Potential environmental effects of CO_2 leakage in the marine and terrestrial environment: Understanding, monitoring, mitigation workshop

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Report on workshop for UKCCSC

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Introduction

Current research into CCS is dominated by technological research into improving the efficiency of the capturing, transport or storage of CO_2. However, there have been relatively few meetings dedicated to discussing potential environmental problems related to potential leaks of CO_2 in the CCS chain. These effects need to be fully understood prior to undertaking commercial scale CCS deployment in order to mitigate against any adverse effects.

The aims of this workshop, funded by UKCCSC, are to:

- Identify the current state of R&D concerning potential CO_2 leakage in the marine and terrestrial environment;
- Identify the issues and gaps in current research;
- Identify what needs to be done to address these gaps;
- Produce a report to highlight some areas of research that may require further investigation before CCS is deployed commercially.

Disclaimer

During this workshop, questions were given to delegates to discuss in groups. Facilitators encouraged debate within groups, whilst rapporteurs captured delegate's opinions as best they could. It is inevitable that not every opinion will be captured and will therefore not necessarily appear in this report. This report has tried to state the views and opinions of delegates as much as possible. However, it is important to stress that the views expressed in this report are those given by delegates who attended this event and do not necessarily reflect neither the opinion of everyone who attended this meeting nor the whole of the CCS community.

Summary of attendees

A total of 70 delegates registered for the event, of which 60 attended. A list of registered delegates can be seen in Annex 1.

Delegates were split into groups of approximately 15 people to undertake discussions on specific questions related to the theme of the event. The results of these discussions can be seen in the section on Workshop session notes.

Programme

09:00	Registration and refreshments
09:15	Welcome (Andy Long, University of Nottingham)
09:20	Introductory address (Mercedes Maroto-Valer, NCCCS)
09:30	Marine projects and dispersion (Jerry Blackford, PML)
09:45	Marine monitoring (Ian Wright, NOC)

10:00 Marine impacts and risk assessment (Steve Widdicombe, PML)

10:15 Natural Analogues (Giorgio Caramanna, NCCCS/University of Nottingham)

10:30 Terrestrial risks (Dave Jones, NCCCS/BGS)

10:45 Industrial perspective on marine/terrestrial risk (Ian Phillips, CO2Deepstore Ltd)

11:00 Refreshments

11:30 **Workshop session 1**

12:10 Lunch

13:10 **Workshop session 2**

14:00 **Workshop session 3**

14:50 Refreshments

15:20 Discussion of results from breakout sessions

16:30 Summing up

16:45 Close of conference

Presentations are available for download on the NCCCS website and also on the UKCCSC website

Key Science lessons

Workshop session notes

Question 1: 'What are the requirements and barriers for detecting CO_2 leaks in the marine environment?'

Delegates generally agreed that a key requirement is to detect potential leakages over the long term. However, there was debate about the definition of leakage itself and most agreed that this should be defined as a release to the atmosphere or sea water (as in the IPCC definition) rather than the stricter definition applied by the ETS.

Delegates agreed that detecting CO_2 is difficult especially in a marine environment, and even more difficult to quantify leakages, especially if these were diffuse over a wide area. Ocean currents will hamper detection due to their changeable nature i.e. they vary over very short periods of time due to the tides, winds and weather. CO_2 monitoring needs to cover a large area as efficiently and as economically as possible. However quantification of leakage within the environment is probably more tractable than quantification via geological monitoring techniques.

The cost of detection equipment was highlighted as a major barrier in monitoring for potential leaks, however, as a proportion of total costs, monitoring costs will still be relatively small. Delegates highlighted that onshore detection (in certain circumstances, i.e. if vegetation is affected) is easier and cheaper because the effects of a leak are more visible and more accessible. Other barriers include identifying the correct owner for the CO_2, the CO_2 detection limit of the monitoring equipment, the natural background variability of CO_2, which in some cases is an order of magnitude above detection limits, and knowing how long to monitor the site.

