
- Norwegian project is seeking international collaboration.
- Green Climate Fund will use Sustainable Development Goals (SDGs) as one of 6 criteria – CCS is lacking evidence-base for support in SDGs [note IEAGHG will be addressing this].

Key recommendations included:

- Explore models for international collaboration on projects.
- An ACT-type model is good for R&D (US is joining), so an ACT for projects is recommended.
- Consider how to build knowledge sharing from hands-on operational projects, including an international collaboration on a project.
- Provide a roadmap to existing information sources [IEAGHG will be addressing this].
- Joint funding between countries has started and should continue.
- Survey which developing countries would be attracted to offshore storage.
- Get developing country representatives to these meetings. Identify key persons and funding sources.
- More advocacy is needed to funders on CCS – future Nationally Determined Contributions will need CCS, so how can we make countries aware of their potential? The research community is ready to inform.
- Complimentary monitoring to be built into MVA plans - different monitoring methods informing each other, including methods for determining trigger points.

Many thanks to the Research Council of Norway for hosting and sponsoring and to Statoil and the Norwegian Ministry of Petroleum and Energy for sponsoring.

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

Welcome and Objectives

The Welcome and Session 1 were common between the Offshore and the Capture workshops being held in conjunction with the US-Norway Bilateral meeting.

Torgeir Knudsen, Deputy Director General, Norwegian Ministry of Petroleum and Energy, welcomed all participants. Torgeir pointed out that Norway has 20 years CCS experience related to Sleipner and Snøhvit. A lot of knowledge is gained from these projects. Making CCS work is a global challenge and we must act fast to fulfil the CCS potential. International cooperation under CSLF, Mission Innovation, and IEAGHG is important. Full scale CCS in Norway is under development. The project is being discussed in the Parliament now. Torgeir thanked the steering committee and the Research Council of Norway for hosting the meeting.

Steve Winberg, Assistant Secretary for Fossil Energy, US Department of Energy, welcomed everybody to the meeting. USA energy policies embrace that there is vast amount of untapped fossil resources in the USA. Boosting energy production and energy security are important. This must go hand in hand with stewardship of the environment. USA is therefore committed to advance CCS. CCS can create jobs and ensure energy security. They will continue to work with international partners. A CCUS summit last November was co-chaired by Rick Perry and IEA and it called for a new push for CCS. In the December CSLF meeting in Abu Dhabi, USA together with others announced strategies for the global deployment of CCS. USA has a robust CCUS R&D programme. Within storage they are developing monitoring technologies and pressure management during injection. They are moving forward with infrastructure for large scale CO_2 storage throughout the country. This includes going forward with potential storage in the Gulf of Mexico. Residual oil zones (ROZ) and organic rich shales are also being researched. The CCS challenges are real. So is the potential. They can help drive down cost and establish best practice. Steve pointed out his observations here in Oslo. There is deep expertise within CCUS in the room and our ability to cooperate is important. What we are doing is powerful - and it seems that people in the room enjoy working together, and that is powerful.

Session 1. Value Chains for Offshore: Chair – Lars Ingolf Eide

Emerging Hydrogen Value Chains for Norway. Steinar Eikaas, Statoil (note Statoil now renamed as Equinor)

Statoil has a new strategy addressing hydrogen production from reforming of natural gas and coupling it with CCS. Almost all hydrogen produced today is from fossil fuels.

There are two important steps in the new strategy:

- Step 1 – establish CCS infrastructure

- Step 2 – utilize CCS infrastructure to produce hydrogen and store CO_2

Statoil sees three flagship hydrogen projects

- Hydrogen for power generation
- Hydrogen for heating
- Liquid hydrogen for transport

Demand for clean and flexible power production is expected to go up. Clean renewable energy solutions require clean energy storage solutions. There is a need for a solution for the seasonal swing in energy demand and hydrogen can be the solution.

Discussion

Can natural gas networks be converted to hydrogen? What is the upgrading cost? What about safety?

Big trunk lines need to be replaced. Low pressure distribution pipes will be in plastic. Equipment, boilers, etc, will need to be replaced. Safety aspects are being addressed. Cost will be lower than transforming everything to electric.

It is possible to produce hydrogen from coal? This was not covered in the presentation.

Statoil are pursuing the presented model based on natural gas because Statoil is a natural gas producer.

Emerging hydrogen value chains for Japan. Ryozo Tanaka, RITE on behalf of KHI

Japan has a long history of R&D on hydrogen. The country has more than 200,000 units of on-site fuel cells based CHP for houses installed since 2009 and nearly 100 hydrogen refuelling stations for fuel cells vehicles.

A strategic roadmap for hydrogen and fuel cells has been established. The ambitions include large-scale deployment of hydrogen power generation around 2030. This will require large-scale hydrogen production.

Kawasaki Heavy Industries (KHI) have ambitions within CO_2-free hydrogen:

- KHI made a concept of CO_2-free hydrogen supply chain: which is to produce hydrogen from brown coal, couple with CCS, in another county such as Australia and then to transport it to Japan for the use of hydrogen.
- Lots of brown coal in Latrobe Valley in Australia. By-product CO_2 can be stored locally in the Carbon Net CCS project.

- Their feasibility study concluded that the concept is technically and economically feasible: the cost of hydrogen power generation, including CCS, is 16 yen/kWh, which is lower than wind, solar, and coal with CCS
- KHI proposed the demonstration of the Australia-Japan hydrogen infrastructure in 2020 when the Japanese Government plans various hydrogen demonstrations at a time of the Olympics in Tokyo.
- KHI successful won public grant for the majority of the supply chain from a Japanese funding agency NEDO and launched an industry consortium called the CO_2 free Hydrogen energy Supply-chain Technical Research Association (HySTRA) to deliver the project.
- As part of the project, KHI is building a ship for transport of liquified Hydrogen.
- They recently won another grant for the remaining parts of the supply chain from the governments of Australia and Victoria.

Discussion

Will there be a ship going from Australia to Japan by 2020? Is the ship in construction?

Yes.

Will you prefer coal or natural gas?

The concept is based on brown coal from Australia. But the concept is valid for natural gas as well.

USA 45Q and how it should accelerate potential CCUS projects. Brian Hill, SSEB

The US 45Q regulatory framework includes tax credits for storing CO_2 and for CO_2 EOR. The value of the tax credits are rising to USD 35 per ton CO_2 for utilization (like EOR) and to USD 50 per ton CO_2 stored.

There are many onshore and offshore areas in the Central Gulf Coast Region that could benefit from CCUS. 45Q is a potential enabler. The economic potential is large. The federal government would receive about USD 25 billion of royalty revenues from the extra oil produced using Gulf of Mexico (GoM) CO_2 pipeline systems.

The Bureau of Ocean Energy Management (BOEM) has issued a Best Management Practices Offshore Transportation and Sub-Seabed Geologic Storage of CO_2

Discussion

What are the requirements that must be fulfilled for 45Q?

It is based on approval of the MVA plan by the Internal Revenue Service (IRS). Subpart RR is viewed as OK to use. There are no offshore MVA guidelines yet.

Are Class 6 wells required onshore? What about offshore?

Yes, Class 6 is required onshore and the Class 6 permitting process must be followed. Not aware of any class 6 requirements offshore.

There was a discussion regarding cost of retrofitting and offshore potential for EOR.

It was stating that wetland areas add to complexity, but can be handled by a robust oil and gas industry in the area.

What is the well density?

It is very dense.

Panel Discussion

30 years ago, there was a hydrogen wave in Norway. Why could hydrogen move forward this time?

There is a different situation now with strong commitment in European countries to deliver on the Paris Agreement. There also seems to be willingness to pay. Complementary solutions to renewables are needed and hydrogen is a very good solution.

There is a similar situation in Japan where hydrogen with CCS is a new concept. This could fly because climate change issues must be considered.

Will we see a competition between fuel cells and turbines for large scale hydrogen?

Statoil is considering a 1300 MW project in the Netherlands and believes turbines is the best choice. We will, however, see more and more fuel cells over time, but in the short-term turbines will be needed to build capacity. One reason is that fuel cells need 100 % pure hydrogen while turbines only need 99 % hydrogen. Another aspect is the capacity to deliver large scale units. Today it would take many years to deliver the needed fuel cells.

What about public and private engagement? What is needed, more money or stability?

Private investors need the cash flow stream. 45Q will be important in the US and we will know for many years what the cash flow will be. The old 45Q had uncertainty that is now fixed. One challenge with the financial model today is the need to fit with a 12-year window. This could, however, be extended. Furthermore, extra capacity in pipelines is an issue. Governments could pay for the extra capacity.

