6th IEAGHG MONITORING NETWORK MEETING

Report: 2010/14

May 2010

INTERNATIONAL ENERGY AGENCY

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DISCLAIMER AND ACKNOWLEDGEMENTS

IEAGHG supports and operates a number of international research networks. This report presents the results of a workshop held by one of these international research networks. The report was prepared by IEAGHG as a record of the events of that workshop.

The 6th IEAGHG Monitoring Network Meeting was organised by IEAGHG in co-operation with The Gulf Coast Carbon Center. The organisers acknowledge the financial support provided by The Gulf Coast Carbon Center for this meeting and the hospitality provided by the hosts at The convention Center, Natchez, Mississippi

A steering committee has been formed to guide the direction of this network. The steering committee members for this network are:

Tim, Dixon, IEAGHG (Chairman)
Sue Hovorka, University of Texas
Kevin Dodds, BP
Hubert Fabriol, BRGM
Don White, NRCan
Charles Jenkins, CO2CRC
Andy Chadwick, BGS
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Executive Summary

This is the report for the 6th meeting of the IEAGHG Monitoring Network, held in Natchez, Mississippi from 6th - 8th May 2010.

There are currently several carbon dioxide capture and storage (CCS) projects around the world with extensive monitoring programs. A review and new results for many of these were presented. As this meeting was held in the USA, a session was given to the work being carried out by the US Regional Partnerships (USRPs). This includes projects at various phases, including several at validation phase, planning phase and ongoing development phase. The latter includes the Cranfield site in Mississippi.

A session was given to how projects are able to develop within an evolving political and regulatory environment. In many regions, there are no CCS related regulations and so these will need to be developed alongside projects, making contact and discussion between the regulators, decision makers and those leading the projects imperative. The politics of regulations is evolving, and for each new site, it may be useful to see what is being mandated, in terms of monitoring, by regulations at other sites. The new US EPA reporting rule is in the proposal phase and would require mandatory reporting for geological storage projects, with elective requirements for EOR and R&D projects. Public perception is known to have a great effect on the evolution of a project, and needs to be considered at each site. It is also important to consider the practicalities of moving from small scale to large scale projects, as more commercial scale projects are developed. For example, it is unlikely to be practical to stop injection in order to carry out monitoring on a commercial project.

Following this session there was a panel discussion on the importance of uncertainty. A major issue is that there is such a broad spectrum of what people describe as uncertainty and it may be necessary to define how we are using the term and address that. Now that there are more monitoring results, there can be more comparison with predictive models. If the monitoring results diverge from the model, it is important to know what the reasons for this could be, but more importantly, it is necessary to know if it is a significant divergence. In other words, will it affect the storage security? An idea put forward, was that the injected CO_2 'illuminates the subsurface' as it increases the area of contact and provides new data on the subsurface. This leads to further knowledge, but also further uncertainty, so that the risk profile may not plateau after a certain point, but continue to increase until injection is ceased.

A session was given to post-injection monitoring. If monitoring is required for the long-term and required over many years, then a strategy to deal with that will be needed. If it is over a long time, then it will need to be cheap and effective. It is also necessary to be realistic about what can be seen and what can go wrong, and therefore what needs to be measured.

The final session was on emerging and innovative monitoring techniques, where talk topics included InSAR, ecological monitoring, ERT and geochemical monitoring. It was found to be useful to compare the same technologies used at different sites, as this helps to show some of their limitations as well as their benefits. One idea discussed was a master class or invited

reviews for emerging technologies, which have already have been tested and are very likely to be used in large scale projects.

Key outcomes from the meeting are that there has been a big shift in the breadth and quality of work being done. There are more details, more knowledge and more projects from which to learn. However, there needs to be more data integration of geochemical, geophysical and modelling work, as well as more research on permanent installations and developing techniques such as microseismic monitoring.

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Monitoring Network Meeting Report

Session 1: Reports from Previous Meetings

1.1 Welcome Address – Sue Hovorka, University of Texas and Tim Dixon, IEAGHG

Sue and Tim welcomed everyone on behalf of the Gulf Coast Carbon Center and IEAGHG. The aims of the network were reiterated:

- **Overall aim:** To facilitate the exchange of ideas and experiences between experts in the monitoring of CO_2 storage, and to promote the improved design and implementation of monitoring programmes.

- **Specific aims and objectives**:
    - Assess new technologies and techniques
    - Determine the limitations, accuracy and applicability of techniques
    - Disseminate information from research and pilot storage projects
    - Develop extensive monitoring guidelines
    - Engage with relevant regulatory bodies

Tim also talked about the monitoring tool on the IEAGHG website, which was one of the early outcomes of the network.

1.2 Summary from the last Monitoring Network Meeting – Kevin Dodds, BP

The previous monitoring network meeting was held in Tokyo. The meeting was a good opportunity for discussion as there had been recent activity at demonstration projects. As the meeting was set in Tokyo, a large focus was on Japanese projects and a session given to discussing monitoring projects there. Key learnings were given from each of the sessions on reports from other initiatives; reports from projects; update on Japanese CCS progress; what regulators want; what monitoring can and cannot do; and emerging and innovative technologies.

The conclusions agreed at the last workshop were:

- Strong recommendation to use pilot-scale projects to focus and learn about post-injection CO_2 behaviour, as at Nagaoka, Japan

- Benefits of multi-scale integration of multiple datasets, e.g. combining seismic and electrical resistivity

- Regulations are based on qualitative rather than quantitative performance and require expert opinion to make decisions. This may become difficult due to a limited number of such independent experts in the CCS field at this early developmental stage.

- Atmospheric and surface monitoring can provide assurance to the public.

- The transmissivity of faults to CO_2 may be different to other molecules such as methane due to the ability of CO_2 to react with some materials in the presence of water. Additionally, more work is required to understand fault and overburden leakage pathways, i.e. Uncertainty over defining what is an acceptable match of predictions and the reality of CO_2 behaviour for the closure and liability transfer of storage sites. The first projects will set the precedent.

- Pressure front monitoring will be required

- Monitoring capabilities are good enough to get on with projects

1.3 SEG CO_2 Update – Don White, NRCan

Don gave a summary of the SEG CO_2 meeting in Banff in October 2009, which largely focussed on the current and future role of geophysicists in CO_2 sequestration. He gave a brief overview of the program with the selected highlights being:

- Observed seismic responses to CO_2 are often stronger than predicted theoretically

- Nature of CO_2 saturation (patchy/ homogeneous) affects seismic response

- Geochemical effects of CO_2 on the rock frame

- More lab studies are needed to understand the behaviour of CO_2 in rocks

Questions and Comments :

Poro-elastic monitoring has the biggest AVO effect, is this greater than 2? 1D modelling was carried out, though in the field there was a bigger response than expected.