Another potential barrier relates to how to detect leakages in displaced brine. Whilst technically possible to detect changes in salinity there is a need to be able to place monitoring equipment in the correct place.

Delegates felt that more needed to be done to understand what a CO_2 leak looks like i.e. not just detecting bubbles or the impact on vegetation, both the effects of CO_2 and the CO_2 itself needed to be monitored. Monitoring should involve the use of a suite of technologies to highlight any anomalies. Current technology includes a suite of physical and chemical detection techniques. There is a requirement to investigate every possible cause of a CO_2 emission before stating that it hasn't come from the CCS reservoir to reassure the public. Geological seismic evidence would, in some cases, be able to detect a leak from the reservoir. Detailed baseline surveys are crucial and should take into account any changes to the baseline that would naturally occur over time. Delegates also highlighted the importance of indicator species to identify potential leaks.

Monitoring should include the impact of the pressure front created as the CO_2 is injected into the reservoir. Saline water will be displaced from the shallow sediments near the seabed by the injected CO_2. What impact will this have on the local environment? Is there a risk that heavy metals could be liberated and transported up to the seabed with the CO_2? Should this be classified as a CCS related leakage?

The group agreed that the biggest risk to the environment from CO_2 leakage was more likely to come from the capture facilities, pipelines and offshore installations. As the CCS industry expands the chance of a CO_2 pipeline rupture or large scale leakage from facilities increases. There has been some research on ruptures with onshore CO_2 but there is a need for more research focussing on the impact of a large volume of CO_2 being emitted over a short period of time from offshore pipelines.

Delegates noted that ultimately there will be a fine balance between the monitoring and leakage cost, although if designed properly, monitoring is likely to remain a fraction of the total cost of the CCS process. This will be dependent on the cost of monitoring equipment verses the EUETS prices.

Question 2: 'What are the knowledge gaps concerning potential onshore/offshore leakage scenarios that need further R&D?'

One of the main concerns about potential knowledge gaps related to the regional geological knowledge of saline formations, fault behaviour, detectability and imaging of fracturing. However, most delegates believed that potential leakages were far more likely to originate from physical infrastructure involved in the capture and transport side of CCS rather than from the storage side of CCS.

Delegates believe that a greater understanding of the impact a large scale emission could have on the environment is needed. There is a lot that can be learned from the oil and gas industry who already have risk models relating to the flux rate and duration of a leak. However there is a perception that the oil industry may not be willing to share all this knowledge with academics.

A set of CO_2 leakage scenarios need to be modelled (with industry input) to include;

- CO_2 leakage from a point source and a series of dispersed sources
- CO_2 leakage in deep and shallow water

- CO_2 leakage over small and large areas
- CO_2 leakage over differing timescales – short and long term

A greater understanding of leakage mechanisms and the subsequent recovery of the environment is also required and this information can be used to validate and improve the models. Furthermore, the quality and reliability of CO_2 sensors needs to be established and improved. Additionally, greater experience of using an entire monitoring portfolio is required along with detailed monitoring plans and a strategy for cleanup. Delegates also highlighted the importance of site specific knowledge.

There are also a number of gaps relating to the social engagement with CCS. The group agreed that constructive public engagement with CCS will be integral to its successful deployment, however, what constitutes well-timed, well-placed and appropriate communication around CCS is unclear and more work needs to be carried out in this area. It was also recommended that work is done to find out what exactly the public and the politicians are most worried about when it comes to CCS.

There was also some discussion that the projects currently running need to finish before it can be clearly identified what needs to be done next. There was some concern of overlap of work, although academics felt that the existing projects worked well together and provide complimentary information and develop wide networks of researchers.

There was a discussion on the possibility of collaborating with organisations such as IEA GHG and GCCSI on an event to design the scenarios and parameters required to standardise CO_2 leakage reporting in the same way the oil industry uses API type standards. GHGT11 in November may be a suitable conference to raise the issue. There is also a need for a coordinated CCS centre in the UK to consolidate the academic and industry knowledge to help inform government policy.

