building knowledge for environmental assessment of CO_2 storage: controlled releases of CO_2 and natural releases workshop

IEA GREENHOUSE GAS R&D PROGRAMME

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. The IEA fosters co-operation amongst its 28 member countries and the European Commission, and with the other countries, in order to increase energy security by improved efficiency of energy use, development of alternative energy sources and research, development and demonstration on matters of energy supply and use. This is achieved through a series of collaborative activities, organised under more than 40 Implementing Agreements. These agreements cover more than 200 individual items of research, development and demonstration. IEAGHG is one of these Implementing Agreements.

The report should be cited in literature as follows:

'IEAGHG, "Building Knowledge for Environmental Assessment of CO_2 Storage: Controlled Releases of CO_2 and Natural Releases Workshop", 2013/02, January, 2013'

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

IEAGHG, Orchard Business Centre, Stoke Orchard, Cheltenham, GLOS., GL52 7RZ, UK

Tel: +44(0) 1242 680753 Fax: +44 (0)1242 680758

E-mail: mail@ieaghg.org

Internet: www.ieaghg.org

Date Published: January 2013, Review compiled by Millie Basava-Reddi, design and layout by Toby Aiken and Becky Kemp.

Front & back cover images: Hydrothermal Breccia pipe / Experiments at the ZERT Test Site / Montana University / Mammoth Springs / Yellowstone – travertine terraces formed at a site of natural CO_2 seepage / ZERT Test Site

Contents

Lee Spangler (host) and Dave Jones considering a CO_2-rich hydrothermal feature in Yellowstone and the effects of different overburden geochemistry (volcanic vs carbonate) on leakage impacts at the surface / Lee, Ameena and Tim agreeing the conclusions of the meeting

Summary

A workshop on 'Building Knowledge for Environmental Assessment of CO_2 Storage: Controlled Releases of CO_2 and Natural Releases Workshop' was held in July 2012 hosted by Montana State University (MSU) in Bozeman, Montana. This workshop focussed on controlled release projects. As such, it brought together for the first time most of the world's controlled release projects, ten in number. This created the opportunity not just for sharing of results, but for future sharing of facilities and techniques, opportunities which were taken advantage of during the meeting.

The workshop also looked at the Environmental Assessments undertaken for real projects, with details being provided by Shell on the Quest project and its recent approval.

In the area of monitoring, great progress is being made. There are increased capabilities and new experiences offshore. The very realisable capability for large-area monitoring was shown, with the potential capability of leak detection, and work on offshore baselines also being ground-breaking. Exciting developments in onshore monitoring were also presented, including the Process-based technique, for assessing the source of CO_2 found in the near-subsurface.

One of the concluding recommendations was to "Keep up the good work" because gaps identified in the previous two workshops are being successfully addressed. The meeting concluded with a request from participants to become a full IEAGHG Network, called the "Environmental Research into CO_2 Storage Network".

Introduction

The third workshop in an IEAGHG series on environmental impact assessment of CO_2 storage was held in July 2012. The 'Building Knowledge for Environmental Assessment of CO_2 Storage: Controlled Releases of CO_2 and Natural Releases Workshop' was held from the 17th to 19th July 2012 in Bozeman, Montana. It was hosted by Montana State University (MSU) and sponsored by MSU, Southern Company and the Center for Advanced Energy Studies. Forty-eight delegates attended from 12 countries.

The main focus of this workshop was on controlled release projects with other sessions on environmental impact assessments and Regulations, monitoring, overburden/ mechanisms of migration from deep to shallow subsurface, leakage scenarios and communication of leakage. The third day of the meeting was spent at Yellowstone National Park, with part of the day observing formations created from natural CO_2 seepage.

Session 1: Welcome and Aims of the Meeting

There have been 2 previous meetings on Environmental Assessment of CO_2, but this is the first workshop following approval of a workshop series. Therefore part of the aim of the meeting was to create a set of aims and objectives that the workshop series will work towards. This was explained in this session with the intention to decide on these during the conclusions session.

Session 2: Environmental Impact Assessments and Regulations

This session consisted of a comparison of existing environmental impact assessments (EIAs), an overview and analysis of current relevant EPA rules and an example of successful implementation at a real project. Some main outcomes from the session are that projects proceeding with standard EAs before dedicated regulations have done so successfully and have assisted and educated regulators to enable development of regulations. Dedicated regulations can provide some problems for demonstrations – e.g. EPA Class V vs. VI, PISC 50yrs; there is a need for flexibility in regulations, and/or the ability for amendment; there may be issues over land access for long term monitoring, which will need to be considered; and there will differences in EAs onshore and offshore.