Looking at scattered energy in the seismic dataset and remnant scattered energy demultiple techniques, how does this relate to the repeated image in Sleipner? Intrabed multiples are difficult to remove. The seabed multiple has been left in, as removing it, would also remove other data, but it is clear what it is. There is also much scattering, but this doesn't form any new horizons so it is very unlikely to be multiples in the interpretation.

The amount of CO_2 can be predicted using forward modelling in reservoir simulation, matching the image with seismic data, in order to validate results.

Is there evidence of multilayers at Sleipner? If you look at velocity pushdown you need 10's of metres of CO_2 to produce that, irrespective if it's a single layer or multilayers.

Regarding geomechanical issues, how does it affect timelapse? Modelling InSAR data results and transmission of stress into the overburden, shows a stress variation, which could be due to saturation effects.

1.4 2010 Modelling Network Meeting Summary – Millie Basava-Reddi, IEAGHG

The last modelling network meeting was held in Utah in February. There were 4 sessions on modelling methodology and recent advances; integrated roles and objectives; real storage projects: case studies and; best practice and modelling protocols. The agenda was designed to provide ample time for discussions between participants, with both breakout and plenary discussions.

Disscussion:

The discussion focussed largely on the possible integration of networks and ideas for other workshops.

The networks usually relate to each other by having a summary of one network in another network meeting and there is an overlap of attendees at each meeting. There is also the possibility of having two network meetings together, or with some overlapping days. There is also the joint network meeting, the last one of which was held in 2008 and the next one due to take place in 2011.

It was suggested that there could be more opportunity for overlap of the meetings, for example 2 days on the well integrity network followed by 2 days of the monitoring meeting. The floor was invited to suggest network combinations that they would like to see.

Most of the suggestions were for monitoring and risk assessment and monitoring and well integrity. It was noted that sometimes you don't get interpretation of results as well as theory as there may not be both sets of people at each meeting.

It was also pointed out that at any joint network meeting, the talks will not be on everyone's speciality. It was also said that we need integrated talks and that monitoring and modelling are intimately linked and that there is no point getting monitoring data if it cannot be put into a model.

It was noted that this was done in the modelling network, but the problem may be that the modellers assume that the monitoring data is all correct and that any problem is with the model. It might, therefore be useful to have monitoring experts to talk about uncertainties in the data.

Delegates were invited to contribute to a list of possible workshops that could take place next year, which could then be discussed later in the meeting.

Session 2: Results from International Monitoring Projects

2.1 Ketzin Project – Conny Schmidt-Hattenberger, GFZ

The Ketzin site, situated 25km west of Berlin and a former gas storage site, has been well explored and is made up of extremely heterogeneous formations. There are a variety of geochemical and geophysical monitoring methods being conducted at Ketzin and the talk concentrated on the geophysical methods that were able to describe the temporal and spatial behaviour of the CO_2 plume – seismic and resistivity. The seismic methods include 2D and 3D surface surveys as well as VSP and MSP surveys. Both methods show similar results and there is a good match between the modelling and monitoring results, though further refinement of the model is needed. Subjects still to be assessed are the quantitative assessment of competitive use of underground (i.e. geothermal activities) and up-scaling to commercial projects, which will be 2-3 times the size.

Questions and Comments

Will Ketzin have a data review and how will we hear when more data is available? There is a planned extended phase by national funding. We need to match results as the CO2SINK project is over. We have a review meeting this year in Vienna.

At Ketzin, is there any insight into why there was late breakthrough at the observation wells? There is very strong heterogeneity as the storage formation is a fluvial system. The first breakthrough matched the models well, but we are looking at possible permeability barriers that could have affected the flowpath and caused the CO_2 to take an alternate route.

2.2 An update of the Lacq-Rousse project – Hubert Fabriol, BRGM

The Lacq-Rousse project site is a complete CCS chain with a 30MW oxycombustion steam boiler connected to an old depleted gas field by an existing pipeline of 29 km long. The project started in 2006 with injection commencing in January 2010 at a rate of 60 kt/yr with a 2 year injection plan and permission for 3 extra years of observation. Throughout the process there was consultation and dialogue with the local populace and finally close to overall public acceptance. The injection stream has a fairly high proportion of oxygen, 92% CO_2 4% O_2, and is injected at 4500 m depth into the Upper Jurassic dolomitic reservoir, which is overlain with a thick sealing overburden. The main risks identified are geomechanical fracturing or reactivation of faults. There is possible fracturing at the top of the overburden and the pressure limit is set at 70 bar. There is also a shallow potable aquifer above the storage formation and the monitoring plan includes environmental monitoring of underground and surface waters. As there is a very thick overburden, the site is considered to be very unlikely to leak, though soil-gas measurements are still taken to comply with the regulations. The passive seismic array designed to detect induced seismicity is composed of seven vertical arrays (4 geophones each) in seven shallow wells (200 m deep) distributed around the injector (2 km distance) and one deep array within the injector near the top of the reservoir plus one surface seismograph. Results from this are not yet public.

Questions and Comments

At Lacq-Rousse, it is an oxyfuel capture plant, what is the impact of higher quantities of O_2? Is it strongly reducing? A research project is being started at the University of Pau to study the impacts of high O_2 content in the injected stream. Unsure as Total are yet to release that information. Since they started the operation, it is necessary to relate information as they need to be careful regarding public acceptance.

2.3 The Energy Technologies Institute – Activities in CO_2 Storage – Kevin Dodds, BP

The ETI involves several major companies, academic institutions and industrial partners in the UK and covers a broad range of low carbon energy solutions, one of which is CCS. A current project is the MMV project, contracted out to BGS, which includes analysis of the

UK's needs and reviews the current technologies and knowledge gaps and to develop a robust monitoring strategy.

2.3 CCP3-SMV – Kevin Dodds, BP

The aim of this project is to identify gaps that are not being worked on, and then publish them as a peer reviewed paper which will be made public. Kevin talked about the monitoring and verification section of this project. Objectives are to access existing demonstration monitoring experience and the response of emerging technology; to identify performance and cost effective criteria and incorporate all this into a defensible approach to define fit for purpose M&V programs. An important aspect of this is to be able to set up a permanent monitoring system, without having to drill several boreholes. Existing projects can be used to determine which sensitivities need to be measured and how this can be done in a cost effective way. They are also working with the Bureau of Economic Geology's EPA and CCP project to avoid duplication of effort.

2.4 Expert-Based Development of a Site-Specific Standard in CO_2 Sequestration Monitoring Technology – Susan Hovorka, University of Texas

The aim of this project is develop guidance for selection of monitoring approaches for a CO_2 sequestration site that is site specific and based on the quantification of monitoring tool sensitivity. This would be carried out by means of an expert panel providing information to those who need it. The panel is an open group to try and gain as much participation as possible, in order to be able to get real life monitoring experience. Ideally, both the favourable and the unfavourable results and methods, the latter of which is sometimes difficult to get information on as is not often published.

