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IEAGHG Technical Report 2020-02
IEAGHG Monitoring and Environmental Research Combined Networks Meeting

20th – 22nd August, 2019

An IEAGHG meeting,
hosted by the University of Calgary

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Attendees of the Monitoring and Environmental Research Combined Networks Meeting
University of Calgary, Canada, August 2019
Image Courtesy of University of Calgary

The report should be cited in literature as follows: 'IEAGHG, "IEAGHG Monitoring & Environmental Research Combined Networks Meeting, 2020/02, March, 2020'

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Date Published: March 2020, Review compiled by Tim Dixon, James Craig and Samantha Neades; design and layout by Tom Billcliff.

Front & Back Cover Images: Network meeting at University of Calgary in progress (Image courtesy of University of Calgary); View of the Containment and Monitoring Institute (CaMI) field research station, (Image Courtesy of CMC).

IEAGHG Research Networks
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The Containment and Monitoring Institute (CaMI) field research station (Image Courtesy of CMC).

Summary

The 13th meeting of IEAGHG's Monitoring Network was this year combined with the Environmental Research Network, to facilitate wider topic broaching and encourage broader discussions. This combined networks meeting was held from 20th – 22nd August 2019 at the University of Calgary, Canada. The two day meeting was preceded by a field trip to the Containment and Monitoring Institute (CaMI) field research station site visit. It was followed by a one day workshop on faults and their significance for CO_2 storage (report number 2020-03).

The meeting was designed to cover the following themes: developments in sensing ; lessons from managing field projects; uncertainty in quantification; monitoring for EOR compared with deep saline formations; fall-back plans; new case studies with real data; environmental impacts of monitoring and stakeholder engagement; up-well leakage; and monitoring post-injection for closure.

Of particular note were the first results from the STEMM-CCS project's controlled release experiment in the North Sea. This showed that a range of monitoring techniques were able to detect the small-scale release of CO_2, including small rapid changes in pH, and were able to quantify the amounts of CO_2 reaching the water column. This ability to now potentially quantify CO_2 seepage offshore was an impressive achievement recognised by the meeting. This experiment again showed that only a small percentage of the CO_2 escapes the sediment to the water column, much of it is caught by dissolution within the sediment, an important characteristic for seepage scenario planning.

Two group exercises were undertaken, many thanks to Sue Hovorka. One was to consider fall-back plans in the event of unexpected challenges in operational situations, and one to consider long-term post-injection monitoring. Both proved stimulating and thought-provoking for participants. Also in terms of post-injection monitoring, the Shenhua project in China was interesting to see the requirements there. The Tomakomai project again provided useful experiences in relation to project- and stakeholder-management in the event of natural earthquakes which they have experienced.

As usual at IEAGHG Network meetings, key conclusions and messages were drawn, and recommendations were made. One message was an appreciation of the need for sites such as the CMC Research Institute's Field Research Station (visited during the meeting) to allow R&D and testing of new monitoring techniques on a real CO_2 injection within the freedom of a research environment. The concluding high-level messages noted the great developments in marine and terrestrial sensing, particularly with quantification. Also the participants recognised the challenges arising from some regulations on requiring prescriptive long-term post-injection monitoring, which, however, should be risk-based and achievable with reliable tools, and noting that the objectives may be quite limited.

Session Overviews

Session 1: Welcome

Welcome and Introduction - Andre Buret and Don Lawton, University of Calgary & Tim Dixon, IEAGHG

Andre Buret, Interim Vice-President (Research) from the University of Calgary welcomed all attendees to this event, noting that the University was proud to host IEAGHG and support the work being done on monitoring and environmental research related to CO_2 storage.

Don Lawton, University of Calgary and Tim Dixon, IEAGHG, welcomed delegates to this combined networks meeting, recognising the generous support from sponsors and the hosts. The University of Calgary sponsored and hosted the meeting, with additional sponsorship provided by CMC Research Institutes, Canada First Research Excellence Fund, Enhance Energy, and Canadian Natural.

'Recent developments and challenges in soil gas sensing'
Katherine Romanak, University of Texas

This work is concerned with soil gas baselines, as the current baseline methods are inadequate; they measure CO_2 concentrations in the soil which are naturally increasing due to climate change. This could provide false positives for leakage and be a risk to any project. New methods are needed to avoid these false positives; methods with clear thresholds and no reliance on baselines. The Gulf Coast Carbon Center is developing a process-based method that doesn't use CO_2 concentrations for comparison, but uses the relationship between co-existing gases to understand the processes that cause the proportion of gas concentrations to occur. There are currently no real-time monitoring capabilities for this method so it's important to investigate continuous capabilities.

The CTSCo Surat Basin CCS demonstration project (storing 180,000 tonnes over three years at the Glenhaven site in Australia) spent time looking at commercially-available sensors for implementing a process-based approach at their proposed CO_2 storage site. It was realised that the project did not have adequate real-time, process-based monitoring with continuous capabilities. Whereas a ratio-based method is good for understanding anomalies and assessing leakage, the data quality of the commercial sensors differed among deployments with a high percentage of unusable data, giving rise to random errors and decreasing the real-time benefits. Process-based methods require that all sensors function concurrently. The sensor artefacts trend toward false positives, and these methods are labour intensive. They also require a lot of effort and maintenance. Commercially-available sensors are not adequate for the needs of such monitoring efforts.

The Raman Spectroscopy is recommended as a tool because it provides simultaneous detection of all four gases (CO_2, O_2, N_2 and CH_4) in one sensor and a linear response to changes in gas concentrations at constant pressures. This would be an ideal tool for the continuous, process-based monitoring.

The discussions after the presentation highlighted that more work needs to be done on this approach. The Raman Spectroscopy could be expensive and difficult to implement. There may be other methods that could provide 99% accuracy, but this opportunity looks promising so the initial research needs to be progressed with more support. It's interesting to note that the sensors work well in the lab, but don't work as well in the field; this could be an issue with deployments.

'The STEMM-CCS project: an introduction'
Doug Connelly, NOC

The EC-funded STEMM-CCS project is looking into marine CO_2 storage, and how to monitor offshore aquifers and depleted reservoirs. The main experiment took place in 2019, in the North Sea above the Goldeneye reservoir. Controlled CO_2 releases beneath the sea bed were conducted and then measured and monitored. This CO_2 was released in a real-life scenario using the methods available.

Modelling and monitoring integration is key in situations where a huge amount of data is produced. One part of the STEMM-CCS project focussed on looking at natural features in the sea bed that may act as conduits for CO_2. The team surveyed what leakage might occur over a large area and what the actual expression of leakage might look like. The project ensured extensive engagement with stakeholders alongside public outreach to help shape the future.

Delegates discussed whether this approach is establishing a criterion, zero percentage leakage, as per the current guidelines, that is too stringent; or should it be more elastic so that an acceptable amount of leakage (rather than no leaks) is tolerated. It was noted that although zero leakage is currently required, the legislation is going to be changed on this issue. Therefore it is important to consider situations where some percentage of leakage is expected; and, consequently, it is absolutely crucial to be able to monitor large areas.

'Optimising marine monitoring programmes'
Jerry Blackford, PML

Jerry outlined the approach needed for optimising a marine monitoring programme. He noted "for offshore environmental monitoring, you need technology and a strategy. The strategy needs to be model-led; and you need to know what signal you're looking for to design the optimal deployment strategy. Modelling is used to draw conclusions, create a picture and provide a baseline description". Evaluated regional (large-scale), high resolution models predict, extrapolate and quantify the natural variability, and help to characterise leakage scenarios. No two leakage scenarios are the same. It depends on the location, the sediments, tides, winds and geostrophic mixing, stratification and topography. Under these circumstance different sensors will see different signals. This work used the gradient approach for their anomaly criteria; understanding the high natural variability, and using really small changes in pH over short intervals to signify the anomaly.