There are two key elements that are needed for the Norwegian case. First, the storage site which is the cornerstone. Then, second, hydrogen projects are more expensive than the natural gas projects we have today. This gap needs to be covered and this could be solved by introducing similar incentives as renewable energy has had.

Regarding 45Q, MVA has to be approved by the IRS. How many MVA plans have been approved?

There are 3 that are approved. These are publiclly available.

Is there interest from the Australian government regarding the Japan - Australian hydrogen project?

Yes. There is Australian funding for the demonstration activities in Australia. This is in addition to Japanese funding that partly goes to the supply chain.

Is there any contact between the Norwegian and Japanese hydrogen cases?

There is some overlap, but not much. KHI shows interest in the Statoil project and there are possibilities for cooperation.

_____ End of joint session between capture and storage _____

Welcome and Scene-setting for Offshore CCS. Tim Dixon IEAGHG

There is a huge potential for CO_2 storage, but it is urgent to realise it. This is well-documented in the CSLF report on offshore geological CO_2 storage which was presented to CSLF ministers in 2015. This led to the start of the series of workshops on offshore geological storage.

Recent developments are two new partnerships for offshore storage in the Gulf of Mexico.

The first workshop was in Austin, Texas, 2016, and the second in Beaumont, Texas, 2017. The third workshop today has the aim to address and build on the recommendations and topics raised at the first and second workshops to update on and take forward offshore storage. Tim thanked the international steering committee.

Welcome and Scene-setting for Offshore CCS. How to 'Learn from our learnings'. Katherine Romanak, BEG

Our objective is to share knowledge and work towards an international collaborative offshore storage project. A survey of countries for the first workshop based on 25 respondents from 15 countries shows that we are very early in the process of deploying CCS. Workshops connect individuals and contribute to building a community of trust. We need to go to the next level. Need to create experiences, and start actions and strategies that brings us to a higher level of learning. It is important to bring CCS forward in developing countries. Many countries are on the edge of implementing CCS but do not have the resources. The last session of the workshop will be brainstorming. We need to define the technical criteria for our ambition for an international collaborative storage project.

Session 2. Infrastructure: Chair – Paulo Negrais Seabra

New subsea systems for CO_2 storage and EOR. Pål Nøkleby, Aker Solutions

The challenges for offshore CO_2 EOR are space limitations on facilities and CO_2 supply chains not established yet. Aker Solutions have delivered offshore subsea systems. By developing the technology further it can become applicable for CO_2 injection projects. Aker Solutions will base this on systems delivered to the Åsgard field. Selective membranes are key subsea building blocks in subsea separation of CO_2 from CO_2-rich natural gas.

A concept for subsea CO_2 separation and reinjection is identified by putting different building blocks together. No showstoppers identified. Up to 98 % of the CO_2 can be separated from the well stream. This can be an enabling solution for offshore CO_2 to EOR projects. It is imperative to reduce the cost, but at the same time have a robust system. Operating at well-head pressure and temperature means that a lot less volume will be handled compared to a top side solution.

Many of the components can be reused from one project to another. A CO_2 for EOR project can easily be converted to a CO_2 storage project.

The carbon footprint is important. Emissions from incremental oil must be taken into account because there are substantial CO_2 emissions from the incremental oil. Some more CO_2 comes from the CCS system. But in the end large volume of CO_2 are stored.

An ongoing R&D project (SUBCOMP) is looking for optimizing the process. The carbon footprint and carbon balance looks very favourable.

Re-using offshore infrastructure – some things to consider. Steve Murphy, Pale Blue Dot

The ACORN project has been used as a case study for this presentation and the aim is to find the most economical way to re-use infrastructure.

The infrastructure for transport and storage will have business limits when it comes to re-use. The following aspects must be considered:

- Reservoir – pressure margin to meet needs of projects
- Jackets and topsides have differential operation hazards because CO_2 is denser than air
- Metallurgy of pipelines, corrosion
- Suitability of wells
- Subsea infrastructure

When it comes to re-use of the platform it is really all about safety but reducing development and operation cost is also important.

The ACORN project is based on re-use of infrastructure at St Fergus, Scotland which is a hub for a large share of UK natural gas. Three offshore gas pipelines are available for CO_2 transport and the Goldeneye Platform could be used for injecting CO_2. All pipelines are suitable for CO_2 transport. A reservoir screening shows capacity for storage of more than 150 MT CO_2.

Cost and risk are important elements in a study showing that re-purposing oil and gas infrastructure is suitable for some CO_2 operations.

Overall, pipelines are more likely to be re-usable than platforms.

New technology for handling legacy well integrity issues. Malin Torsæter, SINTEF

Safety of legacy wells is handled differently from country to country. Each country has its own specification of safe plug lengths for wells and there is no scientific documentation explaining the differences, e.g. the safe plug length is 100 m in Norway and 100 ft in UK.

There are many parameters influencing well safety. The material for plugging wells matters. Post injection characterising of wells at Ketzin gave valuable results. Ketzin had corrosion even in the stainless steel casing. Deformations in real wells is different from deformation observed in labs. Operations have impact on well integrity and this includes thermal, mechanical and chemical loads.

Two studies showed that 13-19 % of production wells leaked and 37-41 % of injector wells leaked.

Smeaheia has been chosen as the storage site for the full scale CCS demonstration project in Norway, partly because it has a scarcity of legacy wells.

A unique experimental setup designed to study well materials has been established at lab scale. Future R&D actions also include working with nature by studying shale and salt. An important question is how we can use formations as barriers and how we can we activate such barriers.

A new R&D project will develop tophole techniques for non-invasively evaluating wells. A new consortium is established: "Tophole" continuous well integrity monitoring.

A key message is that we should not be happy to keep avoiding legacy wells, but instead learn to deal with them. The Mission Innovation workshop concluded that more research is needed for evaluating and remediating wells.

Panel discussion

Can legacy wells be re-used?

It is doable. However, recompletion is cheapest. Abandoned wells cannot be reused for injection, but may be used for monitoring.

There are also regulatory issues. CO_2 injection can raise the pressure beyond original reservoir pressure.

What are the constraints for subsea completions?

It is more about fabrication. Aker Solutions is looking at projects down to 2000 m and then it is mostly about wall thickness.

What is the economics on re-using platforms?

Cost is a main consideration, especially because tax payers are covering 50-70 % of decommission cost (in North Sea region). Reuse depends on the formation as well. If you only need a well, why buy a platform? If you don't already own a platform, you will most likely not buy one.

It is important to challenge the typical requirements. Operators and academia should work together to challenge typical requirements.

We can deal with legacy wells. However, plug and abandon (P&A) often means leaving as much steel in the ground as possible. This is cheap P&A, but it makes CCS tricky.

What is the decommission cost?

UK decommission expenses are predicted to be €45-60 billion. Half of it is on wells, 20 % on safety, and the rest is split on pipelines and subsea installations. A common economic argument is to continue producing with loss to postpone decommission cost.

There is huge decommission ongoing in Texas. What should we do about it?

Whether plugging reservoirs or not is relevant for CCS. How much steel to leave in the ground is an important consideration. Material selection for plugging is also important.

Why are there only two legacy wells at Smeaheia?

It is a question of keeping the cost low. Norway has a huge share of total global decommission cost.

In general, it is also about the dry wells. Holes through the reservoir are a challenge for CO_2 storage. Also to note that if platforms are only handling CO_2, there is no gas for power generation.

Session 3. Monitoring Offshore CO2 Storage and EOR: Chair – Katherine Romanak

Handling microseismic background. Volker Oye, NORSAR

Microseismicity is generally considered as seismic events that are not felt by people, i.e. below magnitude 3. Such small events may occur due to stress changes, associated to fluid movement and pressure changes. As such, microseismicity helps us understand the reservoir processes during and after CO_2 injection.

Monitoring of the background seismicity is important to identify potential differences in the seismicity level before and after the start of CO_2 injection.

Offshore monitoring of microseismic has not been done much on a global scale, and most available data stems from onshore seismometers with the exception of some ocean bottom geophone data. In the region of the planned Norwegian offshore storage site, some larger faults exist that may result in significant earthquakes. Hence a proper assessment of the microseismic background is necessary. Noise removal techniques are of particular importance to enhance the quality of the information obtained from microseismic measurements.

Statoil and NORSAR will start a project on baseline microseismic measurements for Smeaheia.

All offshore challenges, including noise, costs, subsea power and data transfer should be manageable, however, i onshore array solutions may be an alternative/addition to consider.