Questions and Comments

How will you get the information to decision makers? By using models to develop test cases. We will make workbooks, which will match available techniques to each site.

The resultant document has been described as general, but to be applied site specific. Who is the target audience? If we are going to inject at a particular site, then we need to determine which tools would work and what is measurable as well as what is required. It can also be a guidance for regulators on 'what to use for where'.

Comment: It might be useful to have an end user review group in order to get that perspective.

2.5 Gorgon CO_2 injection Project Monitoring and Verification Plans – Adi Widyantoro, Chevron

The natural gas produced at the Gorgon site contains 14% CO_2, which is to be extracted and re-injected via 9 injection wells separated by 7 km. There are also 4 brine production wells for pressure relief. One of the major challenges is to get a large amount of monitoring data as well as value for money. There is a comprehensive current MMV program, including 4D surface seismic, for which the baseline survey was taken in 2009 and soil gas measurements taken at Barrow Island. As more data is collected the MMV program can be updated. The risk assessment suggests that he risk is greater at the start of the project and during injection and lower during post-injection and it has been agreed with the regulators that monitoring should take place for 15 years after the end of injection. The project is currently in 'phase 4', which is the project delivery and operations phase. Drilling is planned to start in 2012.

Questions and Comments

How much of the Gorgon program is driven by the requirements of the government? There are currently no regulations, so we evaluate all methods and demonstrate these to the government. There is no regulatory influence at this stage.

What drove the decision to have pressure release wells and how can you evaluate how they perform? The team recognises that we cannot fracture the reservoir and the modelling suggested that this would happen; therefore it was necessary to manage the pressure, by producing a pressure sink. The challenge is in the location of the pressure management system.

The pressure management system could cause plume asymmetry and therefore the risk of early breakthrough. Part of the key to management of pressure is to make sure this doesn't happen. We have carried out several models, over the duration of 100 years, and found that the plume asymmetry was not affected.

Are there any concerns regarding other pressure effects by extracting water and re-injecting it at a shallower depth? There have been studies carried out on compatibility issues, and the aquifer into which the fluid will be injected has already been depleted.

Can you comment on the quality of the baseline seismic data? There are 3 source types how repeatable is it? The data is processed by 4 different companies, as it is complicated and we want good results. Regarding repeatability, we have set up holes levelled with steel caps, to make sure that each survey uses the same points.

How much geomechanical characterisation has been done on this site? We are working with another company, who are carrying out a full stress tensile model and will continue working on this. There are also regional studies.

There has been extensive monitoring, how much of this is due to regulations, what is the minimum? There is no minimum requirement as there are no official regulations yet.

Gorgon appears to be a very thorough and expensive program. What is the cost per tonne? That is not currently publicly available.

Discussion

Regarding reservoir heterogeneity, what could have been done to better characterise the site in order to predict the late breakthrough? We have the well log data and have built several profiles. There is not just the modelling data, but we can use analogues.

Heterogeneity is important and you need a full range of scenarios, but it may not be possible to build a suitable model as it is so complex, especially with only a few wellbores. It is important to use natural analogues to put into the model. This is something for future monitoring and modelling groups to look at.

Monitoring and building the model needs to be carried out at the same time. There is much more information after monitoring to be able to put this back into the original model.

What is important when looking at uncertainty is to determine how relevant it is. Does it affect the overall performance of the reservoir? Is the ultimate storage efficiency different? In the case of Ketzin, it did not affect the operation of the test site and the CO_2 remained securely within the storage formation, so in that way it was not significant. The further work is to understand the reason, because we want to know the reason.

Was the model calibrated to the rock and hydrologic test? Yes, this has been done.

So this shows that it is a 2 phase relative permeability issue? The model was calibrated to a single phase only.

It may be both a heterogeneity and relative permeability issue. There was a similar situation at another site with high heterogeneity and it was significant to storage potential. You need to have site specific injection tests. It's a complicated issue.

Have geoelectric measurements been taken along with seismic?

At Ketzin there has been both cross-hole and ERT. It is important to evaluate them together and match with the seismic. This will be presented fully on the following day.

At Gorgon, the earlier work was promising, but there is a problem with operability as we don't have 1km spaced wells, they are between 1.5km and 7km apart which is usually too great for effective results, however, we are not yet dropping the method.

At Ketzin, the distances are not so far (30m). It is necessary to show the regulator what this means.

Regarding capacity, a critical part of the resistivity model is to predict where the plume is going to be, as it is necessary to plan what to do next for operations. In EOR, we match oil/water production then match CO_2, each bit of information further refines the model

In Lacq-Rousse, why are the permanent geophones not working? There was a problem with the fibre optic data transmission downhole. Signals were received initially at the surface, but after returning in few months to take readings there was nothing. It was seen that temperature and pressure parameters are more important, which are retrievable and kept channels open for that rather than seismic. A workover operation is planned to start end of November 2010 to fix the situation.

How much of a problem is noise for the geophones in the injector? TOTAL is still carrying out preliminary studies. As soon as the downhole sensors will work properly, this question could be assessed.

It is still useful to see which methods don't always work, so that we can look at how to select methods. This could contribute to Sue's project.

Session 3: Results from US and Canadian Monitoring Projects

3.1 Overview of US Regional Partnership Projects – John Beyer, LBNL

The US Regional Partnerships were set up in 2003 to work on characterisation, validation and development phases. The aim is for at least 99% storage permanence, but a large problem is how to measure this. It is possible to monitor for leakage, but one of the major issues is where to monitor. Another is to have a have a value for CO_2; otherwise there is no economic reason for storage. The partnerships are at different phases and can be summed up below:

SWP (Southwest Regional Partnership on Carbon Sequestration) – currently wrapping up phase II projects, with the reports available summer 2010.
MRCSP (Midwest Regional Carbon Sequestration Partnership) - Is now composed of 9 states, all 3 demo projects have completed and there are currently 3 phase II projects.
PCOR (The Plains CO_2 Reduction Partnership) – There are 2 Phase II projects. An EOR project on the Wyoming-Montana border injecting 0.5 – 1 million t/yr.
SECARB – (Southeast Regional Carbon Sequestration Partnership) They have completed a pilot test at Mt Daniels into the Tuscaloosa sandstone. There are 2 coal projects, an anthropogenic test into a saline formation over an oil formation in Alabama and the Cranfield Phase III project.
Big Sky – Currently in negotiation to get CO_2 for their phase III project.
MGSC (Midwest geological Sequestration Partnership) – Phase II and III projects are combined, with the CO_2 being supplied from an ethanol plant. There are 2 monitoring wells with well logs and 3D surface seismic and 3D VSP surveys. Injection is planned to start next year.
WestCarb (West Coast Regional Carbon Sequestration Partnership) – There are phase II projects in Arizona, which is being complicated by a site access issue, as the test site is on Navahoe and Hopi Nation land. The same formation was tested at another location, but with near zero permeability. They are currently in negotiations with the Hopi Nation, who have a large part of their economy in coal. There is another test site in California, in a syncline between 2 depleted gas fields, where the primary trapping mechanism will be dissolution.