The STEMM-CCS monitoring and decision tool will be developed to 'help users select the most appropriate methods for monitoring an offshore CCS storage complex before, during and after injection of CO_2. This online tool will help with the selection of an injection site, environmental impact assessment, leakage detection, leakage quantification and source attribution.

The ACT (Accelerating CCS Technologies) on Offshore Monitoring (ACTOM) project is a new project to try and make this type of modelling more directly accessible to users, and provide operational tools for monitoring strategies.
Monitoring can be done effectively leading to the identification of strategies, costs and monitoring capabilities. Criteria and strategies will vary geographically and seasonally. Monitoring can exploit the full sensitivity of available sensors. This means that it is now possible to detect below thresholds where environmental harm will occur.

The importance of communication was noted. Communication to stakeholders needs to be carefully handled. If stakeholders have been told that it is possible to model a leak, they may see it as a realistic potential scenario, whereas researchers know that it's just the end of the distribution ranges. This perception and misinterpretation of such models happens frequently; and so care must be taken with current sensitivities.

'Fingerprinting the stable and noble gas geochemical baseline of Carbon Management Canada's Field Research Station'
Rachel Utley, University of Edinburgh

This research work looks into the natural fingerprints, in the subsurface, of the methane within the area of the CaMI research site in Canada. The value of baselines before CO_2 injection begins as been determined by analysing nine groundwater and nineteen well gas samples. Stable isotopes were analysed to look into the mixing between thermogenic and biogenic methane.

Five of the samples show a noticeable deviation from air with depth, confirming that there is an increasing radiogenic signature with depth – a clear trend of a crustal signature within the shallower gases. This research then looked into the CO_2 that was going to be injected. The CO_2 had very high krypton and xenon compared to the CH_4 baseline, showing that there is a strong potential to use the krypton (Kr) and xenon (Xe) in the gas for monitoring. The next stage is to see whether there are any increases in Kr and Xe as the CO_2 migrates through the subsurface.

Stable isotopes initially showed a biogenic source, but after combining these isotopes with the gas wetness it showed that there is mixing between a deeper thermogenic source and biogenic methane in the subsurface. The helium (He) data showed an increasing profile with depth, and that ^4He excess, present in shallow groundwater, cannot be produced in situ at these depths. This observation will help the monitoring at the CaMI site as the injected CO_2 is enriched with ^{84}Kr and ^{132}Xe, which can be used as a natural tracer to compare to the baseline as the CO_2 moves through the subsurface.

The concentrations of Kr and Xe could vary based on the capture processes used. It was noted that at this site, all CO_2 sourced is from the same food-grade capture plant and so the ratios have not changed. It was also noted that ratios could potentially fractionate as they moved through the reservoir.

Discussion

It was questioned whether water temperature impacts the pH in marine monitoring. It does, but in the STEMM-CCS project the models are temperature-resolved, so the pH signal is in the baseline. Care should be taken when different water masses mix, as they could have very different temperature and pH etc. profiles. There was some discussion on real time monitoring and in this case the necessity for recent data for monitoring remediation efforts; and in case of stakeholder claims with the allegations of leaks or induced environmental changes.

Session 3: Lessons learned from the management of the CaMI Field Research Station, Newell County, Alberta

'Lessons learned from the management of the CaMI Field Research Station, Newell County, Alberta'
Don Lawton, University of Calgary

The CaMI facility is a site for demonstration of technologies for monitoring the injection of CO_2 and associated storage, alongside general containment and conformance monitoring. The goals are to: determine CO_2 detection thresholds at shallow to intermediate depths; to develop and assess technologies for reservoir, caprock, overburden, groundwater and atmospheric surveillance; to monitor gas migration; to undertake and advance quantitative monitoring of fugitive emissions; and to provide university and industry field training and research.

As site managers, CaMI facility operators understand the importance of having a clear objective and goals, and the importance of site selection. Engaging with the regulator at all levels is critical, then once site selection has been finalised, community engagement can proceed.

'The STEMM-CCS Project'
Doug Connelly, NOC

The project noted the importance of planning as far in advance as possible, and to use the expertise where it is available. Doug expressed the view that everything takes far longer than you think it will. The costs are usually much higher than initially anticipated. There is a high value of industrial partners sharing their experiences and expertise. With this particular work, it was found that off-the-shelf products could not do their required job. In contrast, those products specially engineered for the project worked perfectly. Doug also emphasised that it's important to utilise established expertise especially if you need construction, engineering and all the other areas to provide the best for your project.

'Lessons Learned from the CO2CRC Otway Project'
Fiona Koelmeyer, CO2CRC

The Otway Research Facility is located in Victoria, south-east Australia. The facility is being used to investigate storage challenges and monitoring containment. In 2004, CO_2 CRC began public engagement with the local farming community, local and state authorities, site selection and regulatory approvals. In 2007 the site was ready for use. One of the factors for this site selection was its close proximity to a large natural source of CO_2 , which has been highly beneficial in experimental work. There are currently three wells alongside the source well, with three to four more wells to be drilled.

The focus area of the Otway project is now on addressing the barriers to CCS uptake, such as storage cost and footprint. The storage Stage 3 project will inject 15,000 tonnes of CO_2 and is moving monitoring technology to the subsurface. Experiments at the capture facility will address the highest costs associated with separation by solvent, absorbent and membrane materials. CO_2 CRC will also look at opportunities to accelerate technology for the use by potential CCUS operators with a focus on better use of data.

At Otway, challenges associated with monitoring and containment have underpinned most of the work with these outcomes, using multiple technologies to monitor the plume. The main lessons learned so far have been: regulatory approvals (from ground up is possible); engagement with the community is critical (using the right process); world class collaboration, alignment of projects with market demands; data acquisition and use (should be planned upfront); and technology (is selected for the site and to reduce key risks).

Update on the Northern Lights Projects
Roya Dehghan, Equinor

CCS in Norway has spanned over 22 years of operations and building confidence in CCS, with over 22 Mt of CO_2 stored since 1996. The Northern Lights large-scale CO_2 storage project combines industrial sources from Norway and other countries and safe storage on the Norwegian continental shelf, aiming to 'stimulate development of CCS so that long-term climate targets in Norway and EU can be reached at lowest possible costs' with injection planned to begin in 2023. Subsurface project risks related to the lack of data in the area include capacity commitments and schedule, and the risk in project maturation.

The main monitoring strategy is a risk-based approach, with different technologies chosen due to their efficiency and cost. The main strategy involves seismic, gravimetry and CSEM in the subsurface, flow, pressure and temperature monitoring in the well, and chemical and seabed imaging for environmental aspects (to confirm containment and effect of contingency measures). Equinor will also be undertaking passive monitoring to meet public concern if earthquakes happen in the area.

Discussion

The key learning that Equinor took away from Sleipner and Snøvhit to help develop the Northern Lights project is that every site has its own characteristics and challenges. The question of costs is important to ensure that the top monitoring technologies can be selected for the site. In Alberta, post-closure monitoring lasts for 10 years, whereas in the UK it is 50 years. There was a theme during this session of the importance of early contact with the regulator. The STEMM-CCS project addressed the issues with the Crown Estate and noted the difference in regulations in Scotland versus the Crown Estate in England. The CaMI project agreed there was complexity in the different regulatory bodies across the world and it was valuable to discuss directly with such regulators and the need to be able to look for non-conformance to help and perhaps guide the regulatory environment, particularly for lab-scale storage. At the Otway project, the legislation allows for research activities, but for the prospect of a commercial storage site it would be different.