Overview and Comparison of Environmental Assessments for CCS, Jun Kita, RITE

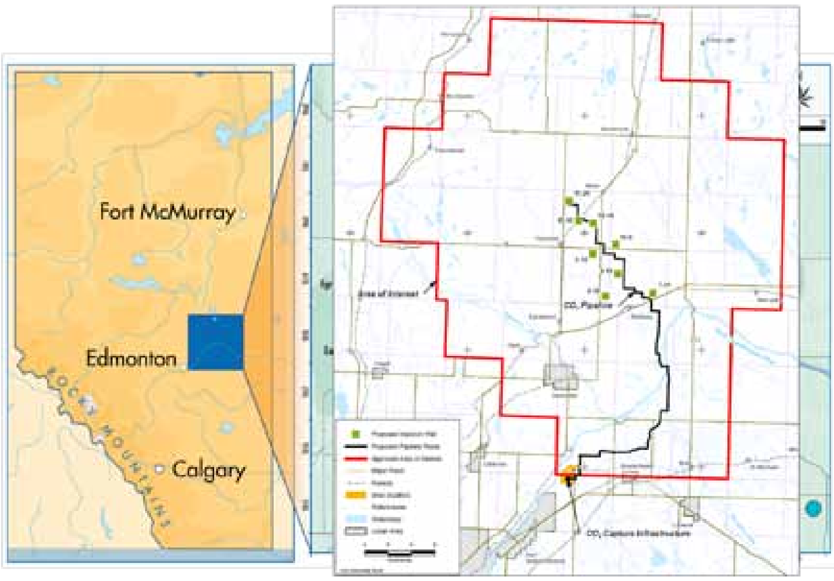
Comparisons across countries show a similar process. First there is a screening followed by an environmental impact assessment (not necessarily needed in some countries depending on the screening) from which an environmental impact statement can be issued. Then follows the key process of the consultation with stakeholders, after which decisions can be made and a monitoring plan put in place. Legal and regulatory frameworks were also compared across countries, differences were noted, but there was not anything that could not be dealt with if necessary.

EPA Class VI Underground Injection Control Rule, Lee Spangler, MSU

More projects will be using the Class VI rule, but some issues have been noted especially in regards to R&D projects. Default post-injection monitoring is 50 years (it is possible to request a lower time), which can be an issue as companies may not be willing to do this on a research project. Financial responsibility can also be a problem for research institutions. Some projects have converted to EOR to be allowed a Class II well permit. There are also some inconsistencies between the reporting rule and the UIC rule regarding language associated with leakage. All R&D CCS projects will have to switch from Class V to Class VI.

Shell Quest Carbon Capture and Storage Project: Environmental Assessment Process and Results, Tara Barnett, Stantec

The focus of this environmental assessment was on the assessment of accidents, malfunctions and unplanned events for the project. When looking at the interaction between the project and environment, valued environmental components (VECs) are identified. VECs identified covered the entire range from air quality and sound environment, to surface and subsurface water quality, to terrestrial and biophysical, and socio-cultural components. The next step was an analysis of what could happen outside of normal operations. For Quest, 9 scenarios were considered and 3 of these were carried forward; including the release of CO_2, formation brine or CO_2 saturated brine from the storage complex or injection wells. Active and passive mitigation methods were considered, including real-time logging of injection rates and downhole pressures and through the selection of the storage site itself, such as the regionally extensive salt seals over the storage complex. Some effects may persist after mitigation and the significance of this was analysed. The Quest project's Environmental Assessment was approved shortly before the workshop.



Quest Project, Tara Barnett, 2012
Location of capture plant, storage site and pipeline route

Session 3: Controlled Release Experiments

This session contained updates from several controlled release projects, some of which are completed, some in progress and some yet to start injection. There are variations in focus across the projects, from testing detection technologies to specifically determining impacts of CO_2. The number of facilities has proliferated giving a wider range of settings, soil and water chemistry types, flora and fauna and the first marine controlled release has been performed.

Some of the main learnings are that surface detection is gaining broader acceptance; there are challenges in relating / scaling lab experiments with controlled releases; indicator species are being identified and benthic species seem to be particularly sensitive; seasonality and timing can affect impact of leakage

CO_2FieldLab, Dave Jones, BGS

The aim of this project was to determine the sensitivity of monitoring systems to shallow CO_2 migration and surface leakage, test and calibrate migration models in well controlled conditions, upscale results to assess monitoring systems and requirements and propose a monitoring protocol. The injection was into a heterogeneous sand deposit with complex bedding and channels, which are poorly sorted coarse sand, with abundant fines and pebbles.

The main conclusions are heterogeneity in sand deposit deviates the plume path, but is not able to be characterised by non-invasive methods. Electrical resistivity methods (and GPR) sensitive to CO_2, show both increasing and decreasing resistivity. Post-injection data is needed to characterise and build a reliable model. From history matching, both high and low permeability layers can match the location and timing of surface seepage. The next step is to build a reliable model which the geophysical methods can be calibrated against to determine their sensitivities.