More information on the partnerships can be found at: http://www.netl.doe.gov/technologies/carbon_seq/partnerships/partnerships.html

3.2 Update on Results of SECARB Test of Monitoring Large Volume Injection at Cranfield – Sue Hovorka, University of Texas

Injection takes place at 3000 m depth. This area was originally a producing well, but when the gas cap was removed, the oil was shut in in 1965, after which there was no further exploration until Denbury took over the site for CO_2 flooding.

The phase III test took advantage of this being an easy place to start, as CO_2 was already being injected, permitting was less of a problem than at other sites. The CO_2 is produced from a natural source, so supply is also not an issue.

Denbury shared all the site characterisation data, so injection and monitoring was able to start in 2008. One million tonnes of CO_2 injection was achieved by 20th December 2009, which was earlier than expected.

The storage formation consists of relatively young, uncompacted fluvial sediments and the caprock is mostly marine black shales. The monitoring data shows the fluvial system is highly heterogeneous. There are a lot of wells on this site, from previous production, which can now be used for monitoring, but could also form possible leakage pathways.

The modelled and observed pressure measurements generally match well. Breakthrough times were faster than expected and appear to show CO_2 flow upwards from the 1st monitoring well to the 2nd, which may be due to the heterogeneity. The ERT data shows a secondary plume, though this is thought to be due to the plume migration being out of the measurement plane, although this is still to be fully interpreted.

3.3 Overview of PCOR Partnership's Phase II MVA Activities – Steve Smith, EERC

The PCOR partnership covers an area of more than 1.4 million square miles, over which there has been much oil and gas production and is supported by over 90 industrial partners. There are 4 validation tests. The Zama field and lignite storage in NW Dakota were talked about briefly, though the talk focussed on the Williston basin site at NW McGregor.

The goal of the project at the Williston basin is to evaluate storage with EOR in a deep carbonate reservoir and to determine the effectiveness of the Huff n Puff technique as well as to test RST and VSP monitoring techniques. 440 tonnes of CO_2 were injected over 36 hours, followed by a 2 week shut in and soak period, then further production. The rate of oil production increased by 3 times. This is a thick reservoir with 2 seal layers. Using the RST tool, it is possible to measure the saturation of the injected gas and oil. 5 days after injection the CO_2 was observed between the perforations and the seal and after 115 days it was mostly located at the base of the seal. VSP was used as the casing was in good condition and the tubing would not need to be pulled out of the well, however it did not provide good results. The reason for this is thought to be due the overlying glacial till package causing the signal to attenuate. To compensate for this the tubing was pulled up 100ft, after which the VSP results correlated well with the model. It is possible that the CO_2 plume could be seen using VSP.

Questions and Comments

Was a microseismic monitoring program carried out? Yes, it was successful program, but not sure if it could be combined with cross-well seismic.

3.4 Subsurface Monitoring Planning in DOE's WESTCARB Partnership and National Risk Assessment Partnership (NRAP) – Tom Daley, LBNL

This talk focussed on 2 of WestCarb's test sites in Arizona and California. The Arizona test site includes a single monitoring well and is not yet completed. There is an extensive MMV programme. The California test site is currently in the planning stage and is in a historically seismic area. The plan is to inject 6000 tonnes into a 3.3 km deep saline aquifer in a syncline, with residual trapping the dominant trapping mechanism. The monitoring plan includes monitoring for induced seismicity and the protocol for EGS (enhanced geothermal systems) has been adapted for storage.

NRAP is made up of 5 national laboratories and was formed to provide scientific underpinning for risk assessment with respect to long term CO_2 storage. The aim is to form a quantitative methodology for predicting a site's long term performance. There are focus groups on monitoring, wellbore integrity, groundwater impacts and systems modelling with each one producing a white paper. The monitoring group research priorities are to improve temporal and spatial resolution of monitoring, detection of leakage, quantification of uncertainty, induced seismicity, to improve integration of measurement and interpretation tools and to address scaling issues in monitoring data. The program is currently in the middle of its first year and the focus is on the high level priorities, which include identifying risks and uncertainties.

Questions and Comments

Regarding the earthquakes, where is the injection site in relation to the fault zones? Initial modelling showed pressure perturbation at the faults. At the depth of injection the fault is 5km away on the other side of the axis of the syncline. The plume undergoing residual trapping will migrate away from the fault, showing safe comparable storage.

Comment: At the Otway project, it is a fault bounded reservoir, but it is a depleted gas field, so there were less pressure issues.

3.5 Microseismic Monitoring of CO_2 EOR in the Aneth Oil Field – Jim Rutledge, LANL

CO_2-EOR has been taking place at the Aneth field since the 80's and the aim of this monitoring program is to monitor induced seismicity, which is expected due to the increased pressure and volume accompanying injection. It was stressed that microseismic monitoring should be an important part of an MVA programme. It can be used to map pressure fronts, infer preferred fracture flow direction and map containment of CO_2 in the target reservoir. It can give a sense of deformation and stress field and monitor and map fault activation and growth.

The microseismic locations revealed NW-SE striking structures near the margins of the reservoir and the main structure is resolved beneath the reservoir. It was also found that microseismic activity does not correlate with current injection activity in the reservoir, nor does it appear to correlate with deeper salt-water disposal. A recorded natural earthquake appears to have affected production and reservoir seismicity, possibly by the stress transfer driving an increase in pore pressure.

Questions and Comments

Has a temporal analysis been carried out? We have just started looking at this. Almost all moving fluid is vertically upwards.

How has that affected production? So far this is just the observations. We are working with partners to look at the production scale stress changes.

What were the location errors? It was mostly fairly good data, but there is a 30-40 m error, though further analysis is still needed. The depth of the furthest cluster is very poorly constrained.

There is no changing volume of fluid in the reservoir, what's the best explanation for the ongoing microseismicity? We are not sure, though the volume changes gradually over the years of production.

Would this have happened anyway? It's possible, but the fact that it all occurs on the edge of the reservoir might be too coincidental. One of the difficulties with ongoing EOR is that it has been going on for many years and we don't know what was going on before; we don't have a baseline.

3.6 Monitoring Activities under MRCSP Phase II field demonstrations – Neeraj Gupta, Battelle

The MCRSP consists of 5 states and a complex and diverse geology, where there are 3 deep, mature basins as well as the coastal plains. The projects discussed were 3 completed phase II projects in the Michigan basin, the Appalachian basin and the Cincinnati arch. At the Cincinnati arch site, injection was into the Mt Simon sandstone and was located below a potable aquifer, so the monitoring program included a 3 year groundwater monitoring survey. The vertical and lateral extent of the plume was able to be mapped by using VSP, while the vertical distribution of the CO_2 adjacent to the well was determined from geophysical well logs.