There was lots of discussion on the monitoring for integrity within a storage complex. The discussion then turned to the expectations with monitoring and regulations and the fugitives from the non-storage components of the projects (i.e. transfers onto ships, gathering systems, compressors, injectors etc.). With the Northern Lights project everything has to be safe and secure as there is a community nearby, and the monitoring on all facilities is stringent. Currently Alberta is going through the offset protocols for CO_2 -EOR and the province is looking at the accounting side. Enhance Energy is looking at all leakage points that may exist, and the quantification of GHG storage in EOR reservoirs by looking at the various emission / leakage points that may exist. This procedure needs to recognise that CO_2 is not always metered, but it has to be quantified in some way. It is important to remember that leakage from infrastructure is transient compared with storage where there is the potential for leakage over a period of time; multiply the leakage rate over the duration. Leakage from the subsurface is a short-term (decadal) experience, whereas leakage from the storage complex is conceptualised; all the efforts shouldn't be placed on the infrastructure. However, on the closure side, the abandoning of infrastructure such as wells is very important.

Session 4: Uncertainty in quantification

'STEMM-CCS - Quantification of CO_2 seepage in the marine environment'
Anita Flohr, NOC

Robust monitoring strategies for the offshore, sub-seabed storage of CO_2 are crucial regulatory requirements to comply with legislation and to ensure that potential leakage from the reservoir are detected and quantified. STEMM-CCS (STrategies for Environmental Monitoring of Marine Carbon Capture and Storage) is an interdisciplinary project which explores monitoring strategies for the offshore, sub-seabed storage of CO_2 . To test the utility of different techniques for CO_2 leakage detection and quantification at the seafloor, a controlled CO_2 release experiment was carried out in the central North Sea, whereby CO_2 gas was injected into sub-seabed sediments at different rates ranging from 2 – 50 L/min (at standard temperature and pressure) over a period of 11 days. This talk summarised preliminary results of the quantification methods tested: optical, acoustical (active and passive) and chemical (tracers, eddy covariance, benthic chambers).

Overall, all techniques detected the deliberate CO_2 leak at low concentrations, demonstrating that the tools tested are sensitive enough. Eddy covariance picked up the CO_2 plume from 2 L/min; the others from 30 to 50 L/min STP. The tracer results covered the seep flow rate and showed CO_2 loss due to dissolution in pore water, with 40-80% of CO_2 staying in the sediment indicating a high buffer capacity of sediment pore waters. The size of the bubbles were checked by the optical flux team. At a low injection rate, the bubbles were not continuous with large gas pockets followed by smaller bubble release, and at higher rates the bubbles were generally smaller and released more consistently. The next steps for this work are to compare the different quantification methods and developing a decision tool.

'Atmospheric CO_2 and CH_4 quantification of emissions at Ginninderra'
Andrew Feitz, Geoscience Australia

Methane and CO_2 seeps can be difficult to find and quantify accurately. The aim of this experiment is to evaluate eight different approaches for quantifying emissions: tracer ratio techniques; eddy covariance with forwards Lagrangian stochastic modelling; eddy covariance with Lagrangian stochastic (LS) footprint modelling; backwards Lagrangian stochastic modelling; atmospheric tomography using point; and line sensors. Quantification of CO_2 data is difficult due to high background noise, so this work focussed on methane. The uncertainty of a single estimate may not contain the true emission rate but an ensemble approach gave good results here. Using a median of a minimum of three different techniques to accurately measure the emission rate, or including model uncertainty in analyses was recommended.

It was noted that only a single release point was used here because the aim of this study was to quantify and not so much detect. The location of the release wasn't varied to ensure that the technologies being used actually worked to build confidence but multiple release points could be looked at in the future. It was also noted that the ensemble technique works because the various areas affect the different techniques in different ways. It must be remembered that model error could affect the techniques differently.

'Extracting features from fibre-optic DAS microseismic monitoring data'
Anna Stork, University of Bristol

Microseismic monitoring is an important technique to assess the response of the subsurface to fluid injection or extraction. Small seismic events, acquired with multi-component geophone arrays, are caused by fracturing or stress transfer. Distributed Acoustic Sensing (DAS) is one technology using fibre optics to detect such microseismic events. This research aims to assess any disadvantages of the technique and develop machine learning techniques suitable for DAS data analysis.

The work successfully detected over 3,000 microseismic events in the DAS data recorded during a hydraulic fracturing operation. Fundamental characteristics to aid in constraining event locations and source parameters were identified. Events in real data using machine learning, a complex neural network trained on synthetic data, were defined.

Machine learning will help to cut down the amount of data that needs to be looked at and therefore minimises the processing time.

Discussion

The discussion related to the STEMM-CCS project centred on CO_2 retained in the sediments versus CO_2 present in the column. There is a lot of biota in the sediment / pore water and eventually CO_2 will saturate the fluid. CO_2 will then go straight through the pore water and into the sea water. It was noted that at the UK-based QICS project bubbles were observed, and although there was a lot of retention, there was a lot of CO_2 moving into the dissolved phase as well. Another high risk scenario is that a flux of CO_2 pools in the subsurface until there is a catastrophic release, when it is assumed that in the marine environment well-formed monotonic bubbles occur. Geology, specifically the bedrock, is not homogenous, so sudden releases are a possibility. Such a scenario is a high risk event and should be anticipated and monitored for. It was noted that CO_2 in brine-rich areas actually increases the density of the fluid and so it sinks, consequently it is less likely to be released in such a way. A positive side of the concept of pooling is that if there is a leak from a primary seal, and there is an accumulation under a secondary seal, it could lead to the detection of a leakage point.

The challenge for any monitoring strategy, designed for environmental detection, is to construct a sensor system for deep monitoring that can be optimised to provide evidence of change in both deep and shallow complex environments. The EU Directive requires quantification of emissions in the water column. The STEMM-CCS project was initiated to enable researchers to actually measure what is released into the biosphere.

The use of multiple monitoring techniques in a terrestrial environment was questioned. For an accurate measure from an emission it would be worthwhile to applying more than one technique. However, if there is sufficient confidence in one area, the number of monitoring techniques can be scaled back. The differences between terrestrial and marine environments may not be that different. The same processes operate. However, what counts is what is required from a regulatory perspective.

Session 5: Monitoring for Storage with EOR compared with DSF requirements

'Experiences in monitoring CO_2 storage in deep Saline Formations and CO_2 -EOR Settings'
Mark Kelley & Neeraj Gupta, Battelle

Battelle has a wealth of experience in monitoring programmes with deep saline formations (DSFs), with two projects where CO_2 injection has been completed (the AEP Mountaineer Plant and MRCSP Phase II). FEED processes are also underway (at FutureGen2 and AEP commercial scale in West Virginia). The monitoring requirements for DSF sites fall under the UIC (underground injection control) Class VI permit, which means that very stringent, comprehensive testing and monitoring is needed, with post-injection requirements spanning up to 50 years. For CO_2 -EOR, Class II permits are required (which are more lenient compare with Class VI), and in this area Battelle has extensive experience: the MRCSP Phase III project; the MRV plan for CO_2 -EOR (Core Energy Reefs); a lifecycle assessment of Core Energy's operation; 45Q feasibility studies for certain applications; CARBONSAFE Phase 2 and work with the Asian Development Bank.