The ZERT Controlled Release Site, Lee Spangler, MSU

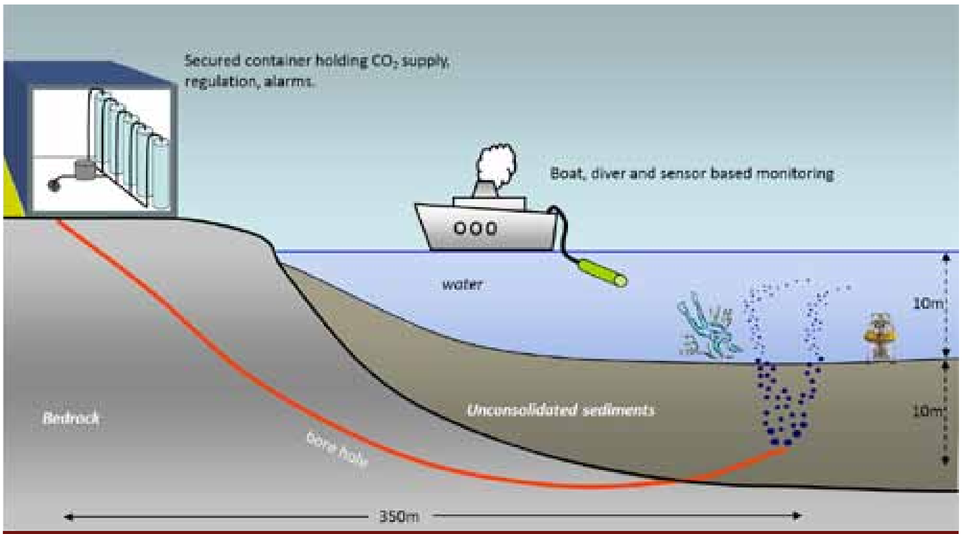
The ZERT test site has been operational for 5 years and has involved 47 investigators, 31 instruments / sensor arrays and 5 universities, 6 DOE national labs and 4 companies. Some of the main learnings over this time are:

- Many near surface methods are quantitative but:
  - Diurnal, seasonal, annual variations in ecosystem background flux affect detection limits
  - Appropriate area integrated, mass balance is a challenge
- Nearly all methods could detect 0.15 tonnes / day release at ZERT site
- Isotopes & tracers have lower detection limits than straight CO_2 flux or concentration
- Scaling, 6 tonnes per day would be detectable over an area 40 times as large
- Surface expression was "patchy" – 6 areas of ~5m radius
- Natural analogues also seem to have "patchy" surface expression
- Will engineered systems that leak have similar properties

ZERT Test Site; Picture courtesy Lee Spangler
Experiments have taken place at the ZERT controlled release site over 5 years. Over this time work has been carried out by 47 investigators from 5 universities, 6 DOE labs and 4 companies using 31 instruments / sensor arrays.

The QICS Controlled Marine Release Project, Jerry Blackford, PML

The QICS project is the first offshore sub seabed sediment release project. The aims of the project are to deliver information that can be directly applied and fully understood by policy makers, planners, public bodies and the public with an interest in planned CCS projects; quantify the fluxes and transformations of CO_2 from the storage reservoir to the seafloor ecosystem, into the water-column, and potentially the atmosphere; evaluate the biogeochemical and ecological impacts in the shallow sediment and the water column; and establish techniques for the detection and monitoring of leaks by examining the spatial and temporal biological, chemical, and physical signatures that may result.



Conceptual Diagram of the QICS CO_2 Release Experiment; Jerry Blackford, 2012
QICS is the first sub seabed release experiment. This experiment considers how CO2 will flow through the shallow subsurface and allows observations of flow in real sediment environment and full scale testing of monitoring techniques.

The CO_2 release phase has now been completed and the project is in the recovery phase. Some preliminary results were presented, which include seismic monitoring showing a 15-20m horizontal spread. CO_2 appeared 3 hours after injection started and a video of CO_2 release shows bubbles and pock marks. Some fauna are thought to have been affected, but this has not yet been quantified and an increase in alkalinity near the end of injection suggests carbonate dissolution.

The PISCO$_2$ Project: Experimental set-up and Perspectives, Fidel Grandia, Amphos 21

The objective of the project is to investigate the effect of CO_2 in soils on different biotopes. Construction for this project started in 2010 and injection is expected to commence in 2013. This will include experiment on lichen, strawberry plants and will consider the kinetics of chlorophyll.

Environmental Impacts of CO_2 Storage: Results from the ASGARD field facility, Karon Smith, University of Nottingham

The ASGARD site has been in operation since 2006 years and its approach has been to inject controlled amounts of CO_2 into soil, test detection techniques, monitor changes in plant and soil conditions and test sensitivity to soil and plant types. This presentation concentrated on the results from the vegetation studies.

The main conclusions from the plant studies noted were that significant effects occur at relatively high levels of CO_2 (above about 10%) and are likely to be highly localised; CO_2 usually damages root development but in some instances stimulates it; the response to CO_2 depends on the plant species and the stage of development when the leak occurs; monocotyledons appear to be more tolerant than dicotyledons but there is variation between plant species; and some species (e.g. clover) are more sensitive, affecting competition.

Other work conducted at the site includes soil gas concentration, soil flux, botanical studies, bacterial studies and the environmental impacts of pipeline leaks.