At the Burger power plant site (Appalachian basin site), a seismic survey was conducted and the injection well drilled. However the injection rate of 20 t/day was not able to be maintained and flow was reduced several times during injection testing, in order to maintain the correct pressure.

The Michigan basin site had 10 kt of CO_2 injected into the bass dolomites in 2008 with an extensive MMV program, the results of this enabled the conceptual model to be refined, especially as there is high heterogeneity in the formation. An extended injection program of 15 kt followed this, with a smaller MMV suite, which showed the CO_2 plume remaining stable below the caprock. This is seen as a low velocity zone on the tomographic image and is corroborated by the RST data.

A phase III project is also planned for the near future and several sites are under evaluation for this.

3.7 New Results from Seismic Monitoring at the Weyburn CO_2 Storage Site – Don White, NRCan

As of November 2009, 15 Mt have been stored at the Weyburn site by injection into at least 19 wells with variable injection rates. The storage formation is a fractured limestone and the caprock is anhydrite. This talk focussed on looking at caprock integrity through seismic AVOA analysis and monitoring the overburden by looking at out-of-zone seismic anomalies (OOZ).

Conclusions of the study were:

- Time-lapse amplitude & travel time anomalies are observed immediately above the reservoir caprock, at the base of the storage complex.
- They may be associated with OOZ CO_2 and/or injection induced stress changes in the overburden.
- Isolated anisotropic regions have also been identified at the caprock horizon that may be associated with vertical fracturing.
- Further work (modelling) is needed to assess the geological cause of these anomalies.
- OOZ CO_2 does not necessarily imply upward migration of CO_2; it may be the direct result of EOR injection procedures.

Questions and Comments

Is this going to be backed up with hydrogeologic or fluid sampling? Not yet, though this is a valid question as you need backup evidence.

3.6 Canadian Projects - Don Lawton, University of Calgary

The University of Calgary Rothney Astrophysical Observatory is used as the CCS test and training centre and is situated just outside Calgary at the foot of the Rockies at a depth of around 800m. The storage formation is a lower Tertiary sandstone and is known to be fractured. The controlled leakage pathway comes to the surface 1 km west of the injection site. There is 1 monitoring well and injection is planned to start in early 2011.

The goal of CCS projects in Alberta is to have 4 projects injecting 1 Mt/year by 2015. These are the Shell Quest/ Pioneer, Enhance project, Harp and Wasp projects and are all clustered around the industrial area near Edmonton. The Shell Quest/ Pioneer project involves capturing CO_2 from a power plant and injecting it into a deep carbonate saline aquifer. The Enhance project is an EOR project in the oil-sands. The HARP project is a federally funded project and is situated NE of Edmonton. Phase I of the project involves soil and groundwater sampling and has been completed and phase II has started and involves baseline soil-gas survey. Drilling has not commenced, though the injection well is to be 80 miles from the EOR site.

Discussion and further questions to the speakers

What is the reason for the observation wells being down-dip at Cranfield? The practical reason was that DOE was promised a non-EOR project and there was a limit on how close we were to the lease boundary. The research reason was that at Frio the observation well was up-dip, but there were also gravity forces during injection. We wanted to know how much the structure affected the flow direction and the results show that the CO_2 did flow down dip as predicted in the models. The gradient is only 1%.

At Weyburn, there is no velocity push down, which suggests that the CO_2 layer must be pretty thin. What is the geology and would it be in the caprock itself? The caprock is an evaporite and directly above this is the Ratcliffe formation, where there are permeable zones within the impermeable rock, then the Watton regional seal. Therefore it is difficult to see where it is, but it is above the caprock. It is correct though, that it could only be a small amount and it would be a very thin layer.

Could it be in the fractures? It could be. The reservoir is well characterised, but the caprock is not, so we cannot be completely sure of the geology.

Is it near any wells and can they be accessed to monitor or test well integrity? There are plenty of wells, but at the moment we do not have access to them, so really cannot say for certain what is there yet.

The anomaly is only in the caprock, not in the reservoir. Is it possible to simulate small amounts of CO_2 in an evaporite to model its effect and see if it matches? This is possible, but has not been done yet.

How repeatable is this and what are the number of sources? The source locations are offset less than 5 m. Some source positions cannot always be occupied as there is water in low lying areas.

Has there been analysis on gathers as well as on the migrated data? This work is currently being done. Preliminary results indicate that the prestacked data is noisy.

It looks like there are 50 new wells in that area, could this be a possible cause? Yes it could be, there are so many wells, but the anomaly is over several wells, so I think that this is unlikely, even though there are injector well integrity issues. It is possible that one injector was positioned above the reservoir for a while.

There has been an MIT paper on AVOA coder analysis, which shows that rays in the fast direction do not get scattered as much as rays in the slow direction, which may help in this analysis.

In the PCOR project, did you consider CO_2 storage in lignite and have you considered that methane is a much stronger greenhouse gas than CO_2? Methane production is one of the primary goals of the project. Gas production went online, but we got nothing back. We tried all different stimulation techniques and acidizing and took samples for methane content, but it was not there. We are not currently working on lignites, but are aware of the significant resource in that area.

At the Aneth field has there been any 3-D geomechanical work, would it make sense of the data? We are trying to make a geomechanical model to see if the volume change could have caused stress changes. There is a rough correlation with salt water injection, but it doesn't correlate spatially, so there may be a geomechanical correlation.

At the Michigan basin project have you been able to analyse the microseismic data? Yes, it shows that only one of the microseismic events is related to injections. Other events seem to be only temporally related to injection. There is also a possible leakage pathway along a wellbore, though this is not clear.

In the Aneth field, when you get the velocity anomaly with CO_2, the amplitude anomalies are even greater. Are you using crosshole tomography as an input to crosshole imaging? They take the tomographic velocity image and use it for timelapse seismic imaging. I agree that it would be good thing to do.

Session 4: Monitoring in an evolving Regulatory and Political Environment

4.1 Overview of US EPA's Mandatory Reporting of Greenhouse Gases Rule: Injection and Geologic Sequestration of Carbon Dioxide – Barbora Master, EPA

The role of the EPA is to develop regulatory frameworks and this new proposed rule is a reporting mechanism for facilities that inject CO_2. The rule was proposed 12th April 2010, and is open for a 60 day comment period until 11th June. EPA aims to finalize the rule in time for reporting to begin January 1, 2011. It would amend the greenhouse gas reporting program, under the Clean Air Act. It is intended to be complementary to and to build on UIC Class VI wells requirements.

As proposed, information to be reported would be the amount of CO_2 received onsite from offsite sources, the amount of CO_2 injected into the subsurface and the source of the CO_2 if known. Sites involved in geological sequestration would be required to develop an EPA approved MRV plan and report the amount of CO_2 stored, calculated by CO_2 injected – CO_2 emitted.