Further knowledge gaps mentioned included the possibility of fault reactivation due to glacial rebound, although this would be difficult to predict. The formation of pockmarks on the ocean floor was also highlighted as an area needing more research.

Question 3: 'Who should be responsible for communicating potential environmental risk of leakage to the general public?'

Delegates generally agreed that communication at a national level should be undertaken by a national organisation, such as the Geological Survey, the Royal Society, or other such body. Government and Industry are not generally perceived as trustworthy by members of the public who see them as having an agenda to issue messages in certain ways.

Delegates agreed that the responsibility for informing the public was not as important as delivering a consistent message. There is only a small chance to influence the debate so the academic and research community have to be in agreement before speaking to the public or media as discord between academics leads to mistrust. It is important that the media understands and reports the message accurately and doesn't oversimplify it. Delegates felt that the media tend to exaggerate the severity of potential risks so the message has to be very clear. Delegates also felt that the public need to be better educated on the risks of climate change in order to understand and put into perspective leaks from a storage site. The public also need to understand the effect of the do nothing scenario. It was felt that UKCCSC organisation was a good platform for communicating to the public. It was also recommended to engage NGO's at an early stage and include them in the process. The role of the academic was clear in being an informer rather than an influencer, which is the role of politicians. In addition, it is also thought that insurance companies will help to communicate risk (or more importantly the lack of) by agreeing to insure a storage site.

Any message should be delivered by someone with good communication skills. Delegates agreed that the representative shouldn't be too slick or professional but they should have some training on how to tailor the discussion to the audience i.e. avoid using words such as supercritical, unconventional and aquifer which at best might confuse the public and at worst could scare them. Using images is a good way of informing the general public, but they have to be accurate. i.e. if there is a picture of a power plant with a CCS well nearby injecting CO2 into the ground the image needs to show clearly just how far underground the reservoir is in relation to the size of the power plant. Images could also show the size and distance of potential pipelines from source to sink. Inevitably it is likely that a great deal of communication about CCS will come from the government and the EU, but this top down approach often leads to different policies and agenda being promoted. Delegates agreed that although policies and politicians change, communication should be robust.

The question of whether CCS should be part of a wider debate on energy issues and climate change was discussed, although no consensus was reached as to who should do this and what form this should take.

In terms of offshore storage, the issue of who are the communities that would be potentially affected was debated.

Question 4: 'What could be done to mitigate the effects of leakage from an onshore/offshore reservoir?'

Delegates discussed the first issue that would need to be addressed, which is, how big is the leak and where is it leaking from.

Delegates agreed that remediation work to existing hydrocarbon wells, improved CO_2 resistant materials in the surface facilities and an improved cement job on the injection well will stop CO_2 leakage from the operations but correcting migration paths that have been created by the injection of CO_2 would be difficult i.e. from fault systems opening up due to the increased pressure. Will reducing the pressure in the reservoir by stopping and extracting CO_2 reseal the fault? Other options include changing the injection site or strata. If an offshore site does leak the pH must be returned to normal as quickly as possible so the only option would be to stop the leak and let natural processes disperse the CO_2. If drinking water is affected, it can be treated as it is drawn out of the reservoir.

There are geobiological studies underway investigating the potential uses of biofilms to help seal the reservoir. Further study is required.

Delegates agreed that a mitigation strategy should be in place for each specific site and that mitigation could be enhanced with improved, faster detection methods.

Question 5: 'How can the academic community work effectively with stakeholders to inform concerns of any potential environmental impacts of CCS?

Different stakeholders have different priorities. An industry stakeholder will look at all risks but will be particularly focussed on the impact on revenue, whereas the public's focus will be on the damage it may cause to the local community or livelihood.