STEMM-CCS project updates on seafloor/environmental monitoring. Maribel Garcia-Ibanez, Uni Research Climate and Bjerknes Centre for Climate Research

STEMM-CCS is a project on strategies for environmental monitoring of marine CCS. Total budget is €15.9 M for the period 2016-2020. The project is funded by Horizon 2020.

The objective of the project is to ensure the selection of appropriate marine storage sites and to monitor marine storage sites effectively. This will increase confidence in CCS. The approach includes leakage detection, localisation, attribution, and quantification.

The project aims to better understand fluid and gas flow in operational conditions, leading to efficient and economic monitoring strategies.

A controlled release experiment will be performed 2019 at Goldeneye. They have started to measure environmental baselines.

Important innovations include an automated system for benthic image processing; new acoustic techniques for quantification of leakage; newly-developed high-precision pH and O_2 optodes on landers and AUV's.

These techniques will be used for the baseline assessments which are planned for Smeaheia.

The project includes outreach and public communication; website, brochure, science policy panel meetings, science briefs, training workshops, research highlights publication.

Discussion

Is it enough baseline when there are seasonal variations?

We will have measurements from two years. It is not enough, but this is what is possible within the scope of the project. Industry has some data and we will also benefit from CCS monitoring.

The baseline is complex. Could you say more about it?

We focus on changes in biology and concentration changes. Trying to benefit from background chemistry. Also trying to quantify how much CO_2 that comes into the ocean and quantify how much of it that comes from the underground. There are different biological processes going on and the project is looking more on processes than concentrations.

There was a comment from the audience that both numerical models and process-based methods are being used to design baseline studies.

What is the depth of CO_2 injection?

The depth of injection is 5 meters. It is important that the CO_2 comes out so that measurements can be made.

UK AUV update on seafloor / environmental monitoring. Graham Brown, Sonardyne -

A completed CCS offshore MMV project was presented. The project had been looking on areal mapping of the sea with the purpose to develop cost effective MMV system.

To find a leak of gas and truly tiny variations in the chemical composition of seawater in a mind-boggling large volume of water is challenging. We need to detect leaks in the form they are expected to emanate from the sea bed.

We need to give the public confidence in CCS in a commercial framework.

The project is aimed at providing capability to detect CO_2 well below 0.01 % loss store-wide per annum. In order to do so there is a need to understand hydrodynamics, CO_2 dynamics, and biology.

There was an extensive system of sensors in the project, including landers with active and passive sonars together with an AUV carrying a suite of sensors. The AUV was operated remotely from shore, from the office and from home out of hours over a period of 10 days. The project gave a much deeper understanding of the application. Testing were performed in lab, harbour, and at sea.

An artificial leak was detected automatically. Cost effective AUV monitoring was demonstrated.

Discussion

How can you deal with vast amount of data?

We collect all data on the AUV or Landers, local algorithms process the data and send a reduced geo-referenced dataset back to shore for visualisation via an Internet based service. At the end of the mission, all data is recovered and further post processing conducted. The system uses algorithms to perform automatic detection of anomalies for both sonar and physical / chemical sensor data, this then points human analysts at the most relevant parts of the survey.

How often would surveys need to be performed?

Baseline survey prior to storage followed by periodic areal survey to meet the need of regulatory compliance. This is likely to be either annual or bi-annual to start with a reducing frequency as confidence in storage operations increases.

STEMM-CCS.

STEMM will be using the AUV on their controlled release at Goldeneye.

Summary:

This gives a picture of the complexity and we get insight into what's interesting. It is important to be good at understanding what is a real leak.

Update on leakage detection. Keisuke Uchimoto, RITE

pCO_2 would increase in the event CO2 leaked into the sea. Threshold methods are necessary to judge observed pCO_2 to be normal or anomalous (CO_2 leakage). Suspected signs of CO_2 leakage may be high pCO_2 and rapid increase in pCO_2, but these are also seen in the natural variability. It is important to avoid false-positives (misjudging of natural phenomena as leakage) and false-negatives (overlooking leakage), but it is challenging to avoid neither of the two.

Two threshold methods, the seasonal threshold using pCO_2 only and the covariance threshold using pCO_2 and dissolved O_2, were studied using data observed in Osaka Bay, where the western bay is vertically mixed and the eastern bay is stratified. The percentages of false-negatives for the two threshold methods were compared under the condition of the similar false-positive rate. It was shown that which is the better threshold depends on the area, the season, or the both. It is conjectured that the seasonal threshold is better in areas and seasons with a large variation in pCO_2 and that the covariance threshold is better in areas and seasons with a small variation in pCO_2.

Discussion

What is better– False-positive or false-negative?

Both are not good, but to avoid neither of the two is likely to be impossible.

Comments from the audience: Is it important to detect CO_2 leakage if a leak is so small that there is no environmental impacts? Could we have different thresholds for the different things we care about? For example. Environment, versus credits. Or cost of monitoring.

How long is the time period for the baseline?

In this study, the thresholds were made based on nine years data of quarterly survey. But the period needed for the baseline remains to be solved. It is noted that continuous observations are likely to make the period much shorter than quarterly surveys.

Update on shallow seismic (p-cable) deployment at Tomakomai. Tip Meckel, BEG -

The project demonstrates and verifies the total CCS system from CO_2 gas compression and CO_2 capture to storage. There is lots of monitoring at the site and marine 3D seismic surveys are presented. The project is funded by US DoE and is a collaboration with Japan.

This presentation is about a monitoring survey in August 2017. Resolution spectrum 100 Hz – 10 kHz: shallow sediment studies.

CO_2 seismic sensitivity study focused on the 1100 m deep Meobetsu formation which is poorly consolidated and has low velocity sandstone with high porosity. In the absence of residual gas

and with high quality seismic data (signal to noise ratio) the presence and distribution of CO_2 should be visible.

A ship was used for the survey. Positioning of the equipment is important. Shooting every 3-4 seconds gives quite precise data with high repeatability

The theoretical sensitivity study indicated injected CO_2 should generate seismic response but that residual natural gas present may mask the signal. A second survey is planned 2019.

Discussion

You are able to image the CO_2. But what about structures in the overburden not related to CO_2? And when will you deploy the tool?

We can use it as a characterisation tool. Need to know where to look first. The targets in the Gulf are at 1500-2000 m.

How do you do the fluid history? Just by looking at gas chimneys?

There are natural gas migrating and disrupting the signal. Energy sending in gets disbursed. Do not get a clear chimney. Will see chimney, but might not see hydrocarbon movement.

When you say fluid, you mean gas?

Yes. Thinking mostly gas.

Would expect it to be more patchy?

More block scale. Trying to quantify the CO_2 in the ground. There is a quantification issue.

Geophysical monitoring offshore, past, present and future. Philip Ringrose, Statoil -

Statoil has 21 years of CO_2 storage experience at Sleipner. 17 MT CO_2 is injected and it is now important to learn from this and apply it to the planned CO_2 storage project at Smeaheia.

Sleipner gives insights from geophysical time-lapse monitoring. The monitoring program includes seismic, gravimetry, visual monitoring, and chemical sampling.

Sleipner was re-permitted in 2015 under the new Norwegian law reflecting the European CO_2 storage directive. Similar re-permitting is also established for Snøhvit. The two storage projects are now in compliance with Norwegian regulations.

The Snøhvit monitoring includes 4D seismic and downhole P/T gauge. As a result there are now operational value of monitoring. There is a lot of learning from Sleipner and Snøhvit that is useful for Smeaheia.

The question for future projects, however, is if we need to do all this. Can we do it cheaper? Future monitoring needs to be smart and cost effective.

Smart offshore monitoring includes:

- Increase use of permanent reservoir monitoring (PRM systems)
- Increased use of downhole monitoring
- Use of advanced AUVs for environmental monitoring
- Use of advanced and integrated data analysis

Subsea solutions look promising together with permanent sensors and advanced data analysis.

The challenge for CO_2 storage monitoring is if it is fit for purpose.

There are learnings from onshore test sites. Also CaMI in Canada has shown a unique opportunity to develop and test monitoring technologies and integrated monitoring systems. This is useful for building experience that could be taken offshore.

Working ideas for future offshore monitoring include:

- Marine streamer seismic acquisition which gives good baseline and require few repeats
- More use of downhole fibre-based monitoring – DTS/DAS
- Development of trigger survey concepts
- Environmental monitoring program
- Advanced data analysis

Permanent reservoir monitoring system are of high value, but cost more. The question is if we can trim the cost and demonstrate the value. Monitoring must be smart and affordable, and one important aspect is if we can move CO_2 storage further into the digital age.