These data will enable EPA to track CO_2 flow across the CCS system, but EPA does not intend to prescribe specific monitoring techniques. As proposed, sites involved in EOR or R&D projects would not be required to report, but could choose to opt in.

Questions and Comments

You will be compiling an electronic database, but this can open uncertainty, as CO_2 is sometimes transferred and sometimes emitted, how will you deal with purchased CO_2? The aim is not to track by molecule, but to get data on how much is permanently stored, then we can see how much new CO_2 is being purchased and can understand the sources.

What is permanence defined as and how does this affect credits? We are not specifying permanence and this is not a credit system.

Are there any requirements regarding post-injection monitoring? Yes, we proposed requirements that are similar to the requirements for Class VI wells. Until the plume appears stabilised, it would be necessary to keep reporting, after that reporting would no longer be necessary.

Does EPA have to approve an MRV plan and how complex a plan is needed? There is a proposed general outline, but it still needs to be fleshed out.

Including a risk assessment seems inconsistent as the UIC asks for zero leakage, that everything must be contained within the reservoir, though it should be based on risk not zero leakage. We worked closely with the office of water which aims to protect USDWs. We are building on top of their UIC Class VI proposed rulemaking.

4.2 Aquistore Project – Kyle Worth, PTRC

The Aquistore project is a collaborative project involving industry and governments. It commenced January 2009 and will run until 2013. CO_2 is to be captured from a refinery and will be transported through a pipeline and injected into a saline aquifer at 2200 m depth.

Saskatchewan aims to reduce GHG emissions by 20%, though there are still regulation uncertainties, which are currently being negotiated. The regulations are planned to be defined by spring 2010.

The storage area will be in the NW Williston basin in Saskatchewan, in an area previously explored for oil and gas as well as potash, and so the area is geologically well understood. Most of the surrounding area is used for potash mining; the storage area was considered unlikely to be used for this, so was made available. Plume migration modelling has been carried out and a comprehensive monitoring program is planned. There will be 1 injection well and 1 monitoring well containing permanent downhole geophones to accompany the pressure, temperature and fluid sampling. The injection well is planned to be drilled in November 2010.

There were no questions following this talk.

4.3 CO_2 Surveillance during CO_2 EOR and CCS Policy Progress in the US – Steve Melzer, Melzer Consulting

One of the major expenses of CO_2-EOR is purchasing CO_2, the cost of which is around \$20/t, making surveillance of CO_2 necessary to make sure that it is cost effective. It is metered at custody transfer points and at collection/redistribution points and efficiently recaptured at producing wells. At custody transfer points, accurate metering is needed as it involves the sale of CO_2; mass, density and sometimes composition is measured. The types of meters used are differential pressure, displacement, velocity and mass. The most commonly used are differential pressure meters, which are generally either orifice or wedge meters.

The talk ended with a summary about how EOR and CO_2 storage can be used together:

- Retention is proven *(and very high – 95-99% CO_2 stored)*
- Is 'commercial' Storage
- Adds domestic oil production
- Avoids 'waste' perceptions with public
- Provides a bridge to deep saline formations
- Regulatory infrastructure in place

Questions and Comments

What is the accuracy of the amount of CO_2 metered? There is much uncertainty, mainly due to impurities in the stream, such as H_2S and CH_4, which complicates the issue.

Is there also uncertainty in the amount of CO_2? 0.5 % accuracy in the meters is good. It is affected by several other factors, a major one being the seasonal delivery from domes, as the volume changes at different temperatures.

4.4 Overview of the PCOR Partnership's Phase III Field Demonstration: Spectra Energy's Fort Nelson CCS Feasibility Project – Steve Smith, EERC

The PCOR partnership is involved in 2 phase III projects, an EOR project at Bell Creek and the Fort Nelson feasibility project, which is the focus of this talk. British Columbia is addressing the issue of CO_2 injection for non-EOR purposes, but there are currently no regulations regarding this. It is anticipated that the existing legislation will be able to be modified for CCS initiatives and regulatory authority would lie with the oil and gas commission.

The source of CO_2 will be from the Fort Nelson gas plant, which currently produces 1Mt/ year, though this is expected to increase as gas production in the basin increases.

Access permits to the storage area have been obtained, though it is only accessible during winter. The storage formation is a saline aquifer 8000 ft deep and the exploration well was drilled in spring 2009. This well was re-entered and subsequent testing occurred in the winter drilling season of 2010. A risk management plan has been developed and a modelling and MVA plan is being developed. The next steps include drilling the next test well, a 3D seismic survey, core and fluid analysis as well as updating the geological maps and the static and dynamic modelling.

Questions and Comments

Is the 85% H_2S supercritical? Yes, as this is a deeper aquifer.

Is the aquifer sour? Yes, the gas is currently 15% H_2S, and when the 12% CO_2 is added, then it will go down to 5% H_2S.

4.5 Monitoring and Outreach:

4.5.1 Carbon Storage Outreach and Education with STORE – Hilary Olsen, University of Texas

The aim of STORE is to create a skilled workforce for the CCS industry and foster the public understanding required to advance the United States in both energy security and a leadership position with regard to climate change mitigation technology. This is to be done by promoting transfer of scientific knowledge and applied engineering technologies related to CO_2 storage in 4 areas. These are sequestration workforce training, public outreach, R&D Transfer and workforce pipeline education.

Training is carried out by running short courses and workshops for scientists and public outreach events are held in schools and museums. Another initiative was to train teachers who would then train 25 other teachers, who would all then be able to educate their students.

Full details of activities can be found on the store website: www.storeco2now.com

There were no questions following this talk

4.5.2 SECARB ED: Southeast CO_2 Sequestration Technology Training Program – Kimberley Sams, SECARB

The aim of this initiative is to develop a self-sustaining regional CO_2 sequestration training program to facilitate the transfer of knowledge and technologies required for site development, operations and monitoring of commercial CCS projects. This is being done in conjunction with universities within the SECARB partnership, each of which specialise in a certain area.

The objectives of the program are to implement sponsorship development program, develop short courses on CCS technologies, conduct regional training and other activities through outreach and networking and perform region/basin technology transfer services.

There were no questions following this talk

4.6 Some Remarks on Uncertainty – Andy Chadwick, BGS

Monitoring activities will be related to the regulatory framework. Pre-injection predictive models are used, which monitoring can verify once injection has started, then further models are created with the new information, which are further verified. Post-injection models need to show a long-term robust prediction verified by monitoring before transfer of liability can take place.

When using predictive flow modelling, instantaneous uncertainty remains roughly constant, but leads to divergent long-term outcomes. However with geological storage, the long-term process is stable and instantaneous uncertainty decreases with time. When comparing the predictive models with monitoring data, the aim is not just to see if they match, but whether any mismatch is significant. For this it is important to look at what processes could cause the mismatch and whether they could compromise storage security.