Delegates believed that more needs to be done to make the link in the public's mind between the CO_2 that has already been emitted into the atmosphere from factories, cars, etc and the CO_2 that could potentially be leaked from a CCS site. If the global community rejects CCS as an option for carbon abatement due to the NIMBY effect, the environment will still be impacted by the effects of the CO_2 that continues to be vented into the atmosphere. It is important that the public have all the necessary information about CCS in order to make a rational decision about the technology.

There are similarities between CCS and the shale gas industries in terms of public perception. In Poland the public raised concerns about shale gas operations being developed nearby. Fears of methane contaminating the groundwater were common. The shale gas companies failed to present all the information at the start of the project and this has resulted in mistrust from the public. The Polish government and shale gas companies are now conducting detailed baseline studies before commencing operations to be able to prove that methane from the shale gas reservoir is not reaching the potable water aquifers due to fracking. CO_2 reservoirs are not likely to leak but the CCS industry needs to be able to prove that the risks have been considered and are being monitored.

There was a discussion on the need for agreement between industry and academics on the scenarios that are being used to model CO_2 injection and migration. The RISCS project (Research into Impacts and Safety in CO_2 storage) has developed a set of scenarios to standardise CO_2 modelling and it may be beneficial for these to be adopted by the CCS community. These scenarios should be discussed and shared to make sure that all realistic scenarios are covered.

Several delegates stated that all stakeholders (government and public) should hear the same key message regarding the potential risks of CCS but that the details could be tailored depending on the audience. The focus in different government departments can be very different and so they may need help with different aspects of CCS. The message about potential risks should be simple and clear – this is what might happen and this is what we are doing to make sure it doesn't happen. 'We do not expect the CO_2 to leak from the CCS site but in the interests of public safety we are monitoring so we can act quickly should anything occur'.

Some delegates stated that academia needs to develop a better way of disseminating knowledge gained from research projects to the wider community. However, several academics stated that it is a requirement for all research council and EU-funded projects that knowledge is disseminated widely. Academics need to be absolutely sure that the science is right before communicating it to the public. It would therefore be beneficial if the results could be shared with the rest of the CCS academia once the project has reached maturity. Academia needs to stay neutral when working for industry. The public trust universities and research organisations to be transparent, however ultimately academics deal with shades of grey – they usually put confidence limits on their results, which the public find difficult to understand so the message cannot come from academia alone.

It was also pointed out that many of the general public do not understand the concept of risk itself. For example, many play the lottery hoping to win when the odds of winning of extremely low, and yet some do not believe, or do not want to believe, scientific research when it indicates that the risk of problems from CO_2 storage is very low. Both of these are examples of people not responding rationally to the odds.

Communicating risk to the public is challenging, but it is important that people understand that Risk = Consequence x Likelihood.

Consequence of leakage is being addressed in many existing projects, but likelihood of leakage is more poorly defined and can be difficult to determine. A robust understanding of risks allows a correct approach to mitigation and remediation.

Delegates felt that the government could do more to integrate industry and academia such as offering specific innovation and communication budgets. Delegates noted that there are already some projects which do this very well. For example, the Longannet project had a good communication strategy which includes a visitor centre and both industry and academia working effectively together. Another example is the QICS project which includes a number of government, industry and academic stakeholders.

Question 6: 'How well equipped are we to quantify leakage onshore/offshore should it occur?'

Some delegates mentioned that this question had been recently dealt with under a IEA GHG report on this by CO2GeoNet which included a review of techniques and classifications.

Delegates generally agreed that existing monitoring kit is adequate to detect the presence of CO_2 either directly or indirectly (e.g. through pH changes). However it was noted that more work needs to be done on establishing the baseline conditions of a site, particularly due to naturally occurring variations in conditions at a site based on yearly (or longer) cycles. The biggest challenges are firstly finding the leak and secondly quantifying the scale of the leakage i.e. mapping the spatial and temporal changes of the CO_2 plume, particularly in the marine environment.