Potential Impacts on Groundwater Quality of CO_2 Geological Storage: The CIPRES Project, Marie-Christine Dictor, BRGM

Planning for this project started in January 2012, the main objectives of which are to characterise biogeochemical mechanisms that control the degradation of water quality and devise a methodology for monitoring groundwater quality above future CO_2 geological storage complexes. The main expected outcomes are recommendations for investigating the potential risks of CO_2 storage on groundwater quality; identification of the biogeochemical reactivity of CO_2 within the aquifer to estimate the impact on water quality and spatial and temporal distribution of the potential impacts on both chemical and microbiological water composition; and methodological guidelines for implementation of monitoring programmes.

Field Results from a Controlled Release of Dissolved CO_2 into Dilute Groundwater, Rob Trautz, EPRI

The objective of this study is to investigate the potential CO_2–induced mobilisation of metals using a controlled release of dissolved CO_2 into groundwater. Injection of CO_2 has been completed and the project is in the post-injection monitoring phase with planned closure in 2013. Groundwater is produced, into which CO_2 is dissolved, then reinjected to a 50m depth. This is carried out in a closed loop system to avoid contact with oxygen. Measurements were focused on pH and some cations and anions

The results show that on injection there is a rapid increase in cations, followed by a decrease; the same is true for anions but to a lesser extent. Lab characterisation of sediments indicates that trace metals are present. The majority of trace metals (e.g., As, Cu, Pb) remained below their respective method detection levels and it is unknown whether they are increasing or decreasing. Sorption/desorption processes are likely mechanisms responsible for rapid increase-decrease in concentrations. However, elevated concentrations of several constituents were observed at 2 wells implying that dissolution processes are starting to dominate later in time; and/or the plume front become comes wider as more metals desorb and begin to accumulate and move with the front.

Ginninderra Greenhouse Gas Controlled Release Facility: First Shallow Subsurface CO_2 Release, Andrew Feitz, Geoscience Australia

The main aim of this project is to test atmospheric monitoring techniques. A pre-release above ground experiment was carried out in 2010 and monitored using atmospheric tomography. CO_2 emission rate was determined within 3% and localisation determined within 4%. The first release was March – May 2012 and the initial results were presented. Soil flux took approximately 4 weeks to stabilise and changes were detected in the soil gas after only 4 hrs, 15m from the hot spot. There was considerable lag between surface expression of soil flux and sub-surface soil gas (1m deep).

The next steps will be to process the data from first release; including finishing analyses and look at gas ratios in the soil gas, inverse Bayesian (atmospheric CO_2 using "cheap" point sources) and micro and tracer data. The second release is planned for October 2012, where there will be airborne hyperspectral (dwarf wheat) and in field phenotyping , inverse Bayesian (atmospheric CO_2 using infrared laser source), AUV helicopter CO_2 survey and more geophysics and soil flux surveys. A third release is planned for 2013.

Ressacada Field Lab for the Petrobras CO_2 MMV Project, Andrea Moreira, Petrobras

The aim of project is to test MMV techniques including new (real time) CO_2 monitoring tools to be applied to commercial scale, as well as testing detection limits for near-surface monitoring techniques. The overall goals for Brazil are moving towards CO_2EOR not storage. Brazil does not currently have any target obligations to reduce emissions, but has taken on voluntary targets. Injection is planned to start in 2014.

Hydro-geochemical impact of CO_2 Leakage from CCS on shallow potable aquifers: Vrogum main release experiment, Aaron Cahill, Danish Technical University

The objective of this project is to look at very shallow aquifers and consider the geochemical impact that may take place following a CO_2 leak. The site has fairly pure water with little to no buffering capacity. The pilot field injection has been completed and the main injection commenced in May 2012. Injection is at 4m and 8m and there are distinct differences observed with depth (between layers).

A sudden increase in electrical conductivity was noted at 8m, while nothing was seen at 4m. A variety of anions and cations are monitored, which can be seen to increase after injection, but again much more noticeable at the deeper wells. The migration of the plume is being monitored and more wells are being drilled as the plume migrates.

Session 4: Monitoring

This session was defined as 3 parts, an overview considering different monitoring methods available; baseline monitoring and sensitivity; and quantification and diffuse leakage. Some of the main outcomes of the session are how the range of methods available has increased. Particularly the ability to screen large areas, i.e. AUV offshore and electromagnetic methods onshore; these methods enable cost and time effective monitoring over a large area, and if an anomaly is detected it can be investigated further.

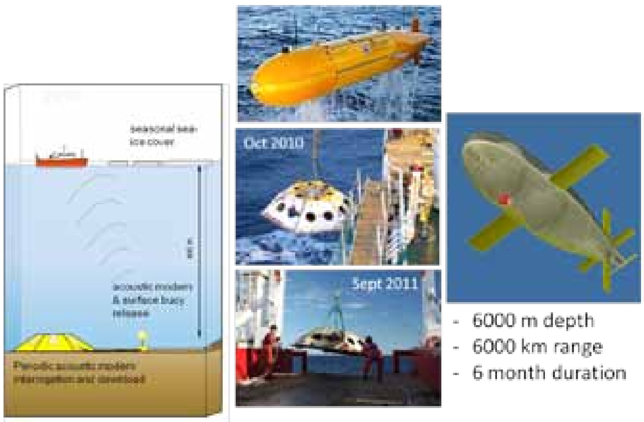
Regarding baselines; there are several indicators that could be monitored to detect CO_2 leakage in the marine environment, though natural variability means significant effort to characterise the baseline. It is now possible to identify leakage without a baseline using the process-based technique; however, it may still be desirable to use survey style background measurements to establish a pre-injection baseline, as well as continual monitoring to identify potential leaks. Advances have also been made in quantification methods as well as wide area techniques.