There will always be an element of uncertainty, but this can be managed by deciding what uncertainty is acceptable. When looking at the EU directives, for example, to show that actual behaviour of the injected CO_2 conforms to the modelled behaviour, it is necessary to demonstrate basic understanding of the processes and show that uncertainty will not lead to future divergence. When confirming no detectable leakage, it must be taken into account that monitoring tools have finite detection thresholds and it is necessary to accept site characterisation i.e. 'innocent until proven guilty'. To show that the storage site is evolving towards a situation of long-term stability the onset of the key stabilisation processes should be demonstrated, possibly by using analogue data from pilot-scale or similar sites.

Panel Discussion

Panel Members: Andy Chadwick; BGS, Kevin Dodds; BP, Sue Hovorka; University of Texas, Charles Jenkins; CSIRO, Hubert Fabriol; BRGM

The discussion started with the need to define uncertainty as it is a big term and can mean different things to different people. The panel members gave some comments on what they thought the most important aspects are.

AC: There is uncertainty in predictive modelling, every time a predictive model is compared to the following monitoring results, there is always a blurred mismatch between the model and the monitoring dataset. What needs to be determined is when that mismatch is significant.

KD: It is necessary to deal with this in a systematic way for projects in the long term. If there is a project, how can information reduce uncertainty? The project can be divided into stages. At the start there is a large uncertainty in knowledge of the subsurface, so to acquire the information there is the site selection process with drilling and well logging. This means that you start with a very high uncertainty, which decreases as you get more information. During injection the model is updated with the results and uncertainty continues to decrease.

Risk follows a different path, before injection there is no risk (defined as impact times likelihood of leakage), as there is no CO_2 to leak. At injection the risk will increase gradually as the CO_2 interacts with possible leakage pathways in the subsurface, then flattens out. At the end of injection the risk decreases sharply as the maximum risk of leakage is reached and the other processes, such as dissolution etc. take over, though never reaches zero. The risk assessment is essential as it will determine the type of monitoring and when to use it. Baselines will need to be established, but the intensity of monitoring will depend on the risk, and will increase before the end of the project and the number of wells will decrease. The main question is how to choose what monitoring programme is needed.

AC: This describes a convergent site, that behaves as predicted, but if it does not behave as predicted then it will start to diverge. There might be a problem, if injection is into a closure, but the CO_2 then moves to another closure with a fault in it, the risk will increase again and we will need to get back to convergent circumstance. So uncertainty can increase as well.

KD: There is a general decrease in uncertainty as we get a better understanding of the geology, but there may be some intermittent small increases. In Salah is a good example, as there is time to gain a better understanding of the geology, gather more information and update understanding. There was uncertainty about fractures, which were anticipated, but we didn't know if that would be a dominant process. If you start with a risk model, gather data to address risk and then come back and do this again once more information is available, eventually uncertainty goes down.

SH: Proposing a hypothesis: When CO_2 is injected it "lights up" the subsurface that could not be seen before, such as the geochemistry and pressure limits, which the predictive model is dependent on, and as more of the structure is seen, an improved understanding can be gained. In the initial stages of pilot testing, decisions are made as to the viability of the project, so it may be a better indication of the risk if the chance of leakage is given as a percentage, similar to how the weather is predicted. That way a range of uncertainties can be considered.

CJ: Regarding probability as just mentioned, it is necessary to be clear on different kinds of uncertainty, for example that found in financial literature compared mathematical modelling. There is uncertainty, which means you don't know, but also an uncertainty related to probability, where there is a range of possibilities, which is how a risk assessment is formed. This can be shown using breakthrough curves and error bars on data points. The problem is not knowing if the conceptual models are realistic and the concern is a Rumsfeldian uncertainty. If something has not yet been found or has been missed, there is no control over it.

AC: This illustrates a convergent model, there is an initial inaccuracy, due to the uncertainty of the CO_2 behaviour, but is ultimately correct.

HF: A major issue is how to get accurate measurements, which is very important in monitoring. We need to talk about how it is difficult to get good instrumentation and good data. Accurate measurements are a way to reduce uncertainty, It is necessary to find what is the best configuration for tools and which processes to use.

The discussion was then opened to the floor.

The statement 'innocent untill proven guilty' was used, but it was suggested that if there is evidence of leakage then it is certain that there is no containment, but if there is no evidence of leakage, it is not certain. You cannot say if you haven't looked.

Using the EU regulations for example, it can be seen that it would not be possible to get into the situation where the site is not monitored, as there needs to be MMV plans. After injecting for 30 years or so, there will be a significant amount of measurement, and if they show the site to be behaving as expected, there is no reason to think that there might be leakage. The initial characterisation is more important. Take Sleipner as an example, the 3D seismic data shows a uniform unit. There are lots of wells, not at the site, but through the Utsira formation. So it can be said, that it is not likely to be faulted, which is strong evidence of no leakage, then add the extra data, which confirms this, which means that it can be assumed that there is no leak.

Part of the problem is that everyone has different ideas of who is to be convinced that there is no leakage. It is one thing to have a technical discussion with regulators and another to convince the public.

How much uncertainty is ok, depends on who the audience is. The public probably want zero error bars.

There is always uncertainty and unexpected things can happen, so there needs to be some kind of range, which is an acceptable uncertainty and a way to be able to assess what is acceptable.

It was suggested that we need to use probability more. Though saying that 95% certainty of containment and 5% uncertainty, does not mean a 5% chance that things will go wrong and it will leak.

Part of the problem is that policy people and regulators want uncertainty, and therefore risk, to be zero, which is not possible. If we can show something like 65% of outcomes look one way and 25% another, all of which is acceptable, this could be a strategy for managing uncertainty and drive risk towards zero. We can plan to change the injection strategy, depending on new information whenever we have it. So we could have a minimum and maximum and if it falls outside of this, then we would go to the contingency plans. It will be necessary to plan for high probability and contingency.

There will never be zero uncertainty and therefore risk can never be reduced to zero However, uncertainty and risk are not coupled that strongly, so it is possible to have a high uncertainty and low risk.

It was suggested that the uncertainty is not reduced that much beyond the site characterisation and injection stages. During the operational phase, measurements still need to be taken and the uncertainty in that has not decreased.

There was some disagreement as it was pointed out that the CO_2 illuminates the reservoir in a way that you couldn't see in the pre-injection geological characterisation stage.

The front of the plume is much harder to determine, it will quite often diverge from the model after a few years, so it is not definite that uncertainty should decrease once injection is started.

However, he number of measurements taken will increase, which will give more information over time.

In modelling there is uncertainty about permeabilities and how to tighten up the distribution. It is hard to get more information on these input parameters. Sufficient parameters may not always be taken into account, for example there were two possibilities or scenarios at

Sleipner impacting on different containment risks. The westwards migration scenario can now be seen to be not happening, so uncertainty, in that respect is massively reduced.