Panel discussion

Introduction:

It is of interest to know how expensive baselines are.

When we find anomalies we must be able to tell where they come from.

Regarding significance of baselines. Will that change? What will it tell?

Microseismic baselines can be used for locating anomalies. The real time measurements give data that enables a quick response to anomalies. The initial monitoring system can be a coarse network to detect the M2 and M3 events. The network can then be enhanced based on what the initial measurements.

What can we do with anomalies?

It is hard to sell a good baseline, but a baseline can reduce cost later. Going for false-positives all the time is costly. It is all about reducing cost for the whole project.

Surprises have turned up in all projects. The key is to know how to deal with it.

One important aspect of baselines is to make sure that there is not anything active in the area before starting baseline measurements. Think carefully in shallow environment before setting up baselines. Different rules might apply in deep water.

It is interesting to understand fluid flow history. What is the perturbation from the sediments to the water column?

This is more or less insignificant.

3D surveys have shown to be sufficient and too much monitoring is not necessary. It is possible to save money on baseline by using available data.

Is it researchers or national geological surveys who should go deep into the understanding of processes?

It is not how much we can monitor, but how much can we afford to monitor. It could, however, be wise to take some insurance to avoid troubles. But in the end, you might not use everything you measure.

It is also a question about how often you should monitor. The public will push you to high standards, but they will also appreciate it being cost effective.

Should we look for geochemical signals or bubble streams?

It is important to be there when the signal is passing through. The monitoring plan should also take into account that you often know where the places for possible leaks are.

Should we monitor leaks or the damage?

There is a need to monitor whatever harms the environment. We could monitor the damaging leaks, but not all leaks. Damages must be quantified.

Underground storage of natural gas has taken place for many years. We can learn from it.

CCS is about locking up carbon for a long time-scale. That is why even small leakage at about 0.01 % of the volume must be detected.

The public are often afraid of onshore storage. One reason is a lake in Africa (Lake Nyos, Cameroon) where people were killed because of a natural release of CO_2. When monitoring offshore we must keep in mind that a small damage can be a precursor for a large damage. There is a logic behind what can be an acceptable leakage rate.

Session 4. Offshore CO_2 Storage Resource Assessment. Chair – Mike Carpenter

Storage resources assessment for offshore CO_2-EOR in Norway. Eva Halland, Norwegian Petroleum Directorate -

We don't have any CO_2 for EOR projects in Norway. Not even a pilot, even though there are potentials for CO_2 EOR projects.

Mapping of Norwegian storage capacities are documented in storage atlases for the North Sea, the Norwegian Sea, and the Barents Sea. The theoretically storage capacity is measured in tens of GT.

The main goal for the Norwegian Petroleum Directorate is to contribute to realizing maximum value for our society from the oil and gas activities through prudent and efficient resource management.

Average recovery rate on the Norwegian Continental Shelf is 46 %. Several fields have potential for CO_2 EOR, but all field need to be treated differently.

CO_2 for EOR have several advantages; Swelling to improve flow characteristics; Vaporization ensure oil components are recovered; Reduced oil viscosity; Solubility in water; Miscibility at relative low pressures.

A screening study of 23 oil fields in the Norwegian Sea was based on injecting 70 MT CO_2 annually, resulting in increased recovery rate in the range 4 to 12 %. The increased oil production was estimated to 320 million Sm^3.

Discussion

Does the resulting 90 % storage include mature and immature fields?

In most cases in the study the injection does not start at day one, but later. However, in some cases injection starts from day one and ROZ is also considered for some cases.

It was said that several fields were more or less ready for CO_2 EOR. What does 'more or less' mean?

In our studies we list large theoretical storage capacities. When different constraints are accounted for we end up with a lower capacity that could easily be realised. Some have already wells that could be used, and other needs new wells. Some fields already have seismic data, and some fields need more seismic.

Update on US DOE supported offshore storage activities. Darin Damiani, US DOE

DOE has three CO_2 storage programmes addressing advanced storage, Ssorage infrastructure, and risk and development tools, respectively. There are in addition seven Regional Partnerships that has stored more than 10 MT CO_2.

ARRA (American Recovery and Reinvestment Act) has funded two projects to characterize offshore storage. The CarbonSAFE initiative intends to develop storage complexes. There are 13 Phase 1 projects and two of them are looking at offshore storage complexes.

The most recent award are for partnership projects for offshore carbon storage resources and technology development in the Gulf of Mexico. The objective is to perform comprehensive assessment of potential to implement offshore CO_2 storage. Two partnership projects have been started, one with University of Texas and one with Southern States energy Board.

NETL has completed an initial offshore geologic database and developed methods to estimate CO_2 storage.

International collaboration with Japan and Norway are of high relevance. This includes validation of P-cable at Tomakomai, reservoir integrity studies at Snøhvit, and work on a well integrity atlas.

Concluding remarks:

- DOE is actively engaged in offshore storage characterization
- Need to narrow gaps in technology needs offshore
- Technology development for offshore CCS/CCUS can be accelerated further through continued international collaboration

Approaches to evaluations: inner-shelf deltaic example GoM. Tip Meckel, BEG -

Details on the geology of the Gulf of Mexico (GoM) was presented. A lot of the work is summarised in the Geological CO_2 sequestration Atlas of Miocene Strata, Offshore Texas State Waters. Similar work has also been done on faults. Gas fields in the area are basically set up on faults. Knowledge on the petroleum system can indicate the possible storage area. 50M tons can be stored in depleted gas fields.

A trend is that the column height that systems can sustain gets higher the further down you go. Much data from the studies are very relevant for CO_2 storage.

Panel discussion

There will be a cost related to infrastructure for Norwegian CO_2 EOR projects. Who will pay for it?

Other infrastructure has often been paid by the state. The starting point will be studies to evaluation the possible income for companies.

Resource assessments are often optimistic. Are there any recommendations related to this to a country that is ready to embark on CO_2 storage?

Don't spend too much time on reginal capacity assessment. It is a useful exercise pointing you to the right direction. From there you can do a refined assessment.

Structural elements are well known at the Norwegian Continental Shelf, but not in the context of CO_2 storage. There has been good communication with other countries related to the North Sea regarding development of CO_2 storage. In the Norwegian sea we have many natural gas fields with high CO_2 content. CO_2 storage might therefor be needed in the Norwegian Sea. It is a similar situation for the Barents Sea. There are different needs for different areas.

Have you seen good and pore resource assessments in the US?

It is important to look at it from a high level to get an idea of how infrastructure might work out. High level assessments are thus very important. However, you don't know the capacity until you start injecting.

Resource capacity can be assessed along similar procedures as for the petroleum industry. But there are risks related to well connections. Will there be a standardised way for characterise capacity?

Yes – a study for the US will be out soon and it can be downloaded. A guidance document will be out in a year.

USA has long experience producing CO_2 capacity atlases and has developed several methods.

The Society of Petroleum Engineers (SPE) will release a Geologic Storage Resources Management System (SRMS), analogue to oil and gas guidelines.

We need to stay away from the wells when doing resource assessments. How do you join the spots?

Understand local geology is the key. Based on known information it becomes an extrapolating exercise. There are similarities that are transferable, but the North Sea is fundamentally different from the Gulf of Mexico. It is recommended to start with wells and then put together stratigraphic information.

During project development the dynamic capacity is needed. Will mapping of dynamic capacity be more interesting than static capacity assessment?

In the Gulf we went to an attractive block and started with static figures to quantify it. Then we were working back to see how many projects we could get in this block.

It is not all capacity that can be accessed in economic terms.

In Norway there is information for drilled wells. This was used to extrapolate into areas that had no wells.

It was commented from the audience that dynamic capacity should be linked to economy. On top of the static capacity there should be data on injectivity per well. With more wells it will be possible to inject faster. Such as tool could be useful, provided that the same standards and definitions are used worldwide.

The total storage volume is economically limited. In some cases the challenge is that you need to how much CO_2 that is available. Capacity is in the end availability. Cost constraint is info we not always have at hands. The question is often how large the injection rate can be.

Session 5. Project Updates. Chair – Philip Ringrose

Overview and status of the Norwegian full-scale storage project. Mike Carpenter, Gassnova –

Parliament will publish an update on the Norwegian full scale project on 15 May in connection with the revised national budget. The decision will be taken by Parliament in June.

Capture and transport have had less activity lately as they were somewhat ahead of storage. The storage part, also called the Northern Lights project, will finish their concept phase this summer. Statoil has joined forces with Shell and Total. Statoil is also responsible for conceptual work of the transport. If parliament decides to go ahead, the feed study to be finished August 2020.