Monitoring CO_2 Storage: How Far should we go?, Rob Arts, TNO

An overview of potential monitoring techniques was given as well as the importance of a monitoring strategy, which while specific for each site, aims to show no leakage, though this is difficult to prove. Difficulties in developing a monitoring strategy include consideration of large areas versus more accurate point measurements (will enough area be covered to identify a leak), indirect deep (geophysical) early warning methods versus shallow direct (late) methods as well as the impact of large area methods (seismic) versus benefit. Examples of how this has been done in the CO_2ReMoVe and ROAD projects.

Marine Monitoring of offshore CCS Storage – Challenges and Solutions, Ian Wright, Southampton University

There has been much progress in the area of marine monitoring, but there are still some challenges, including issues of what to monitor for, as if there is a leak, CO_2 may be preceded by saline fluids, which in turn may be preceded by anoxic fluids.



Deployment platforms – seafloor landers and autonomous underwater vehicles (AUV's); Ian Wright, 2012
AUVs are able to monitor a large area allowing more detailed monitoring should an anomaly be detected.

Some of the main conclusions include CCS sites with large spatial seafloor extent and overlying ocean volumes (with potentially dispersed and localised emission sources) provide a monitoring challenge; the essential rationale for monitoring will be baseline studies, leakage detection, and flux emission quantification; potential CO_2 leakage may have precursor fluid release of reducing sediment pore fluids ± aquifer brines (each of which has a unique chemical signature); new marine sensor and underwater platform technology is developing to deploy long-term point observing and remotely surveyed monitoring of the critical fluid parameters at the necessary sensitivity and spatial scales for CCS sites (and at relative low cost); seafloor / ocean monitoring can detect both dissolved phase (using chemical detection) and gas phase (using passive and active sonar), but is not yet commercially deployable; chemical and sonar monitoring systems may also provide a tractable and robust method for quantifying leakage loss beyond just detection; quantification of CO_2 loss is probably easier and more accurate at the seafloor.

Conductivity Measuring to Assess Brine Impact, Katherine Romanak on behalf of Jeff Paine, University of Texas

This covered the use of magnetic and electromagnetic conductivity methods to find brine impacts; a method which has been used successfully to locate leaky wells. The magnetic survey is used to identify potential preferential leakage pathways by identifying the casing of plugged and abandoned wells. EM conductivity can detect salinisation as well as discriminate among salinity source types; the change over time can then be monitored.

These are both airborne methods, therefore able to screen large areas rapidly with generally unrestricted access. This can then be followed up with more focused on-ground monitoring activities.

Challenges include, magnetics only being able to detect abandoned wells with casing in place and EM having a limited investigation depth of a few hundred meters, but this is still potentially useful for CCS and CCUS applications.

Setting the Standard for baseline studies for sub-seabed CO_2 Storage – the CO_2BASE Project, Andrew Sweetman, NIVA

The main objective of the CO_2BASE project is to perform a pilot baseline study on two sites in the North Sea in order to determine best practices for baseline data acquisition; the study will run for 6 years.

It is necessary to understand the natural system, in order to ascertain if any changes are due to CO_2 leakage or part of the natural variability. This project will consider and monitor very shallow biological and chemical processes on the seafloor. This includes animal behaviour on the seafloor and benthic biodiversity; bioturbation shows burrowing to the seafloor, which may indicate potential leakage. Geochemical variability is considered and mixing rates will be determined. Modelling will be used to simulate local current conditions and tracer transport at sites, biochemical processes and sensitivity of local ecosystems to elevated CO_2 content.

Process Based method, Katherine Romanak, University of Texas

This methodology can be used to test for leakage in the absence of a baseline by considering the source of CO_2 based on the ratio of key gases: CO_2, CH_4, O_2, N_2. Background processes are biological respiration (plant and microbial), oxidation of methane, dissolution of CO_2 into groundwater and reactions with soil carbonate and atmospheric exchange. Leakage can cause exogenous CO_2 or CH_4 from a storage formation.

The ratio of CO_2 to O_2 will indicate whether the CO_2 is produced by biological respiration, oxidation of methane, or leakage while the total concentration of CO_2 is not relevant. N_2 that is higher than atmospheric values indicates that CO_2 has been consumed in the system (possibly by dissolution into groundwater) whereas N_2 that is lower than atmospheric values may indicate a leakage signal. N_2:O_2 ratios can be used to determine the amount of consumption of O_2, which may occur most vigorously in the case of a methane leak being oxidised to CO_2. This process-based methodology has been tested and proven at a number of sites and can be used as a targeted response tool for unexpected reservoir behaviour, landowner concerns, or observed changes in the biosphere.