Delegates discussed where the monitoring should take place, either within the reservoir, in the overburden or at the seabed. It is easier to monitor at the seabed but would this be too late? Shouldn't we be aiming to stop any CO_2 leak before it reaches the marine ecosystem? It was agreed that each CCS site is different and that the best monitoring option should be determined on a case by case basis. Quantifying the amount of CO_2 leaking from the CCS site will be important to industry as the government could deduct any CO_2 leakage from the total injected.

There may be a disconnect between the research being funded by industry who are focussing on the quantification of the leakage and academia who are still concentrating their efforts on the detection of CO_2. It was felt that the academics were focussing on purely detecting small amounts of CO_2 in the environment whereas the quantification of leaks was more important. Delegates agreed that the size and duration of a leak was more important as a small amount of CO_2 leakage from the CCS site may not be problematic. A 'Macondo' scale emission is what the public fears most; however, as knowledge of reservoirs becomes greater, the likelihood of such instances occurring is reduced.

Question 7: 'What levels of confidence in the long-term storage of CO_2 can realistically be achieved, and how can they be demonstrated to the satisfaction of regulators and the public?

How long is 'long term storage'? It was felt that this phrase was a bit ambiguous as the government has not yet legislated on the obligations for CCS operations to continue monitoring after CO_2 injection ceases. Delegates believe that confidence in a CCS reservoir depends on three parameters;

- The sealing integrity of the caprock, how well it will hold the CO_2 in the reservoir over time.
- The rate at which the CO_2 will dissolve in the formation waters in the reservoir rock
- The rate at which the dissolved CO_2 will form carbonate rock, effectively trapping the CO_2 for thousands of years.

A risk to the stability of a reservoir and caprock is seismic activity caused by the injection of CO_2. The oil industry has used this to their advantage in the form of hydraulic fracturing (fracking) in shale gas and coal seam gas extraction and has a fairly good understanding of what will happen with time.

In terms of dissolution and carbonation, a study conducted by SINTEF (Eric Lindeburg) stated that 7000 years after the cessation of CO2 injection there could be very little CO_2 remaining in the reservoir. However trace elements and gases such as H_2S may affect this result.

Given that the timescales for the CO_2 to become permanently trapped in the subsurface are so large how long should the CCS industry be expected to monitor the CCS site after the injection of CO_2 has completed? The current guidelines are that monitoring should continue for up to 30 years post injection but this is an arbitrary figure. Delegates agreed that more research was needed to understand how CO_2 behaves in the reservoir over time. The current CCS demonstration sites have not been operational for long enough yet to produce enough monitoring results.

Levels of confidence in long term storage will grow once projects have been running for a number of years, as the storage time increases, confidence in the storage site will increase, particularly from the public.

Question 8: 'What further developments are needed in the science and in monitoring techniques to support decision making processes and to inform public opinion?'

Delegates agreed that communication of the science to the public needs to be better rather than the actual monitoring techniques themselves in most instances. However, monitoring is important as it demonstrates confidence that no leakage is occurring and that the public is being listened to regarding their fears.

Large scale demonstration schemes need to be operational to demonstrate the safety of these plants, as well as to find out areas of work that need more research.

Transport issues may be more important as pipelines etc will be crossing land and under the sea.
It is important to present the information academia and industry have in a more transparent way to inform the public, as well as continuing to undertake monitoring work (e.g. on groundwater) even though the likelihood of any problems is very low.

Planned next steps

One of the aims of this event was to further research partnerships between industry and academia in addition to producing this report to highlight some of the issues that may still need to be addressed.

Industry/academia collaboration is ongoing through a number of existing projects and when results of these projects are known, many of these will present their findings to the general public.

Further issues may then be discussed based on the results from this work, and if appropriate, events similar to this workshop may be produced.

It is recommended that Academics, Government and Industry review the findings of the workshop, as reported in this document, along with the industry recommendations in the APGTF strategy document, as an aid to prioritising R&D needs.