Battelle have identified some distinctions between DSF and EOR that may affect monitoring. With EOR sites, wells will generally have equipment in them already so accessibility for monitoring can be limited, whereas in DSF sites wells have to be drilled for injection/monitoring enabling accessibility. There is also a greater potential for well integrity issues at EOR sites compared with DSF sites. EOR operators generally have little tolerance for interruptions for monitoring, but at DSF sites such extended interruptions can be accommodated easily. Some simplified data analysis or modelling methods (such as pressure tomography for the plume front) cannot be applied with EOR but are can be applied at DSF sites. In EOR situations, fluid geochemistry and PNC-log (pulsed neutron capture) monitoring are difficult due to the presence of hydrocarbons as a third phase. Microseismic monitoring is more relevant with DSF as there are higher reservoir pressures. At EOR sites the reservoir pressure is maintained at the lowest level to achieve miscibility. Dissolution, residual/capillary and mineralisation are generally more important than structural trapping at DSF sites whereas structural trapping is likely to be the most important mechanism at EOR sites.

'CO_2 storage through EOR: An international (ISO) perspective'
Steve Carpenter, University of Wyoming

In order for a CO_2 storage project to qualify for the credit with the new 45Q legislation, construction must begin by 31st December 2023 (an ambiguous criteria to meet), the credit must be transferable (could be challenging for those companies with capital investment interests; they must have a tax liability for there to be any value) and 'safe and secure storage' must be certified (again, somewhat ambiguous; what is safe and what is secure?)

There was much discussion on this new standard. Who the competent authority would be, and how this standard would be decided, was open to question. Under the 45Q it would probably be the IRS (the US Inland Revenue Service). The US Department of Energy (DOE) and the US Environmental Protection Agency (EPA) would offer guidance. From each state's perspective, outside of 45Q or ISO, this would be up to the state's regulatory authorities. It was noted that the California LCFS (Low Carbon Fuel Standard) was more stringent than 'subpart RR' (a requirement under the US Greenhouse Gas Reporting Program) in the EPA's Greenhouse Gas Reporting Program. The LCFS is internationally accepted so it's more likely to be accepted. California completed its CCS protocol and it's very much like Class VI.

'Monitoring for CO_2 EOR & Storage in Alberta'
Brendan McGowan, Enhance Energy

The Alberta Carbon Trunk Line is currently under construction and will integrate capture, transport and utilisation in the world's largest capacity (up to 15 Mt per year) pipeline system dedicated to manmade CO_2 . "CCUS is Alberta's opportunity" and with three commercial projects, nine pilot projects and wide public acceptance, this wealth of CO_2 -EOR experience means a wealth of monitoring knowledge. Monitoring for CO_2 -EOR provides long-term assurance for containment, is effective, cost-efficient and site specific. The selection of monitoring environments that are specific to CO_2 storage is similar to normal oilfield monitoring, but perhaps with more frequency or spatially a little different. Slightly different geochemical techniques might also be applied.

Like other projects, Enhance Energy overlays different tools for monitoring, notably soil gas and potable water monitoring, which is essential for public assurance. One of the primary tools is detection via surface casing in the wellbore. The regulatory standards in Alberta have been in existence for almost 80 years and are recognised worldwide for their excellence. Fields are set up to ensure containment. Measurements and monitoring are kept to a high standard.

A lot of sour gas is injected in Alberta as a routine safety procedure. Because of this legacy public explanation of CO_2 -EOR should be fairly easy. Enhance Energy confirmed that the public do really understand it, as do the regulators. However, government bodies are less understanding. They have more of an issue with uncertainty. The Nisku production unit is a unique example where there are monitoring wells that will be looked at extensively. There is also coalbed methane (CBM) production in the area, which will be monitored. It's a complex site with a lot of attributes. Alberta is currently working on a new protocol for EOR to better define the accounting procedure. It should be published before the end of 2019.

'Geologic Storage in the US'
Bruce Hill, Clean Air Taskforce

Since 2010 there are better methods, technologies and understanding of geological storage to help inform commercial scale projects, but tracking CO_2 remains a challenge. To move research into policy would require a greater dialogue between regulators and those that really understand the subsurface. The current challenges include the quantification of leakage, the acceptable limits for potential leakage, agreeing processes for selecting the best methods for commercial MRV and questions regarding regulations, protocols and potential credit award systems.

The EPA's UIC Class VI rule is one piece of legislation that 'protects underground sources of drinking water during CO_2 injection for storage'. This regulation is specific to CO_2 injection. It was introduced to protect against the uncontrolled release of CO_2 (for example by site selection, well design, injection operations, monitoring programmes etc.) and runs alongside the US Greenhouse Gas Reporting Program, an emissions accounting and reporting programme. Other protocols to help facilitate CCUS include the 45Q tax credit and the California Low Carbon Fuel Standard (LCFS) Protocol, which has set lifecycle carbon intensity targets for transportation fuels sold in California with credits for greenhouse gas reductions. The closure plan in the LCFS requires demonstration of security of the CO_2 following 15 years of monitoring, after which monitoring must continue for 100 years. This standard, and the 45Q credit, make stringent demands that maybe unreasonable.

There was a widely held view expressed about the necessity for careful dialogue with regulators. The use of every monitoring technology currently under development may not be necessary. It is possible that regulators can gain the wrong impression at times and go in a different direction. Consequently, it's important to make the effort, enhance the dialogue, and communicate effectively with regulators. Tim Dixon (IEAGHG) noted that there have been representatives from regulators at previous Network meetings.

It must also be remembered that there have been some failures, but there are a large number of subsurface disposal / storage projects that are simply monitored by the wellhead pressure, and many of these have been operating for a number of years with no sign of environmental impacts. It's important to look at the general background of all the analogous studies. There have to be real, achievable goals with policy in particular.

Discussion

The discussion began with the potential transition path from CO_2 -EOR to CO_2 storage. With EOR permanent storage is assumed whereas in a storage project it has to be monitored for 10-50 years. The ISO Working Group 6 is evaluating a technical report to do just that; transition from EOR operations to permanent storage. There is also an EPA guidance document on this subject, published in 2014. When the EPA first looked at this area, EOR operators translated this transition concept as it is eventually they will have to use (Class VI). It's really important on how this transition is communicated and what language is used as to whether such issues are classed as a voluntary or mandatory requirement.

The cost that is added in for DSF monitoring is higher than that for EOR. An investment is required for data density and the cost of report production. The costs need to be fairly distributed between the two. There is a tendency to think about CO_2 -EOR going to brine, but there is another scenario which leads to a revenue source from brine under 45Q, which involves the concept of stacked storage. With the thought that the use of EOR data, and the application of subsurface monitoring technologies, there is a question on how a site with stacked storage and EOR could be monitored? Production above a storage reservoir provides an obvious and easy way to monitor. There maybe more information in the operating field above the storage formation, but there's also an opportunity to transfer to simpler, more generic monitoring in the zone above the saline formation. If this were based on pressure techniques alone, and if there are perturbations above the system, this approach would be more of a disadvantage. The DSF monitoring does need to be matched too.

When the Greenhouse Gas Reporting Program subpart RR monitoring plans were approved they were largely based on the use of oilfield technology. This approach may not be rigorous enough and perhaps much of what the CCS community is doing hasn't been taken into consideration. It is possible some aspects have been missed. However, it was noted that operating an EOR system requires monitoring to distinguish material balance of injected and recovered fluids. EOR still demands large amounts of monitoring to control and manage the risk of injecting and displacing so much water / CO_2 . This is what current R&D efforts are managing and monitoring. Historically, what is fundamentally different in EOR is the long term liability which lies with the project operations, whereas with CO_2 storage, the liability is often transferred to some sort of public organisation. This difference justifies a higher level and more stringent need for monitoring programmes.