The location for the terminal has been chosen to be the base at Kolsnes. A town Hall meeting has been held. This is an area with many holiday cabins. Local and regional politicians are positive. A real project will test the regulations.

The commercial model for operation of the infrastructure is still under negotiations. On storage a new company needs to be formed. Company to be responsible for operation of transport is still open. The government will absorb risk between elements in the chain.

On the technical side, the preliminary design of receiving terminal has progressed. It still remains to evaluate the need to use glycol to avoid hydrate formation. Seismic data for and characterisation of Smeaheia need to be up-dated. Dynamic uncertainty on the storage capacity

still exists. There are two legacy wells in the area and several in Troll field to the west. production at Troll lowers the pressure and we need to know how this will influence the storage in Smeaheia. Data and reservoir model results have been shared with researchers. The collaboration with researchers is positive.

Brazil's Pre-Salt Development and CO_2 Management. Paulo Negrais Seabra, Petrobras (retired)

Oil production onshore Brazil started in 1950, and offshore production started in 1974.

In the 1980's one started to go into the deep water, production in ultra-deep started around 2006 and, in the pre-salt area (also ultra-deep) around 2010. Today, 53% of the production is from the pre-salt area. The other areas have declining production. Petrobras stands for about 93% of the operation.

Pre-salt reservoirs have oil and natural gas and are at 2000 m water depth or more. They are located outside the south part of Brazil.

Lula is 300km from onshore and reservoir depth is approximately 4900m beneath the sea floor. In some areas there is a salt layer with more than 2,000 m thick. The CO_2 content of the gas is 8-20% in the pre-salt area. It was decided early-on that the CO_2 should not be vented to the atmosphere. Flaring is not allowed.

CO_2 is removed on seven Floating Production Storage and Offloading vessels (FPSO) with membranes, as these have small footprint and wider range of separation and injection of CO_2. Two units use spiral wound membrane, the remaining five use hollow fiber membranes. The main goal for the measure was not EOR but to store CO_2. The CO_2 is part of a WAG EOR-system. The gas is exported by pipeline to shore and oil exported on offloading tankers.

CO_2 separation with membranes are used with success. About 7 Mt CO_2 have been injected by December 2017.

Jiro Tanaka JCCS – Tomakoma CCS Demonstration Project

Japan CCS is a private company that represents several industrial sectors with interest in CCS. It is set up to perform CCS projects sponsored by the Japan government, namely the Tomakomai project and the investigation of potential sites for CO_2 storage. The Tomakomai project is funded by the Ministry of Economy, Trade and Industry (METI), and the potential site investigation by METI and the Ministry of Environment (MOE).

Tomakomai design and construction started in April 2012, and injection started in April 2016. Monitoring continues two years after injection until 2020.

Objectives include the need to remove concerns regarding to earthquakes, and to establish public outreach program.

The CO_2 source is a hydrogen production system in a refinery, which provides a CO_2-rich gas stream that is transported by a 1.4 km pipeline to the Tomakomai Project. The Tomakomai capture facility has a capacity of 200,000 t CO_2/year, but the actual output is dependent on the CO2 supply from the refinery. The aim is to inject about 100,000 t/y over three years, i.e. totally 300,000 tonnes. Injection wells are surrounded by monitoring system observation wells offshore and onshore seismic monitoring.

Tomakomai capture system depressurization lowers the energy required compared to conventional systems.

Injection is from onshore wellheads to two reservoirs, one shallow at 1000 m and one deep at 2400m. The maximum injection rate is $22x10^4$ tonnes CO_2/year. Regarding the shallow reservoir, the upper limit of the injection pressure was set at 12.6 Pa. The actual injection pressure is well below this limit.

Monitoring includes sensors in the well, extended perforated liner, CO_2 flow meters, as well as P, T, and 3 component seismic sensors. It is required to conduct extensive marine environmental surveys, including, water samples for analysis.

As of 1 May 2018, 174,279 tonnes CO_2 have been injected.

Natural seismicity is monitored. An earthquake took place on 1 July 2017, but did not have any effect on T or P. Injection did not take place during earthquake. The micro-seismicity observed in the area is not related to the CO_2 injections.

Preliminary analysis of the first 4D seismic monitoring have been made, and the CO_2 plume at around 61,000-69,000 tonnes has been imaged.

Panel discussion

Why are Total and Shell involved?

Sharing knowledge. License is operated by a partnership. The government foresees partnership also for storage projects. Statoil contracted with Gassnova. Statoil went into a partnership with Total and Shell.

Why FPSO and not platform.

It is more cost-effective than platform at those water depths and the big distances from the shore.

For monitoring at Tomakomai- is monitoring around the onshore injection well for only seismic?

CO_2 detection in the injection facility. All other monitoring is only seismic monitoring.

How is oil exported from Lula?

Need to deliver oil by tankers, it is 300km from shore.

How is risk allocation in Norwegian project?

Source, shipping and storage are all different companies. Government absorbs the risk between the different partners. Government probably also takes some of the long term risk.

Norway appears not to have liability towards the fisherman, but how to take care of the activities of others that use the area?

This is done through environmental impact assessment plans that go out for hearing.

How popular is CCS in Norway? Are there any aspects of concern?

Most concerns from the people that have their cabins there. Have already a lot of oil and gas activities in the area.

And how about Tomakomai?

Initially there were 150 potential sites. Tomakomai had a history of oil and gas exploration. There seemed to be acceptance from local population and it was away from faults.

Session 6. Standards and Regulatory Frameworks. Chair – Tim Dixon

Tomakomai lessons learned in offshore CO_2 storage regulations. Ryozo Tanaka, RITE

CO_2 injection at Tomakomei was suspended due to natural fluctuations in seawater parameters larger than a conservative threshold. The injection started again after revision of the monitoring plan.

The regulatory framework of CO_2 storage is based on the Marine Pollution Prevention Law. This law does not intend to promote CCS, but to protect the environment. Operators must obtain a permit from the Minister of Environment (MOE).

The main monitoring method is seismic survey. Downhole temperature and pressure is also measured together with water sampling.

There were difficulties in setting a threshold based on pCO_2 and DO (dissolved oxygen). The threshold was determined based on curve fitting of one year of data where pCO_2 is inversely proportional to DO. This gave a conservative threshold relative to four years of data from the regulator.

In the end it became clear that thresholds must be based on more than one year of data.

Injection started April 2016. Some measured points of DO and pCO_2 went above the threshold. It was concluded that the irregularity was due to natural seawater fluctuations. MOE required a revision of the monitoring protocol. These were additional steps being added, in addition to water sampling, multiple methods for detecting CO_2 leakage was added, e.g. pH sensor and side-scan sonar. This was pragmatic and did not require a change in the regulations or the threshold line.

An important lesson learned is that CCS regulations should be established for the purpose to promote safe CCS and should be flexible, and immature monitoring plans can be detrimental. Monitoring plans and protocols should be practical and flexible, and there should be good communication with the regulator.

Discussion

What happened to the CO_2 from capture plant during the suspension?

It was released to air.

The CO_2 injection was suspended for 6 months. The permit is held by METI, and they requested changes to the protocol. The threshold was also exceeded the following year, but then there was no suspension.

When an anomality occurs, it is important to understand what happens.

The final solution was interesting and pragmatic.

Did the regulator demand more monitoring and did they require more frequent measurements?

Yes. pH and sonar was required. Measurements are required once every season. We also have to do an extra survey if we go above threshold.

Has the project been set back?

It is only an extension of injection.

It was commented from the audience that groundwater technology has been available for many years and that it makes sense to do more than just background monitoring.

An option to the challenges the project faced could be to change the law, but this is difficult. However, the ministry said they are flexible. It is important to share documents and facts.

ISO storage standard (ISO 27914) and certification framework. Jørg Aarnes, DNV

The objective has been to provide recommendation for safe and effective storage of CO_2. The standards were developed over 7 years by approximately 100 individuals from more than 10 countries.

An important aspect of such standards is trust building.

The hierarchy of laws, regulations, etc, is as follows

- Acts, directives, conventions. This is the top level and there are few details.
- National laws and regulations
- Standards and guidelines, company policies, operating procedures
- Best practices. This is the bottom level and there is a high degree of details.

The new ISO standards do not replace national regulations. There are additional documents.