Dial and Other Wide Area Detection Methods, Kevin Repasky, MSU

This talk focused on the development of surface monitoring technologies for large area detection of carbon dioxide for ensuring public safety and site integrity. Various methods of CO_2 detection will be needed for carbon sequestration site monitoring, but DIAL (Differential Absorption Lidar) is useful in providing near surface detection over several square kilometres. The methodology works by using 2 closely spaced wavelengths and the light collected indicates the CO_2 density. Fibre sensor arrays monitor the difference between a reference and transmitter array, which provides a cost effective scalable network of point sensors. Hyperspectral aerial imaging takes images at different wavelengths and looks at the brightness; this has been tested on a vegetation plot and can provide large scale coverage.

"No Detectable Leakage": Accuracy and Sensitivity of Storage Monitoring Methods, Anna Korre, Imperial College

Quantifying leakage depends on the methodology being used and in most cases there will be nothing to detect, so it is important to assess accuracy and sensitivity in monitoring. A statistical analysis is needed to detect the signal through the noise. Classic hypothesis tests are vulnerable to false alarms and highly dependent on data uncertainty. A specific leakage model in Neyman-Pearson acceptance testing allows evaluation of probability if correct decision making over whether leakage exists. Extension to multiple leakage models probability of leakage.

Detailed information is needed in the statistical structure of the data and the uncertainties. Accumulation of enough background data may be impractical, but there are still many statistical techniques available. False alarm rates are likely to be encountered with data with very low statistical power to detect leakage.

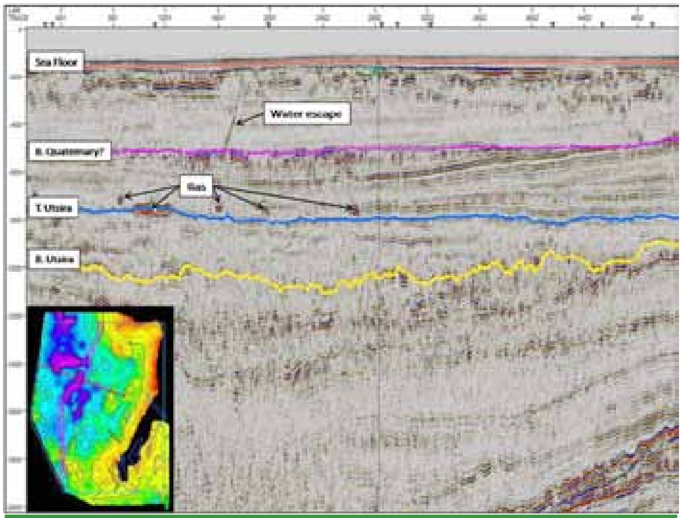
Session 5: Overburden / Mechanisms of Migration from Deep to Shallow Subsurface

To understand potential impacts it is necessary to understand processes and mechanisms of migration through the overburden. Mechanisms are currently poorly understood but there is ongoing research and an idea from this session was to engage with external communities with more knowledge e.g. methane seepage, hydrocarbon, geomechanics. Seismics are useful to characterise overburden and identify potential pathways and large spatial coverage can be achieved using hydro acoustics. Other learnings from the session include bacterial mats on seafloor can be a good indicator for pathways; monitoring is needed at depth for early detection, as a potential leak may not manifest itself immediately; O_2/DIC flux ratios may be used to identify potential leakage including diffuse leakage and potentially quantify leakage rates; and further research needed in sedimentary systems to understand potential mechanisms and define how analogous natural systems are.

Sub-Seabed CO_2 Storage: Potential Leakage Pathways and Effect on Marine Ecosystems (ECO_2), Klaus Wallman, GEOMAR

This focused on the work carried out looking at potential leakage pathways at Panarea, a site of natural CO_2 seepage and Sleipner, a current storage site. The Panarea site is part of an active volcanic area with fumarolic activities and gas vents; acoustic monitoring has been used to map a large surface area of the seabed and eighty previously unknown bubble flares have been found in the study area.

At the Sleipner site, potential leakage pathways are being mapped with seismic data. There is currently almost no surface monitoring and this is now being conducted as part of the ECO_2 project. Numerous vertical seismic pipe and chimney structures in the sedimentary overburden have been identified; there is methane seepage through abandoned wells, but no detectable leakage of CO_2. Also identified was 3km long fracture 25km north of the Sleipner site, through which there is also methane seepage and no detectable CO_2. It is not expected that CO_2 will be detected at the site as it is separated from the storage site by several thick impermeable layers. The gases continue to be monitored.



ECO_2 Interpretation of Seismic data of the Utsira sandstone Formation; Klaus Wallmann, 20112
Seismic 2D line close to the fracture/fault zone depicting possible water escape features and small gas pockets at top Utsira and above

Fluid Transfer Modelling from the Basal Cambrian Sand through the Overburden to Useable Groundwater Formations for the Quest CCS Project, Jeff Duer, Shell

The biggest risk on the quest project was considered to be through legacy wells, so modelling was focused on this to determine potential leakage pathways. The talk focused on 4 wells on which cross-flow modelling was carried out.