Session 6: Fall-back plans – what to do if primary technique doesn't work? Delegate Interactive Session

For this session, the delegates were given three different scenarios with process-based soil gas monitoring and remote satellite vegetation stress monitoring, which were then looked at further in small discussion groups.

Discussion

Following the smaller discussions, the group came together and noted the importance of calibrating models and showing the performance, particularly for the benefit of regulators. With anomalies that could come up, all of the tools must be looked at in detail because many of them are independent. There was a consensus that developers have to work with the regulators to give them confidence that there is enough observational data to demonstrate that the CO_2 is not leaking and there is conformance. An operator needs to show that models are continuously updated to match data. Each developer's team of scientists needs to be trusted because they have sufficient confidence in their arguments.

Session 7: New Case Studies of real data – Offshore and Onshore

'STEMM-CCS preliminary results and forward direction'
Doug Connelly, NOC

The STEMM-CCS project applied many new monitoring technologies that could be applied elsewhere in other scenarios, using new advanced sensors, chemical analysis, bespoke material construction, imagery and also by using machine learning to process the wealth of images obtained. The team found that all of the sensors worked well, but agreed with other views expressed at this meeting, that a combination of technologies is needed.

This project conducted a full technology readiness level (TRL) review throughout the project. This is a requirement of the European Commission. The TRL uplift assessment carried out on all approaches during the research went from 3 to around 7, some even went up to around 8, however the artificial intelligence work is still at an early stage so its TRL has yet is to be defined.

'Estimation of the extent of injected CO_2 and the reservoir geometry at Tomakomai using 4D seismic data'
Hideo Saito, Japan CCS

The Tomakomai CCS demonstration project has injected 270 ktons of CO_2 since operations began in April 2016. This is the first full chain CCS system in Japan. There are two storage formations at the site, the lower reservoir (T1 Member of Takinoue Formation) which is a volcanic lithology and the upper (Moebetsu Formation) which is a sandstone. The upper reservoir was selected for storage. Injection into the lower reservoir was suspended after 98 tonnes. 2D, 3D and 4D seismic surveys were used to observe the CO_2 plume evolution during September and October 2018. Amplitude anomalies were distributed around the upper portion of the injection interval with the highest anomaly being located on the injection well trajectory. Attenuation observed through the highly saturated CO_2 zone.

These surveys allowed estimations of the reservoir geometry to be made. The observations demonstrated that the CO_2 plume extent and evolutions could be tracked by using 4D seismic data. Enough repeatability can be achieved by using the conventional OBC (ocean bottom cable) and air-gun source system. The next steps for this project are to estimate the reservoir geometry quantitatively and to update the geological models. Estimation of the effect of CO_2 dissolution processes on the seismic response, using repeat surveys, is also planned.

'Injectivity evaluation of the extended reach injection well with long completion interval at Tomakomai'
Yasushi Yamaguchi, Japan CCS

This work at Tomokomai is looking specifically at the evaluation of the pressure and temperature profile, and injectivity, at the main injector. Reservoir pressure and temperature (PT) data are needed for reservoir simulation, pressure transient analysis and to evaluate system technology. The PT data are obtained by monitoring the PT sensor, which has been installed at a 50m vertical distance between the sensor and the top of the completion interval, so there is a need to estimate the pressure and temperature distribution in this completion interval. Friction loss effects increase with well inclination (friction loss is larger than hydrostatic induced losses when the inclination exceeds 80°). Well temperature also increases during injection due to CO_2 compression. Adiabatic compression is the main factor affecting well temperature. The CO_2 input increases as the injection rate rises. This phenomenon is caused by an expansion of the injection zone along with the presence of high permeability areas within the injection zone. Operators saw an injectivity decrease following an extended suspension of injection.

This observation was presumably caused by a rise in formation water in the completion interval, and crossflow into the reservoir, which led to a decrease in CO_2 saturation near the wellbore and therefore a decrease in the relative permeability. The increase in injectivity was not due to fracturing as the injection pressure was controlled to ensure that this process could not occur. The use of an evaporite cement, and CO_2-resistant casing, should prevent leakage. The well is partially cemented down well, with just open-hole casing in the intervals.

'CarbonNet pre-commercial studies of the shallow water environment and monitoring options for the Pelican storage site'
Nick Hoffman, CarbonNet

The CarbonNet Project is investigating the feasibility for a commercial scale, multi-user CCS network in Gippsland, Australia. The biggest challenge here is community and public acceptance. The project developers need to find a way to show people that this project is safe, secure and beneficial. CarbonNet is working heavily on public engagement. The development team has realised that a range of characterisation methods and monitoring tools may be needed to optimise the project, not only for technical reasons but also to help with public acceptance. CarbonNet is investigating a range of modelling, monitoring and verification technologies for its storage site. The preferred option is time-lapse 3D and 4D seismic but there are public acceptance issues with seismic data acquisition. Alternative options are being investigated, including studies on natural seismicity, seabed processes, marine environmental monitoring, atmospheric assurance, well-based lateral monitoring, injection zone monitoring, AZMI (above zone monitoring interval) well pressure and temperature monitoring and an onshore 'sentinel' monitoring well to give assurance that any CO_2 will be detected should it move towards the shoreline.

It was noted that currently, seismic monitoring activity is feasible in Australia but there is a risk it may not be in the future, particularly in shallow waters. Every couple of months, the project team engages in community outreach activities to ensure communication paths are kept active with key players. Many of the community near the CarbonNet site are supportive, but there are a small portion that are not. It's a long term and slow process to build trust with the public.

'Advances in new monitoring technologies for CO_2 storage'
Don Lawton and Marie Macquet, Uni. of Calgary & CMC Research Institutes Inc.

The team at the CaMI research site is investigating distributed acoustic sensing (DAS) VSP (vertical seismic profile) imaging. They have seen encouraging results from the application of new methods such as using a vibe source. A new permanent pedestal seismic source is generating opportunities for repeat surveys plus better coverage for well integrity (with full well depth coverage). The acquisition of continuous seismic data allows microseismicity events to be linked to CO_2 injection.

Several datasets are used for baseline characterisation in the development of tomography, particularly because of environmental factors (such as wind, snow, temperature, water table level etc.) that could be affect the observed velocity changes. This research work at the CaMI site has shown a high quality of daily correlations for the October 2017 dataset, in a very challenging field as the expected changes in velocity are small. In general, using ambient noise for CCS monitoring proved beneficial. All the theory and tools are developed, the data can be easily acquired but can quickly reach a very large volume. The technique is low cost, easy to deploy, easily repeatable and environmentally friendly.

'Characterisation for environmental monitoring at Glenhaven, Queensland'
Katherine Romanak, University of Texas

This research addresses the attribution that will be needed if a leakage anomaly is indicated during process-based monitoring at a geological CO_2 storage site. The research emphasises the importance of pre-project characterisation and the development of a full 'process-based' attribution methodology for the Glenhaven site in Australia and the broader storage site (the Surat Basin). The research presents the acquisition of characterisation data before the project begins, to help assess anomalies, environmental changes and / or address stakeholder concerns in the event that process-based monitoring indicates a potential leakage signal. Such pre-project characterisation is critical when it comes to stakeholder concerns regarding land disturbances, such as happened during the Kerr leakage claim in 2011 at the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project.

At the Glenhaven site, the research team has been using isotopic characterisations of anthropogenic and naturally occurring CO_2 within the Surat Basin. In this area, there is a lot of coal seam gas production which could affect gas signatures and process-based ratios. The new dataset with a full geochemical characterisation represents the first full pre-project characterisation for a process-based attribution method. At this site, substantial geochemical overlap was observed but the complexity was minimized by excluding the potential inputs where gas concentrations are too low to create a signal. The important inputs to the Glenhaven site are methane oxidation from local coal seams, injected CO_2 and possibly CO_2 from intermediate strata where natural methane oxidation is occurring.