Different stakeholders can use the ISO standard for different purposes:

- Operators can use it for project execution and as a reference document for dialogue. The ISO will also be relevant when applying for storage permits.
- Investors can use it for technical due diligence, for understanding risk management and uncertainty, and when making FID with operators.
- Regulators can use it when providing injection permits, for sanctioning, and as an additional guidance to regulators.
- Policy makers can use the ISO for developing regulations and for funding support for CCS projects.

A new certification framework was designed by DNV GL to guide verification of a projects conformity with the Storage standard ISO 27914. The document was out for review and received positive feedback from many key stakeholders.

An expert panel is put together when DNV GL perform reviews. If a positive evaluation then a certificate of conformity is given together with a verification report.

DNV GL review experience include Quest, CarbonNet, and Gorgon.

Discussion

Are there other standards for CO_2 storage?

Not for storage, but there is one relevant ISO standard for CO_2-transport.

Have there been any discussion with regulators in this process.

No. But they have been listening to the process.

What is the language capabilities and what is the cost?

Language is not necessarily a constraint. Ideally, English will be preferred language. In other cases, there must be hire people that can communicate with the project.

The cost depends on the stage of the project. It is roughly 100,000 USD to 150,000 USD for a feasibility study. A storage permit is more comprehensive and will probably double the cost.

Is there restriction on the number of organisations that can perform the certification framework process?

No. Any (qualified) company can perform the required verification for each certificate, and can in principle also issue a corresponding certificate, but only DNV GL can issue the DNV GL certificates listed in the document. DNV-GL are not aware of others that do this.

Comment from the audience:

This is very useful and it is beneficial to projects.

Discussion on London Protocol application to Norwegian projects

Introduction by chair Ryozo Tanaka, RITE

The objective of the London Protocol (LP) is to protect and preserve the marine environment. LP allows CO_2 storage, but export CO_2 is not yet allowed.

Norway raises concerns on the prohibition of CO_2 export for offshore CO_2 storage at Smeaheia. However, this could be out of scope of LP since CO_2 is to be transported by pipeline from onshore.

Is Snøhvit within the LP scope? The exemption for CO_2 derived from offshore processing may not be applicable since it does onshore processing. Transport via pipeline from onshore could be a reason for Snøhvit to be out of scope of LP.

There could be also a discussion if offshore CO_2 for EOR is within LP scope. In this case CO_2 is a commodity, not a waste for dumping. Could this be a reason for CO_2 for offshore EOR to be out of scope of the LP?

Ingvild Ombudstveit, GCCSI

Some forms of cross-board CCS collaboration may face some challenges because according to LP article 6 says that export of waste for dumping at sea is not allowed. Challenges related to this are addressed in the 2009 amendment to LP where transport and export restrictions were

removed. However, two thirds of 45 member countries have to ratify the amendment and only a handful of the countries have done so.

Tim Dixon, IEAGHG

The LP is a good thing, but there can be challenges for transboundary CCS. The 2009 export amendments will only come into force when two thirds of member countries have signed. 31 countries must sign, but so far only five have signed.

Seven scenarios were considered years ago in the early legal work for the original CCS amendment in 2006. Scenario 2 includes pipeline from land to sub-seabed. This was considered out of scope of LP.

EOR is another interesting subject, but this should not be a problem related to LP because CO_2 for EOR is not disposal of waste.

There were differing views on other scenarios. This led to the CCS amendment of LP in 2006.

There was convergence of views years ago, but LP has developed scope since then.

The Snøhvit and Smeaheia cases related to LP are complicated. We welcome Norwegian Lawyers to advise.

Discussion

A case where Norway imports CO_2 by ship to an onshore hub and then transport the CO_2 in offshore pipeline to a storage site was discussed. Can this be accepted by the LP? There are different views on this.

How was CCS handled in the original LP amendment?

CO_2 was included in the list of exemptions in the annexes to the LP.

Are there examples of prosecutions because of the LP?

It can happen, and cases could end up in court. Norway as a country can get problems if an operator is allowed to do business that are not in line with LP.

Why does pipelines matter as long as the reason for LP is to protect the marine environment?

Because the source and route to seabed have different legal implications.

It seems like EOR is used a loophole by claiming that CO_2 is a commodity. Could this make it difficult to get credits for storing CO_2?

LP is not about commodities, but protection of the marine environment. ETS credits should still apply (if the EU Storage Directive is met).

Does LP applied for international sea or sea related to countries?

LP applies to national waters.

Can CO_2 transport from NL to Norway be handled through bilateral agreements?

This is one of six option that could solve the problem.

It is not necessary the best option because it can set precedence that the LP is not happy about.

In such a case we are moving into diplomacy. It could work with a bilateral agreement. However, it would still be an idea to seek support for the not-ratified countries.

At Snøhvit CO_2 is separated onshore and then transported back to the field where it came from. Is there any embrittlement with LP?

It should be in compliance with LP. However, it can be questioned if it is still OK if the project is extended to import gas from other sites.

Is CO_2 EOR accepted or is it still an open issue under LP?

It is not an open issue. There may be risk in terms of tracking where molecules come from. In CO_2 EOR projects the CO_2 can be anthropogenic or not.

Comments from the audience:

National waters are regulated by countries and this must be based on LP. In this context I do not see that the Snøhvit project should be a problem for the LP.

If CO_2 is transported for EOR it could be said that CO_2 is a commodity. But the main reason for CO_2 transport is to store the CO_2.

US operators would never do EOR with CO_2 recycling. CO_2 taken out must be replaced and therefore no exception from the LP.

Panel discussion

In the panel: Ryozo Tanaka, Ingvild Ombudstvedt, Jørg Aanes

Comments from the audience:

The ISO is used actively in the Norwegian project. It is very useful to refer to ISO instead of writing several pages with documentation.

Learnings from Tomakomai are significant. Anomalies in marine environment are complex and we need to understand the reasons for anomalies and where they are coming from. We must be able to say if anomalies comes from our projects or not.

Regarding ISO - Does permits include reporting?

It is included in regulatory framework

Still regarding ISO – Is it required to include public communication?

It is important to distinguish between permit and verification process.

Processes for establishing regulations often includes public hearings. If there are comments from the public they need to be addressed.

Session 7. Brainstorming Towards an International Collaborative Project. Facilitated by Katherine Romanak and Tim Dixon

Discussion on criteria for international collaborative project.

How can we facilitate learning throughout all stages of a project?

We can learn a lot from real projects like Weyburn. There is a lot of Best Practice documents based on such projects. We should have "*where to find information*" roadmaps.

The atmosphere is a shared resource and CCS is a global project. We are all participants of the global CCS Project. This is like space research sponsored by key countries.

Countries are at different stages. Some countries have not started yet, but a large part of the solution must take place in developing countries.

The real learning is learning by doing.

The Norwegian government wants learnings from the planned full-scale project to be shared.

We need actors that can transfer technology. Oil companies are important.

We must identify countries with offshore storage potential and get them into the room.

International Ocean Discovery Program (IODP) is an interesting model that could work for CCS. IODP is a shared resource that has been highly successful. We could need an IODP model for CCS.

A shared CCS infrastructure could include a ship just like in the IODP. It could even be an FPSO (Floating production storage and offloading vessel).

One challenge is that it would take time for different communities to engage.

An important question is if we need integrated capture, transport and storage or only an injection pilot.

The OGCI (Oil and Gas Climate Initiative) can be a gateway to larger transnational CCS projects. OGCI could fund good project.

Guidelines to the guidelines

Implementing a guideline to all the existing guidelines is a good idea, but this must be more than just a collection of documents. Someone must run this because there will always be questions. It is important to have a champion driving this forward. A Champion Crew is needed to get this up and running. IEAGHG provided summary reports with links to UK FEED documents, so is well placed to do this sort of activity.

ACT (Accelerating CCS Technologies)

ACT is an EU initiative to establish CO_2 capture, utilisation and storage (CCUS) as a tool to combat global warming. There is a potential for broadening ACT and one possibility is to link ACT and MI (Mission Innovation) and develop ACT to be the operationalisation of MI.

This would be a big project and beforehand it must be defined *who* can do it and *why* it should be done.

ACT is today about technology development. We need a project version of it.

Panel on Public Funding and New Funding Mechanisms

Hans Olav Ibrekk, Norwegian Ministry of Foreign Affairs

It may be that our CCS agenda is not playing together with the agenda from environments dealing with international funding and investments!

When international funding bodies consider sustainability, they look at the UN sustainable development goals. Energy is covered in goal number 7: *Affordable and clean energy*. Working processes related to international funding mechanisms very often focus on renewable energy and do not mention CCS. There is a move to exclude fossil fuels.