The main conclusions were that investigation of the legacy wells illustrated that minimal invasion of brine occurred and that the cooking lake acts as a pressure sink. Investigation of the injection well illustrated that minimal invasion of CO_2 occurred. Investigation of a fault leak path illustrated that minimal invasion of CO_2 occurred through a 1 mD leak path 1000 metres from an injection well at 1/3 total field rate. MMV in one of the wells would need to be very close to the leak path to observe fluid invasion, whereas pressure build up can be seen considerably farther quite readily.

Gas Migration over Gas Reservoir in Different Geological Scenarios: Comparison among Geological, Structural and Geochemical Data and Modelling, Salvatore Lombardi, University of Rome

The study of natural analogues, allows understanding of migration mechanisms, pathways, and geological controls that influence the potential for CO_2 leakage. To this end a range of different sites have been compared to conclude that most fluid circulation is controlled by fractures and faults and their features; density, connectivity, and grade of strain localisation, which controls porosity distribution in fault zones.

This can be used to establish criteria for risk assessment and safety strategy. For site assessment, methods developed at natural analogue sites can be used to show if there are any potential migration pathways at a site considered for CO_2 storage. For monitoring, knowledge of where and how CO_2 may leak helps define a monitoring and safety strategy, as well as planning any eventual remediation plan.

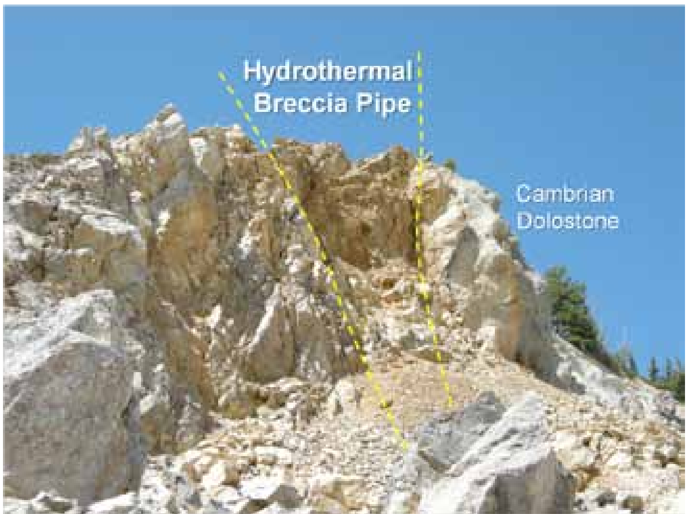
Session 6: Leakage Scenarios

This session consisted of talks on considering natural systems to identify potential leakage scenarios and work carried out in the ECO_2 and RISCS projects to identify potential leakage scenarios. Some of the main outcomes were that natural systems can be used to look at how leakage could potentially occur and what the effects would be, as can be seen with deep sourced hydrothermal fluid leaks. Leaks are improbable but possible, and therefore plausible leakage scenarios need to be developed. To consider leakage scenarios it is important to know flux rates, the duration of the leak and the area and form of leakage.

Hydrothermal Systems and Analogues for Breached Traps and Subsurface Healing: Outcrop and Subsurface Examples and Escape Mechanisms, Dave Lageson, MSU

As some likely sites for CO_2 storage are where naturally occurring CO_2 already exists in the deep subsurface, then it is important to understand the processes that occur in these regions. Many of these systems are associated with magmatic or non-magmatic sources of hydrothermal fluids, making understanding of these high-temp reservoir conditions through surface and core studies essential.

This study concluded that surface analogues can be excellent laboratories for studying subsurface reservoir conditions; fracture and fault systems are predictable and mappable across many scales of observation; low-temperature hydrothermal brine systems are important diagenetic components of carbonate reservoirs that must be understood for long-term carbon dioxide storage. Key to understanding these systems are detailed, integrated studies involving structural geology, carbonate diagenesis and geochemistry, at all scales of observation.



Hydrothermal Breccia pipe – Using Hydrothermal Systems as Analogues for Breached Traps and Subsurface Healing; Dave Lageson, 2012 Surface analogues can be used to study subsurface reservoir conditions.

An Environmental Perspective on Leakage Scenarios, Jerry Blackford, PML

Part of the ECO_2 project is to develop site specific scenarios based on modelling work and initially generic scenarios are needed to enable progress. Factors that are needed are flux rate, duration and area (and form of leakage). Three main categories were identified; worst case leakage, with injectivity on an industrial scale: 5-10 Mt/yr over a short period (~0.5 years); leakage through faults/fracture with several spots on the seafloor; and leakage through an open well (~ 1t/day). From these a range of plausible scenarios can be created.

A particular issue noted was moving from leakage flux to CO_2 dosage. Tidally driven plumes and CO_2 density effects imply that perturbation at any given location is likely to be intermittent.