Discussion

The discussion following Session 7 looked into machine learning and whether it can actually help with the need for huge data processing. This process-based method increases the ability to deploy more sensors than before, assist with data collection, efficiency and reduce costs. There must be a balance between getting the information that is needed and not creating more problems. Perhaps learning from onshore experience could be crossed into the offshore. There should be some persistent anomalies from deeper sources. One way forward would be to cross onshore maturity with offshore development and look at the complexities on a sliding scale.

'Status of the Tomakomai CCS Demonstration Project with emphasis on measures taken in response to recent earthquakes'
Jiro Tanaka, Japan CCS

The project developers have had to work in recent years to remove concerns about earthquakes in the Tomakomai areas. To help the public to understand that earthquakes won't be affected by the injection of CO_2 , and that there are no perceptible earthquakes induced by CO_2 injection, the developers need to be able to demonstrate that the CCS system is safe and reliable, with no leakage. Project information and data is regularly disclosed to enhance the understanding of this CCS project by local residents. There is an extensive monitoring system across the project site that measures background seismicity. PT sensors are also used and the local marine environment has been, and continues to be, surveyed thoroughly (monitored pre-injection for baselines, during injection and after injection).

On the 6th September 2018 the area suffered a magnitude 6.7 earthquake (epicentre around 30km from the Tomakomai project). Japan CCS (JCCS) (the developer) posted their technical view of the incident, noting that there was no relationship between CO_2 injection and the earthquake; and that there was no CO_2 leakage. Plots of reservoir temperature and pressure data on the 12th September were also shared. An expert review meeting was convened on the 19th October, with the summary posted publicly on the 21st November 2018. A 5.8 magnitude aftershock occurred on the 21st February 2019 and on the 26th of that month JCCS posted their views of this incident.

The review found that the relationship between CO_2 injection and this earthquake was inconceivable. The triggering mechanism was the upper crust being thrust up and lower crust subducting underneath, with the earthquake originating from the bending of the crust. The CO_2 injection is at 1-3km depth (the earthquake epicentre depth was 37km) and injection is into a different geological formation. The earthquake didn't affect the CO_2 reservoir; there was no microseismicity indicating abnormalities before or after the events. All of this data was reviewed by experts and verified. JCCS adhered to several key principles to ensure that the right protocols were followed for the best public acceptance, including very fast response times and the inclusion of technical information in the response.

'How do the public and stakeholders engage with monitoring? Learnings from the Tomakomai CCS Demonstration Project and the 2018-19 Hokkaido earthquakes'
Leslie Mabon, Robert Gordon University, Aberdeen

The earthquakes in the area of Tomakomai were a real-world example of how to deal with controversy arising from an operational offshore CCS project; controversy which started when the ex-president of Japan (with 900,000 followers on Twitter) said that the earthquakes were human-induced and caused by CCS. This incident is an example of how CCS can become a flashpoint for wider socio-political divides with the loudest voices are often heard most but not necessarily expressing rational views. Opinion-shapers may not select the best information sources and researchers, working in collaboration with government or on CCS, can often become perceived as shills by virtue of association.

Leslie Mabon stressed that in the emotional context of a climate emergency, it's important to consider how projects and organisations involved in CCS, that present CO_2 monitoring data to the public and stakeholder, are perceived. Operators and communicators should look at the relationships between researchers, government and industry. Issues like gender, race and ethnicity, and whether well-meaning actions (i.e. caution with sharing data) could be viewed as defensive. The key questions raised from the Tomakomai experience are how can researchers intervene to ensure factually correct information is in the public realm; and how should researchers engage in public discussions about CCS. Initiatives are needed in situations like this where public debate platforms are not geared up for long-term discussion.

'An overview of the potential impacts of anthropogenic underwater noise associated with offshore resource activities'
Dr Andrew Carroll, Geoscience Australia

Marine seismic surveys are a fundamental tool in monitoring but are a source of noise, so it's important to look at the potential impacts of such an anthropogenic source. This is a contentious subject with conflicting evidence and views and a perceived bias. This artificial noise could interfere with marine organisms (the frequency range of marine surveys is within the hearing range of cetaceans, the majority of fishes and can neurologically and physiologically affect some invertebrates too). One case study looked into predicting potential ranges of acoustic impact on sperm whales, and found that sound propagation levels caused sufficient physiological damage between 50 and 390m distance, but PAM (passive acoustic monitoring) could be used for real-time detection and location of sperm whales. This has operational and environmental benefits as once a creature has been detected, the seismic survey could be stopped. It's important to understand that mitigation is not just about compliance; it is needed it to fill knowledge gaps, improve standards and inform regulators. Another multi-component study combined field and desktop investigations to examine the impacts of marine seismic on fish and scallops. Acoustic telemetry and AUVs (autonomous underwater vehicles) were facilitated for in-situ observations to simulate ecological realism. In this case there was little evidence that consistent behavioural changes were induced by the seismic survey. However a subsequent study found physiological and behavioural effects, demonstrating the importance of a manipulative experiment.

The research has demonstrated that ecologically realistic studies are important for capturing variability in environmental conditions. Managing a perceived bias needs transparency and independence and it is essential to apply a wide range of tools and technologies in all aspects of monitoring. The application of innovative technology can help facilitate in-situ monitoring but limitations must be considered. The challenges of field-based studies need to be acknowledged and accompanied by lab experiments. The spatiotemporal variability of field populations and environmental conditions can mask impacts so baselines and time series data are important to consider as well. Standards are needed to ensure that measurements are accurate. Geoscience Australia are currently scoping development of best practice guidelines for monitoring anthropogenic noise.

Discussion

In the case of the Tomakomai earthquake, a figure of authority held negative views on CCS reinforcing a widespread public perception. There is a requirement for a public, positive champion for the technology from someone that people can trust in and is more pro-CCS. Attitudes are shaped by perceived impressions and bias against the extractive industries. It's hard to shift opinions on issues with a pre-existing bias. How the general populous perceive issues is important. For technology advocates there is a choice: do you talk to leaders in the community; or should you be aiming for high-up establishment figures or journalists. Is there a critical order for the approach? To get effective support a high profile figure is needed but for more traction a larger number of people with clout are needed. Pragmatically there's a need to focus on those who are directly involved in particular projects (from a monitoring and environment aspect). Project promotors are the people that citizens will look to for translation of data and information. On a national level they may not provide technical details in such depth, but they can provide a rationale on why CCS projects are needed.

The emphasis applied in many previous projects has focused on local guidelines and impacts, whereas contemporaneous attitudes are now influenced by social media. There is a trend towards issues becoming more national, with society becoming increasingly polarised by emotive sentiments that don't readily relate to specific projects. Recently, communities are generally starting to talk less about the costs and more about the value of CCS for society and benefits for all. There is evidence that if unions are involved and on side, people will see the benefits not only societally but also in terms of jobs and other benefits.

‘Observations of Up-Well leakage within a monitoring well. Experience from the shallow CO_2 controlled-release experiment at the CSIRO In Situ laboratory’

Ludovic Ricard, CSIRO

The South West hub project is a controlled CO_2 release experiment mimicking a leak from a deeper storage reservoir in a fault zone. Around 40 tonnes of CO_2 were injected at 340m depth to evaluate monitoring methods applicable for leakage in the shallow subsurface, and the impact of a fault zone on fluid migration, using downhole monitoring, time lapse induction, groundwater sampling and surface soil gas and fluxes. This shallow release experiment injected 38 tonnes in four days in February 2019, and breakthrough was detected with all methods (apart from time lapse induction) on the 7th February, after 7 tonnes of CO_2 had been injected. Temperature changes were detected after just one day. There was a loss of well integrity on the 9th February, with a release of CO_2 at 7:19pm, and six further releases overnight, before the well was capped at 10am on the 10th. The loss of integrity was CO_2-driven and due to overpressure pushing the brine out.