Annex 1

List of delegates who registered to attend the workshop.

First name	Surname	Organisation	
Luqman	Abidoye	Loughborough University	Academia
Matt	Baggaley	EON	Industry
Antony	Benham	NCCCS	Academia
Terry	Bennett	University of Sheffield	Academia
Jerry	Blackford	Plymouth Marine Laboratory	Academia
Ralf	Bublitz	University of Hull	Academia
Ameena	Camps	IEAGHG	Industry
Giorgio	Caramanna	NCCCS/UoN	Academia
Kit	Carruthers	University of Edinburgh	Student
Doug	Connelly	National Oceanography Centre	Academia
Louise	Crook	AECOM	Industry
Lyn	Dario	Nabarro	Industry
Diganta	Das	Loughborough University	Academia
Thomas	Demetriades	University of Nottingham	Student
Marie-Christine	Dictor	BRGM	Academia
Tim	Dixon	IEAGHG	Industry
Sebastien	Dupraz	BRGM	Academia
Tony	Espie	BP	Industry
Anna	Firmin	AF Associates	Industry
Den	Gammer	ETI	Industry
Dean	Gouveia	3LC International	Academia
Jean	Hall	University of Newcastle	Academia
Akiyoshi	Hashimoto	Japan Electric Power Information Centre	Industry
Ian	Hedges	Scottish and Southern Energy	Industry
Tim	Hill	EON	Industry
Dave	Jones	NCCCS/BGS	Academia
Michael	Jordin	National Grid Carbon	Industry
Pranab	K. Barua	University of Edinburgh	Academia
Kamal	Khudaida	Loughborough University	Academia
Jun	Kita	RITE, Japan	Academia
Mariëlle	Koenen	TNO	Academia
Astri	Kvassnes	Norwegian Institute for Water Research	Academia
Janice	Lake	University of Nottingham	Academia
Mark	Lewitt	Lewitt Consulting	Industry
Darren	Lincoln	University of Sheffield	Academia
Julie	Lions	BRGM	Academia
Barry	Lomax	NCCCS/UoN	Academia
Andy	Long	University of Nottingham	Academia
Daniel	Lucas	University of Hull	Student
Iain	Macdonald	Imperial College London	Academia

Sarah	Mackintosh	NCCCS	Academia
Mercedes	Maroto-Valer	NCCCS	Academia
Jenni	McDonnell	Environmental Sustainability KTN	Industry
Richard	Metcalfe	Quintessa	Industry
Judith	Nathaniel	LQM	Industry
Mark	Naylor	University of Edinburgh	Academia
Rhonda	Newsham	BGS	Academia
Tony	Oliver	Energy Generation & Supply KTN/APGTF	Industry
Jonathan	Pearce	NCCCS/BGS	Academia
Laura	Pettit	University of Plymouth	Academia
Ian	Phillips	CO2Deepstore Ltd, a Petrofac company	Industry
Nicola	Power	Nabarro	Industry
Judith	Shapiro	CCSA	Industry
Philip	Sharman	APGTF	Industry
Kiminori	Shitashima	I2CNER, Kyushu University	Academia
Karon	Smith	University of Nottingham	Academia
Henrik	Stahl	Scottish Association for Marine Science	Academia
Mike	Stephenson	NCCCS	Academia
Derek	Taylor	Bellona/GCCSI	Industry
Pete	Taylor	Scottish Association for Marine Science	Student
Christopher	Teasdale	University of Newcastle	Student
Kate	Thatcher	Quintessa	Industry
Xiaolong	Wang	Caterpillar	Industry
Wei	Wei	Heriot-Watt University	Student
Yang	Wei	University of Nottingham	Student
Anna	Weston	Environmental Sustainability KTN	Industry
Rosemary	Whitbread	Health and Safety Laboratory	Industry
Steve	Widdicombe	Plymouth Marine Laboratory	Academia
Ian	Wright	National Oceanography Centre	Academia