Development of Leakage Scenarios in the RISCS Project, Dave Jones, BGS

Even though all leakage is improbable at a well-chosen and operated CO_2 storage site, it is important to create a range of leakage scenarios to act as a basis for designing monitoring and mitigation plans, as well as a communication tool and to provide a context for the discussion of project results.

A range of scenarios were developed for the RISCS project by considering marine and terrestrial reference environments. The marine reference environments are cool, temperate, deep; cool, temperate, shallow; warm, shallow; and low salinity. Terrestrial environments considered are maritime temperate; continental; Mediterranean; and generic urban. Aspects of the scenarios include what kind of environments there will be, patterns of leakage (point source, alignments of point sources, diffuse etc), things that could be affected ("receptor classes"). The scenarios will initially be simple descriptions, by are expected to become more complex later in the project.

Session 7: Communication of Leakage – Discussion Session

Session Chair: Katherine Romanak, University of Texas

Panel Members: Tim Dixon, IEAGHG; Travis McLing, INL; Lee Spangler, MSU; Lori Gauvreau, Schlumberger CS; Jerry Blackford, PML

This session started with an opening presentation from Katherine Romanak to introduce the discussion. This focused on using natural analogues and controlled release projects in public communication and how the analogue used should be relevant to CCS or what is being explained. The other panel members each gave a short presentation, before opening up the discussion to the floor. Tim Dixon talked about how negotiations to have CCS in the CDM were positively affected by the preceding UNFCCC technical workshop, which allowed stakeholders and technical experts from the IEAGHG networks to interact. Lee Spangler talked about how the ZERT site has been used to communicate with the public and regulators. Issues have arisen due to an emotional response, but if the time is taken to explain the situation, this can be resolved. Lori Gauvreau talked about the importance of developing consistent terminology, which the public are able to understand and avoiding terms that can be misunderstood, such as overburden, supercritical CO_2 and plugged and abandoned wells. Jerry Blackford talked about the communication strategy at the QICS project, which has been very successful. All local stakeholders were involved from the start and the point of view taken was not to advocate CCS, but to answer questions related to the science. Travis McLing talked about past experience and how easy it is to get misquoted by the press, especially if they do not get all of the information. Pictures can also be used to communicate, but this needs to be thought about, as this will be the lasting image people take away with them.

The main outcomes of the discussion were:

- Terminology should be consistent and clear to the audience.
- All Projects need a Communication Response Plan
- Open and honest communication is needed with all groups of stakeholders
- Be proactive not reactive
- Information needs to go to the right people, e.g. Technical workshop for UNFCCC negotiators
- Be careful with the press as it is easy to be misquoted
- Pictures are what gets retained – remembered forever
- How analogous are natural systems – what is relevant to CCS

Session 8: Conclusions and Decision of the Aims and Objectives

The meeting concluded with a request from participants to become a full IEAGHG Network, called the "Environmental Research into CO_2 Storage Network". The Network should have the aim of a "A network to build and advance knowledge for environmental research of geological CO_2 storage", with the objectives being to "Stimulate and nurture international collaboration and knowledge sharing to improve understanding for environmental research of CO_2 storage, and to act as a source of technical information".

Key points from the meeting included:

- EIA regulations are not a barrier to projects
- There are now a good number of controlled release projects, providing useful knowledge
- CO_2 release behaviour in the near-subsurface can be unpredictable
- Marine work – very good progress on monitoring and on baselines
- Electro-magnetic remote monitoring of brine appears very useful for 'early' leakage detection
- Environmental Assessments will be substantially different for offshore to onshore, we don't have offshore examples yet
- If leakage does occurs –it will be 'patchy' and in small localised areas, not over a large area
- The Process-based technique is an example of monitoring moving in right direction – able to provide important information where there are no baselines. This technique uses ratios of gases present to determine source of CO_2
- Still need baselines for leakage detection and impact assessment
- Indicator species are being identified, especially benthic and terrestrial plants
- Seasonality and timing can effect leakage impact
- Broader acceptance of near-surface monitoring then in 2008

Research needs or gaps identified included:

- Need for deep subsurface release experiment
- Understanding overburden processes
- More on brine intrusion – industrial analogues
- Bringing in new research communities
- Challenging to find small leakage spots
- Need more wide area monitoring techniques and proven: need for high spatial resolution
- Need to understand how analogues compare to CCS sites

The recommendations from attendees included:

- Keep up the good work! – gaps identified in the past are being addressed
- Consistency in terminologyData sharing in between projects, and engaging with other research communities
- Further meetings could be focussed on:
  - Transport mechanisms through the overburden and surface expression and natural attenuation
  - Remediation – possibly in conjunction with the risk assessment network
  - Biological impacts
  - Groundwater impacts
  - Comparison of environments: systems assessment

Evaluating technology options to mitigate greenhouse gas emissions

IEA Greenhouse Gas R&D Programme

Orchard Business Centre, Stoke Orchard,
Cheltenham, Glos. GL52 7RZ, UK

Tel: +44 1242 680753
Fax: +44 1242 680758

mail@ieaghg.org
www.ieaghg.org