This project concluded although the injection incident did have some health and safety issues. The dynamics of CO_2-driven well leakage through the observation well, were recorded (with distributed DAS and DTS), and gave unique insights into well dynamics. In addition, the releases were captured with extensive datasets. Lessons learnt included the importance of triple of checking the drilling of the well and perforations, whilst monitoring if possible. Real-time data processing and interpretation would have helped in this scenario to identify early warning indicators and to inform the decision making process.

‘Learnings from oilfield challenges in addressing surface casing vent flow’

Lee Spangler, Montana State University

There are three typical leakage pathways in a wellbore: through the cement; between the rock and cement; and between the casing and cement. The causes of leakage pathways include poor mud displacement, poor centralisation, cement circulation issues, gas flow while session, pressure and temperature induced stress during well operation, corrosion and cement degradation. Leaks can present a number of challenges: they typically have small apertures; there can form tortuous pathways; they can also be difficult to locate, characterise and access. Ultrasonic (USIT) logs of wells will show what is in contact with the outside surface of the casing and does not penetrate appreciably into the annulus.

To seal leaks in wells, a microbe that contains a ureolytic enzyme converts urea to ammonia, changes the pH and the end result is calcium carbonate precipitation, thus sealing any unwanted spaces. Other options for sealing well leaks in oilfields would be a cement squeeze job or fine cement. This work by Montana State University addresses surface casing vent flow. The technique demonstrates that centimetre and larger apertures can be squeezed with cement or fine cement, but anecdotal data shows that between 5 and 25% of annular well leakage have apertures too small for traditional squeezes. CO_2 wells and oil wells in EOR operations are likely to have similar issues. Ultrasonic logs can give useful information when the leak is between the casing and the cement (and when the casing is not too badly corroded). Leakage apertures can be crudely estimated with the Cubic Law; and the pressure-flow relationship has the potential to be a useful diagnostic for the type of squeeze needed.

'Detection of small leakages based on recent field data using fibre optics'
Ziqiu Xue, RITE

The work carried out here was focussed on strain measurements (coarse - versus fine-grained) and looking at leakage detection using fibre optic sensing. The fibre optic shows the geomechanic response and a visual of the plume is created using a complementary x-ray system. The strain response was measured when CO_2 entered the fine grain sample. The study found that the fibre optic can give a first response or indication of pressure, which is useful for small leakage detections to ensure caprock and well integrity. The second application for this method would be with buried pipelines. The distributed fiber optic strain sensing (DFOSS) clearly revealed responses due to drilling even the drilling well located up to 3m. The DFOSS results demonstrated its usefulness for pipeline leakage detection and monitoring.

'Qinghai leaky CO_2 well research site, China'
Dr Andrew Feitz, Geoscience Australia

The Qinghai site is used for geological storage research, namely the mechanisms of CO_2 leakage, environmental impacts and monitoring. In 2002, a blowout occurred where underground water was mixed with very high pressure CO_2 when a CO_2 -rich artesian aquifer was intersected at a depth of 190m. There is no obvious gas leakage around the wellhead, but there is a bubbling spring nearby (and a number of natural CO_2 springs in the region) plus groundwater flooding. A drainage system has been installed but gas leakage still occurs through the soil, measuring at approximately 1 tonne per day. The source of the CO_2 leaking here was shown (by isotopic analysis) to be crustal, with some mantle input and fractures were discovered by a shallow seismic survey.

The impacts of the well leakage have been identified from the groundwater flooding, small bubbling springs, impact on local vegetation, high soil gas flux, altered soil gas ratios and mineralisation of soil. The research plan will characterise the regional CO_2 accumulation and leakage, conduct field characterisation, understand the mechanism of the leakage across layers or fractures, and the CO_2 / water blowout. It will also determine the characteristics of CO_2 leakage and accounting.
It was noted that studying extreme wellbore integrity failures could be considered a useful analogue for if CO_2 was to come into a shallow aquifer; this particular case is an extreme scenario.

Discussion

More detail is needed on leakage pathways and pattern pathways, particularly the intersection between the geology and the wellbore. In most cases it seems to be related to cement issues, but this is largely based on conceptual models and so more research should be done. With well leakage, the leaks can find their way far from the well but in some regulations (e.g. LCFS) it states that monitoring technologies should be placed near the wellbore. This stipulation seems to be based on a misinformed perception as leakage does not necessarily occur near wellbores. The most likely leakage locations are usually near the wellbore, but this will depend on the geology and the origin of the leak. This association again emphasises the need for more research on the integration of deep with shallow monitoring instead of an undifferentiated blanket monitoring programme. A deep monitoring programme could inform an inter-related shallow programme along with site characterisation to help create more of a systematic plan. Fibre optics behind the well casing also can help to give more understanding; it's a powerful tool for integrated monitoring.

The leaks studied in this session are consistent in that they have all originated in the well. Geophysical techniques can be used to investigate old / legacy wells and mechanisms inside and outside of the wells and should be researched in detail. Fibre optic technologies are able to do this form of monitoring in active wells, but not legacy wells.

‘Post-closure Monitoring of China’s First Full Chain CCS Demonstration Project at the Ordos Basin’
Qi Li, Chinese Academy of Sciences

The Shenhua coal-to-oil CCS project is located in Inner Mongolia and is China’s first full chain demonstration project. Injection began in May 2011 and stopped in 2015 with well abandonment. There were issues with permit applications for the project (as it was the first CCS project in the country). With no laws or regulations on specific well abandonment, the operators had to refer to the oil and gas industry to determine the plugs and casing programme to proceed. The CCUS ERA (Environmental Risk Assessment) guideline was released in 2016 and is currently on trial. The guideline is similar to ISO guidelines on risk assessment. This protocol calls for pre-injection monitoring to establish baselines and help enhance the environmental management process of CCS.

Seismic surveys showed that at this particular project, the CO_2 was successfully trapped in the reservoir. Post-closure monitoring was carried out at the wellbore, atmospherically, and in the soil gas at fixed points. Surface deformation analysis (InSAR) and shallow groundwater sampling to determine the pH distribution; with the aim to find cost-effective key monitoring indicators was also performed. No anomalies have been found at this site and post closure monitoring is proceeding as expected.

‘Is risk-informed adaptive monitoring worth the risk?’
Jonny Rutqvist on behalf of Preston Jordan, LBNL

Inactive wells may be leaking due to the length they have subjected to CO_2 alongside standard well aging. Active wells may also leak due to errors in the well caused by poor installation. If steam blowouts are caused exclusively by well aging, the frequency of this event should increase with time from the first thermal recovery project. This in fact is not the case, and the frequency evolution and blowout timing of such events supports the hypothesis that initial well defects are to blame. With the addition of cement annealing, chronic CO_2 leakage is even less likely and based on these findings, a risk-informed monitoring system has been developed. In such a system, the plume is measured by remote sensing, the plume front by surface geophysics, the wells at the plume front by atmospheric and groundwater methods, and the injectors by atmospheric, groundwater and downhole geophysics. Such a risk-based approach could provide cost savings on 4D seismic and additional savings from targeting other monitoring methods, but are these savings worth the risk of not monitoring the entire CO_2 plume at every time step?