There are dedicated trust funds relevant for CCS. Two examples are the Asian Development Bank CCS trust fund and the World Bank CCS Trust fund

The Green Climate Fund (GCF) can be a catalyst for paradigm shift. Pledged contribution is USD 10.3 billion.

GCF has six investment criteria; Impact potential, paradigm shift potential, sustainable development potential, country ownership, effectivity, and responsive to needs.

GCF requires a fit-for-purpose accreditation. CCS has not been specifically discussed in GCF, there is an Innovation Call latter this year which may be relevant. Net negative emissions are required at a reasonable cost per ton CO_2. However there could be a concern if CO_2 is used for EOR.

The GCF now has a new Technical Advisory Board.

Egil Meisingset, Norwegian Ministry of Petroleum and Energy

The plans for full scale CCS in Norway is being reviewed by the Parliament and an update on the project will be published 15th May in the revised national budget.

If the Parliament goes forward the next step will be FID (Final Investment Decision).

CCS is a hard fight in all budget discussions, but the Norwegian government have the ambitions for full scale CCS in Norway under certain conditions:

- National funding must be limited by attracting international funding
- International funding must be based on international cooperation.
- Industrial partners involved are challenged to find more partners.
- It is vital to attract CO_2 sources outside Norway.
- Low marginal cost must be ensured.
- Acceptable cost and risk must be demonstrated.
- Show benefits for other projects.
- It must be shown that a cost efficient full-scale project in Norway will lead to technology development internationally.
- In the longer perspective we must see business models that do not require public funding.

EU funding to the project will be important and the Norwegian government have started discussions with EU. Similar mechanisms as the ROAD project had could be useful. The Innovation Fund and PCI (Projects of Common Interest) are two other interesting mechanisms.

If the Parliament goes forward with the project 15th May we need to intensify the project. Financing the project is a big task.

Panel discussion

Will it be possible for other countries to learn from the Norwegian project?

Yes. We are very open for ideas. There are resources for capacity building and transfer of learnings to developing countries.

Will it be up to the CCS community to define ways developing countries can be involved?

CCS cooperation with China and South Africa is already established.

Are there any views for developing countries in the audience?

Mexico: We have plans, but need technical support.

China: We have large storage potential offshore and we are developing offshore CO_2 storage. We have established collaboration with UK. Without the UK funding it would have been difficult for us to study CCS. We also have close collaboration with USA and Canada. We have been testing at cofired plants and we have collaboration with TCM (Technology Mongstad) and University of Texas. We have support from GCCSI and Asian Development Bank. International collaboration is important for us.

How can we identify relevant countries and increase knowledge building?

Sustainable development criteria related to CCS are important and will be considered by GCF.

We must emphasise that CCS can create jobs and lead to added value locally.

A white paper on oceans was published last year. Oceans are a new priority and energy and CCS is a subject that could be discussed under this priority.

Ocean acidification is an issue. CCS can be important for the oceans through Bio Energy with CCS (BECCS).

The NDCs (Nationally Determined Contributions) under the Paris agreement are important. Ten countries have included CCS in their NDC

The biggest challenge is that CCS is too expensive. Through projects we must reduce cost. Countries like USA, Canada, and Norway, should take the lead to lower the cost so that the financial burden lessens.

How to transfer knowledge and experience is a vital. This is one of the main aspects of the Norwegian full-scale CCS project.

Workshop Conclusions and Recommendations

The following conclusions and recommendations were agreed at the end of the workshop.

Value chains:

- There is a new interest in the EU and Japan for value chains combining hydrogen production and CCS.

- 45Q tax credits may be significant to stimulate projects. There could be timing challenges for storage project development as the deadline for construction is 2024. Permitting challenges may exist for CO_2 storage, but not for EOR.

Infrastructure:

- Re-use of infrastructure is not necessarily easy. Reuse of pipelines is more likely than reuse of platforms.
- More R&D on legacy wells is needed, specifically how to deal with the challenges presented. Different standards exist in time, region, and purpose.

Monitoring

- The benefits of permanent reservoir monitoring outweigh the extra cost, but coverage is inflexible with this method.
- Different monitoring methods should inform each other, including methods for determining trigger points. This type of complementary monitoring is crucial.
- Marine environment baselines – very complex but we are learning more.
- AUVs are proving successful for long term surveillance, both temporal and spatial, and for public assurance.
- The workflow is to find anomaly and then attribute its source.
- HR4D seismic can be used for characterisation of shallow leakage structures and for monitoring the plume during injection.
- Microseismic techniques require background data.

Resource assessment

- Don't spend too much time on refining broad static assessments – leap from regional to more local assessments including dynamic capacities, and to well injectivity basis.
- Society of Petroleum Engineers are developing and releasing a Geologic Storage Resources Management System (SRMS) this year.
- Resource quantification will be more important as projects mature.

Projects

- Norway has plans for full-scale CCS.
- USA is developing robust offshore R&D programmes.
- Japan and Brazil have matured projects emerging.
- 4D seismic imaging is very encouraging at Tomakomai. First imaging of CO_2 at 60,000t at 1km depth.

Regulatory frameworks

- Regulations should adapt to learnings.
- ISO certification could be useful for building trust in a project and useful for communication with different stakeholders.

- London Protocol: scope still needs clarifications. Projects can help test applicability. Not one-size-fits-all, but case by case assessment.
- Key message from Tomakomai: additional techniques needed.

Brainstorming Criteria for International Collaborative Project – (the what and the how, not the where)

- Objective is to share learning by doing from the real projects.
- Need roadmaps on where to find information on CCS
- Can we learn from the International Space Station or the International Ocean Discovery Program, for CCS.
- The ACT initiative could be used for projects, not just for R&D.
- Develop ACT to be the operationalisation of Mission Innovation
- Could Oil and Gas Climate Initiative (OGCI) fund a real project?

Funding

- International funders are keener on non-fossil fuel technologies.
- The value of CCS needs better and more advocacy to funders.
- Norwegian project is seeking international collaboration.
- Green Climate Fund will use Sustainable Development Goals (SDGs) as one of 6 criteria – CCS is lacking evidence-base for support in SDGs.

Key recommendations included:

- Explore models for international collaboration on projects.
- An ACT-type model is good for R&D (US is joining), so an ACT for projects is recommended.
- Consider how to build knowledge sharing from hands-on operational projects, including an international collaboration on a project.
- Provide a roadmap to existing information sources.
- Joint funding between countries has started and should continue.
- Survey which developing countries would be attracted to offshore storage.
- Get developing country representatives to these meetings. Identify key persons and funding sources.
- More advocacy is needed to funders on CCS – future Nationally Determined Contributions will need CCS, so how can we make countries aware of their potential? The research community is ready to inform.
- Complimentary monitoring to be built into MVA plans - different monitoring methods informing each other, including methods for determining trigger points.

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

Appendix 1 – Agenda, Posters, Steering Committee, and Attendees

3rd International Workshop on Offshore Geologic CO_2 Storage

May 3 - 4, 2018

Research Council of Norway
Oslo, Norway

GCCC Gulf Coast Carbon Center

The Research Council of Norway

CLIMIT

ieaghg

carbon sequestration leadership forum

Norwegian Ministry of Petroleum and Energy

Statoil

sonedi

3rd International Workshop on Offshore Geologic CO_2 Storage

Venue: Research Council of Norway, Drammensveien 288, Lysaker, Oslo

Auditorium Moser

DAY 1 THURSDAY MAY 3, 2017

08.00 – 08.30 Registration

08.30 Common Session Capture and Storage workshops

Welcome, Objectives of meeting, agendas, logistics (safety announcements)

08:30 Welcome:
Torgeir Knutsen, Deputy Director General, Ministry of Petroleum and Energy, Norway
Steve Winberg, Assistant Secretary for Fossil Energy, Department of Energy, US

08:40 Safety moment, Research Council of Norway

Session 1: Value Chains for Offshore: Chair - Lars Ingolf Eide

08:45 Emerging hydrogen value chains for Norway - Steinar Eikaas, Statoil

09:05 Emerging hydrogen value chains for Japan - KHI/Ryozo Tanaka, RITE

09:25 USA 45 Q and how it should accelerate potential CCUS projects – Brian Hill, SSEB

09:45 Discussion

09:55 COFFE BREAK and POSTERS

3rd International Workshop on Offshore Geologic CO_2 Storage

10:20 Welcome and Scene-setting: How to 'Learn from our learnings' Tim Dixon IEAGHG and Katherine Romanak, BEG

Session 2: Infrastructure: Chair - Paulo Negrais Seabra

10:35 New subsea systems for CO_2 storage/EOR– making it cheaper and more efficient - Pål Nøkleby, Aker Solutions

10:55 Technical considerations in re-use of pipelines platforms - Steve Murphy, ACORN / Pale Blue Dot

11:15 New technology for handling legacy well integrity issues - Malin Torsæter, SINTEF

11:35 Discussion

Session 3: Monitoring offshore CO_2 storage/EOR - Chair: Katherine Romanak

11:45 Handling microseismic background – Volker Oye, NORSAR, Norway

12:05 STEMM-CCS project updates on seafloor/environmental monitoring – Maribel I. García-Ibáñez, University of Bergen

12:35 UK AUV update on seafloor/environmental monitoring – Graham Brown, Sonardyne

12:55 LUNCH and POSTERS

13:55 Update on leakage detection – Keisuke Uchimoto, RITE

14:15 Update on shallow seismic (p-cable) at Tomakomai– Tip Meckel, BEG

14:35 Geophysical monitoring offshore – Philip Ringrose, Statoil

14:55 Discussion

Session 4: Offshore CO_2 storage resource assessment - Chair: Mike Carpenter

15:05 Storage resource assessment for offshore CO_2-EOR in Norway - Eva Halland, Norway Petroleum Directorate

15:25 Update on US projects – Darin Damiani, US DOE

15:45 Approaches to evaluations, example from Gulf of Mexico - Tip Meckel, BEG

16:05 COFFE BREAK and POSTERS

16:35 Updates on databases for CO_2 Storage - informal discussion

16:45 South Africa depleted fields and platform re-use - Noel Kamrajh, SANEDI on behalf of PetroSA

17:05 Discussion

Session 5: Project updates: Chair - Phillip Ringrose

17:25 Update on Norwegian project under development - Mike Carpenter, Gassnova

17:45 Pre-salt development and CO_2 management - Paulo Negrais Seabra, formerly of Petrobras

18:05 Tomakomai - Jiro Tanaka, Japan CCS

18:25 Discussion

18:35 Adjourn day 1

18:45 Reception at Research Council of Norway, drinks and tapas to be served, co-hosts Statoil, Norwegian Ministry of Oil and Petroleum and Research Council of Norway.

3rd International Workshop on Offshore Geologic CO_2 Storage

DAY 2 FRIDAY MAY 4, 2018

08:30 Welcome - Åse Slagtern, Lars Ingolf Eide

Session 6: Standards and Regulatory Frameworks - Chair: Tim Dixon

08:55 Tomakomai lessons learned in offshore CO_2 storage regulations - Ryozo Tanaka, Rite

09:15 ISO storage standard (ISO 27914), and certification framework - Jorg Aarnes, DNV

09:35 Discussion on London Protocol application to Norway and EOR- Ingvild Ombudstvedt, GCCSI and Tim Dixon, IEAGHG, Chaired by Ryozo Tanaka, RITE

09:55 Discussion

10:05 COFFEE BREAK and POSTERS

Session 7: Interactive Session - Brainstorming towards an international collaborative project - facilitated by Katherine Romanak, Tim Dixon

10:25 Discussion on technical criteria for international collaborative project

10:50 Comments on public funding and new funding mechanisms from Hans Olav Ibrekk, Norwegian MFA, and Egil Meisingset, Norwegian MPE

11:00 Discussion

11:30 **Workshop Conclusions and Recommendations** - Lars Ingolf Eide, Tim Dixon, Katherine Romanak, Tip Meckel

12:00 LUNCH (Box lunches distributed)

12:30 BUS DEPARTURE FOR KLEMETSRUD WASTE-TO-ENERGY PLANT

15:00 BUS RETURNS FROM KLEMETSRUD TO OSLO CENTRAL STATION

POSTERS

Title	Presenter/author	Affiliation
Integration of laboratory rock physics and field scale monitoring for offshore CO_2 storage	Joonsang Park, Magnus Soldal, Guillaume Sauvin and Lars Grande	Norwegian Geotechnical Institute (NGI), Oslo, Norway
Simplified transport models for statistical representation of seep footprints, with application to machine learning and inverse modelling.	Anna Oleynik[1], Kristian Gundersen[1], Guttorm Alendal[1], Hans J. Skaug[1], Helge Avlesen[3], Jarle Berntsen[1], Jeremy Blackford[2], Nello Blaser[1], Pierre Cazenave[2].	[1]Department of Mathematics, University of Bergen, Bergen, Norway, [2]Plymouth Marine Laboratory, Plymouth, UK., [3]Uni Research, Bergen, Norway

Acoustic and chemical technologies for environmental monitoring of geological carbon storage	Ann Blomberg, Espen Eek, Ivar-Kristian Waarum, Joonsang Park	Norwegian Geotechnical Institute (NGI), Oslo, Norway
Sub-sea compression	Zabia Elamin, Pål Helge Nøkleby	Aker Solutions, Bærum,Norway
CO_2 Data Share - establishing and sharing reference datasets from CO_2 storage projects	Odd Andersen	SINTEF Digital, Mathematics and Cybernetics Oslo, Norway
Fast tracking infrastructure development for future offshore CO_2 storage	Brian W. Hill	Southern States Energy Board, USA
Integrated pre-feasibility study for CO_2 sequestration in the Cascadia Basin, offshore of Washington State and British Columbia	Lydia Cumming on behalf of CarbonSAFE Cascadia Phase 1 Project Team	Battelle, USA
Ensuring CO_2 reservoir containment from well pressure monitoring	A. Shchipanov, L. Kollbotn, R. Berenblyum	International Research Institute of Stavanger (IRIS), Stavanger, Norway
The stoichiometric ΔC_{seep} method as a monitoring tool for detection of CO2 leakage from subsea storage sites	M. I. García-Ibáñez[1], A. M. Omar[1], and G. Alendal[2].	[1]Uni Research, Bjerknes Centre for Climate Research, Bergen, Norway, [2]University of Bergen, Bergen, Norway.
Carbon storage resource assessment for offshore Mid-Atlantic United States	Lydia Cumming	Battelle, USA
DEMODAS - Distributed seismic monitoring for geological carbon sequestration	Kirtsi Midttømme, Arvid Nøttvedt	Christian Michelsen Research (CMR), Bergen, Norway
Structural derisking for Smeaheia -Improved fault characterization workflow	Elin Skurtveit[1,2], Mark Mulrooney[2], Johnathon Osmond[2], Jung Chan Choi[1] and Alvar Braathen[2]	[1]NGI Oslo, Norway, [2]Department of Geosciences, University of Oslo (UiO), Oslo, Norway
STEMM -Ensuring efficient and robust offshore storage – the role of marine system modelling.	Jerry Blackford[1], Guttorm Alendal[2], Yuri Artioli[1], Helge Avlesen[3], Pierre Cazenave[1], Baixin Chen[4], Andy Dale[5], Marius Dewar[4], Kristian Gundersen[2], Matthias Haeckel[5], Sorush Khajepor[4], Gennadi Lessin[1], Anna Oleynik[2], Umer Saleem[4].	[1] Plymouth Marine Laboratory, Prospect Place, Plymouth, PL1 3DH, UK [2] Department of Mathematics, University of Bergen, Bergen, Norway [3] Uni Research, Bergen, Norway [4] Institute of Mechanical, Process and Energy Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, UK

		[5] GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstrasse 1-3, 24148 Kiel, Germany
Numerical estimation of the position and rate of CO2 seepage at the seafloor	Ryosuke Sakaizawa[1], Chiaki Mori[1], Toru Sato[1], Hiroyuki Oyama[1], Daisuke Tsumune[2], Takaki Tsubono [2], Yuki Kano[3]	[1]University of Tokyo, [2]CRIEPI, [3]AIST
Safe CO2 Storage Workflow	Roland Kaufmann,	Uni Research CIPR

INTERNATIONAL STEERING COMMITTEE

Tim Dixon, IEAGHG (Chair)

Katherine Romanak, BEG (Co-Chair)

Lars Ingolf Eide, Research Council of Norway (Host)

Åse Slagtern, Research Council of Norway (Host)

Susan Hovorka, BEG

Tip Meckel, BEG

Philip Ringrose, Statoil

Noel Kamrajh, SANEDI

Ryozo Tanaka, RITE

Owain Tucker, Shell

Michael Carpenter, Gassnova

Mark Ackiewicz, US DOE

Traci Rodosta, US DOE

Di Zhou, China Academy of Sciences

Filip Neele, TNO

Paulo Negrais Seabra, formerly of Petrobr

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