‘Reaching site closure quickly’
Steve Bryant, University of Calgary

The storage approach chosen dictates not only the time to closure but also the method of closure. The good news is that a short time to closure is possible, but confident fast closure is not free. Post-injection fluxes depend on the storage approach. In an open aquifer where conventional storage of supercritical (sc) CO_2 is planned, the buoyancy will drive the long-term post-injection flux and mitigation will involve the reduction of the injection-induced pressure gradient by brine extraction and disposal. Under these circumstances it will be a long time until the buoyancy-driven change is below tolerance. If $scCO_2$ is injected between slugs of sweep efficiency enhancers it will reduce the CO_2 mobility and reduce the rate of post-injection change. If a foam / emulsion of $scCO_2$ is injected, the yield-stress fluid cannot flow post-injection so a short time until change is below tolerance can be expected. If it was possible to store brine saturated with dissolved CO_2 , the driving forces for post-injection flux could be eliminated, meaning zero time before change is below tolerance. These different approaches demonstrate that there is a trade-off depending on injection strategy. Operators would need to decide what approach to use depending on the most cost, the most time, and the most confidence.

Discussion

It's important to consider the underlying assumptions for the decisions made and to note that the CCS community doesn't necessarily know how much the next (for example) 50 years will cost for post-closure monitoring. Research is currently focussed on injection strategy, to mobilise the CO_2 plume. In large industrial projects, are there techniques that can be used to help with post-closure monitoring and active testing post-closure, such as injecting tracers to track CO_2 migration?

Session 11: Long-Term Monitoring Post-Injection for Site Closure (Part B) Delegate Interactive Session

This session focussed on the great deal of uncertainty in the field of long-term monitoring for site closure, and looked at providing recommendations that should be acted upon to help reduce this uncertainty with the focal questions of whether there were situations where monitoring is needed post end of injection, and whether more research is needed in this area, and why. Delegates were separated into groups and given different 'realms' to consider for each of the focal questions; atmosphere, soil, water, wells and subsurface.

Atmospheric monitoring

- In the future, this type of monitoring will be cheaper and easier with the more frequent use of technologies such as drones and satellites
- The highest risk here will be public perception
- More research is needed to improve tool design

Soil monitoring

- There are situations where soil monitoring is needed post-injection
- If something unusual is seen towards the end of injection, then monitoring is definitely a necessity
- There is a need here for a risk-based monitoring approach
- More research is certainly needed; soil sampling is currently localised and there is a real problem in trying to take flux measurements on non-ideal surfaces / substrates.

Water monitoring

- All delegates agreed that again, there are situations that monitoring would be needed post-injection. If injection was normal, the only rationale to do monitoring in the water column would be for public acceptance purposes
- For public perception in particular, location and environment is important
- More research is needed in this area too, especially into operational and pre-operational processes, and more understanding is needed of the tools to be able to do more modelling.

Well monitoring

- Again, monitoring post-injection is needed in many situations
- With legacy wells, this would be context-dependant, but an area with lots of wells would have a higher potential for issues and so plume characterisation and projections would need to be done to plan the monitoring plan and identify which wells are likely to be at risk in such a situation
- There is likely to be a need for a progressive sweep of low-level monitoring over a long period of time
- More discussion and research is needed in this area of work.

Subsurface monitoring

- In this realm, monitoring may or may not been needed; again, if you know exactly what is going on in the subsurface there is no need to monitor
- However, you do need assurance that there won't be any issues
- If there are other operations nearby, monitoring may be needed for such assurance, which should be risk-based and done on a case by case basis
- Research is needed, particularly into well abandonment.

Session 12: Conclusions and Recommendations

A number of key messages, conclusions and recommendations were drawn from the presentations and discussions throughout the two-day Network meeting.

Key Messages & Conclusions

- There has been a rapid maturity in marine monitoring, particularly for breakthroughs in quantification
- In marine monitoring care should be taken with expectation management, for example for detection
- In monitoring, care should be selective; the purpose of monitoring needs to be known and specified
- There have been many advances in terrestrial quantification techniques, for example the infra-red laser based system linked to a spectroscopic analyser deployed at the CaMI site.
- There was a wide range of answers in the discussion on monitoring plan failure
- Marine sensors are becoming more commercial and leveraging off other research. It was noted that off-the-shelf kit was less reliable than in-house built equipment
- There are a lot of sensor types on the market, but the context and application in how sensors are used needs to be carefully considered
- There is a need for terrestrial sensor reliability for a wider range of parameters, e.g. N_2, O_2, CH_4
- Chemical species monitoring and fibre-based detection systems are rapidly evolving; there is a better signal to noise range, higher volume acquisition and more sampling points.
- Uncertainty needs to be acknowledged appropriately in models
- Having a rigid timeframe for first generation sites is too prescriptive; this needs to be adaptive, non-prescriptive and risk-based whilst being adaptive to context
- The Network participants would like to commend the CaMI project for demonstrating the operation of a high value R&D site testing monitoring technology and facilitating international collaboration. Having more sites like this is important
- The meeting facilitators and attendees also commend the high level of industrial participation in this particular event

Future Work

- There is a need for more reliable terrestrial sensors
- A topic for a future Network meeting would be heat sensing, and the use of this parameter for monitoring, both onshore and offshore sites
- Processing a high volume of data, and how to apply artificial intelligence (AI) and machine learning to help collate and analyse information, needs to be reviewed. Following on from this observation, the management of such datasets, and the full integration of all monitoring measurements and integration of multiple data inputs, is essential
- There is a need for geophysics techniques to assess legacy wells

- More R&D is needed for flux measurements on non-ideal surfaces (for example, rocky outcrops)
- More effort is required to strengthen the link between shallow and deep monitoring, and how shallow monitoring can be informed from deep work
- The development of fibre casing that can bond with cement without creating micro-annuli.
- Century gauges which can last beyond 10 years, i.e. instrumentation that can provide long-term monitoring without an open well or re-installation, as this constitutes a risk
- More R&D on monitoring that doesn't compromise the integrity of caprocks
- More R&D on materials for well casings
- Instrumentation to improve well integrity and well processes
- Energy harvesting and how to take this concept from engineering and mining, to help improve wireless technology and therefore provide the solution for the battery issue in well monitoring
- A review of how monitoring techniques and technologies are being developed or applied in other industries
- The broader purposes of monitoring to determine what it is trying to achieve needs to be implemented
- Conversations with regulators on accepting uncertainty to allow closure needs to be improved

Recommendations

- The research community associated with CO_2 storage should stick to detection, attribution and quantification
- The same research community should learn from social scientists on how to communicate with various stakeholders, particularly how to improve the concept of uncertainty with regulators
- The simplification of systems appropriate for small operators should be explored
- There should be a better connection between the Monitoring and Modelling Networks and the Risk Management Network. More collaboration with other similar research communities would be widely beneficial to all parties

High Level Messages

- There have been some great developments in marine and terrestrial sensing technologies.
- Everyone involved in CCS must learn to live with social media (both positive and negative) and it should not be seen as a maintenance problem
- Long-term monitoring needs to be achievable with reliable tools
- Quantification is now achievable in marine environments

Gaps

- More R&D needs to be done on the application of fibres used in cement casing
- There is a gap around the minimum viable product for safe, effective, scientifically-defendable monitoring

Steering Committee

Tim Dixon, IEAGHG (Chair)

James Craig, IEAGHG (Co-Chair)

Don Lawton, University of Calgary (Host)

Jerry Blackford, Plymouth Marine Laboratory

Steven Bryant, University of Calgary

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Tom Daley, Lawrence Berkeley National Laboratory

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Evaluating technology options to mitigate greenhouse gas emissions

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