Uncertainty drops greatly during the site characterisation phase, but there is still uncertainty as to what the plume will do, and more measurements will need to be taken. In the injection phase, you will be tightening up some things and also eliminating some things, but a range of parameters will be taken into account. It may then be possible to reduce 3 model possibilities into 1. There is a change in the uncertainty curve, but it is still not flat, unexpected things may still happen.

The area of convergence between predictions and observations keeps growing, if injection continues for a long time. An increasing amount of space is affected, so the amount of relevant things that will be known increases. It is necessary to find out more, retesting the hypothesis with the same data.

There are other factors that are not taken into account. It could be possible to reduce the amount of information required to understand these factors and accept a level of uncertainty (although rigorous processes are needed to properly define those uncertainties). They may be outside of control, for example earthquakes, but when we follow processes, there is a close interaction with the risk assessment, which will dictate the amount to measure.

There is uncertainty in many things and we need to assume that some uncertainty exists. It will be necessary to go into the field and acquire data to improve confidence. Then it needs to be decided what mismatch between predictions and observations needs to be acted on. For example, if the model is off by 5 days after 350 days of injection, do we act on it? A worst case scenario example could be unexpected fault related containment failure, and then it would be necessary to make adjustments to the operation. Uncertainty needs to be handled throughout the whole project.

Session 5: Post-Injection Monitoring

5.1 Otway and the risks of monitoring – Charles Jenkins, CSIRO

Monitoring is carried out for public assurance, quantification and climate change regulations. When measuring for public assurance, the stakeholders wish to see that nothing has changed and that that storage of CO_2 has had no adverse effects.

There are 2 types of error Type I and II. A Type II error is when you do not see a change that has taken place due to noisy data. A Type I error is when you see a change, but is in fact caused by noise; this is also called the “false alarm rate”.

The assurance program at Otway consists of 4 components, groundwater, soil-gas, headspace gas and atmospheric monitoring. The groundwater survey showed an anomaly post-injection, but when the data was scrutinised more closely, it was found to be a false positive and well within the noise level.

In summary, it is necessary to understand, ahead of time, how you will draw conclusions from monitoring, which will involve some heavy-duty statistical work if monitoring techniques are being pushed to the operational limits.

5.2 Post-Injection Monitoring at the Nagaoka Site – Saeko Mito, RITE

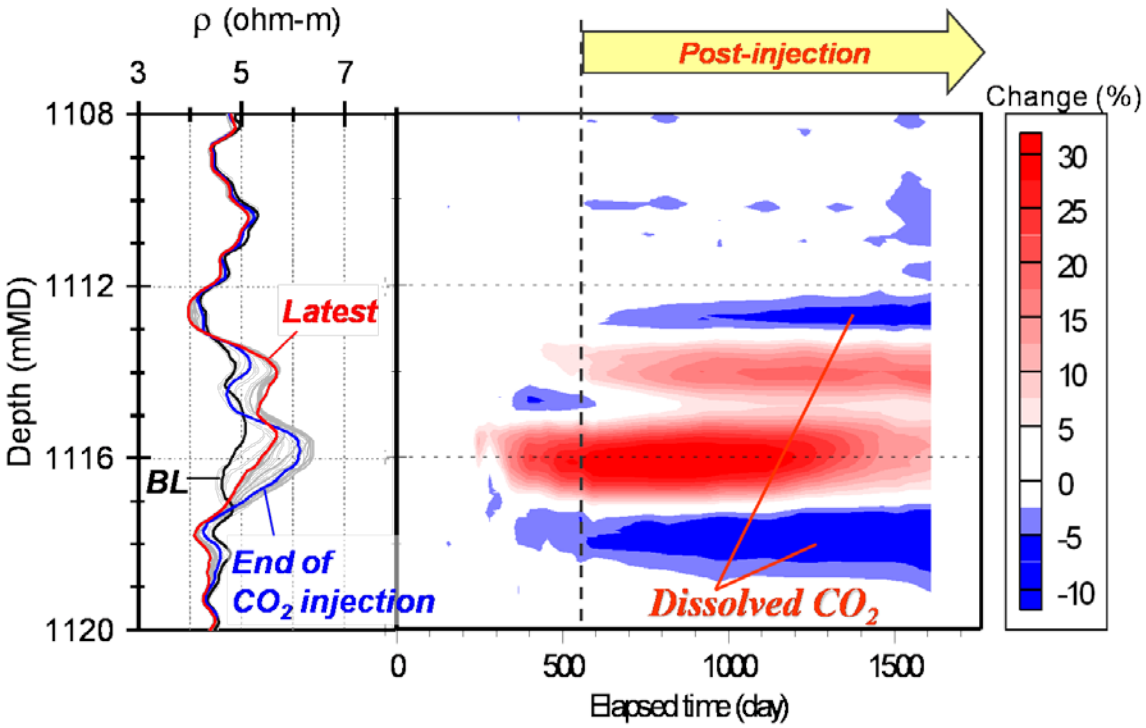
10,400 tonnes of CO_2 was injected into the Pleistocene sandstone of the Haizume Formation by 2007. There is 1 injection well and 3 observation wells (OB1-3), 2 up-dip, 1 down-dip and seismic tomography sections between OB2 and OB3. The post-injection monitoring program has been completed, but is planned to start up again later this year. The aim of the future program is to monitor pressure and CO_2 distribution and to predict the long-term fate of the injected CO_2.

The modelling results correspond closely to the monitoring results, which is important for site abandonment to take place.

During injection, increased pressure was seen and breakthrough was detected in OB2 and OB4, but not in OB3. The seismic tomography section shows the CO_2 at the top of the reservoir. The anomaly seen is 100 m by 30 m, which is a good match to the model, which predicted 105 m by 20 m. Preliminary trapping data showed CO_2 trapped as a gas phase. In OB2, after breakthrough there was a decrease in neutron porosity followed by an increase. Over time there is a decrease in resistivity at the top of the reservoir. This is evidence of solubility trapping of the CO_2 (Figure 1).

The future monitoring plan involves well logging, seismic tomography and 3D VSP, all with the aim of improving the understanding of CO_2 distribution.

Figure 1 Resistivity monitoring at OB2; Mito, 2010



5.3 Post-injection monitoring at Frio – Sue Hovorka, University of Texas and Tom Daley, LBNL

1600 tons of CO_2 were injected in 2004 at a depth of 1500 m, which was followed by a second injection in 2006 of 300 tons at 1650 m. VSP surveys were taken, the third VSP, before plug and abandon (P&A), was taken in 2009. The storage formation is a steeply dipping (11-16˚), mineralogically complex reworked fluvial sandstone saline aquifer, with a multilayered shale caprock.

The 3 VSP surveys were re-processed together and there is a response seen from the 2 plumes formed from the 2 injections, but not from the known leak. The two known plume amounts are monitored in the same VSP dataset, leading to implications of a minimum quantity of CO_2 detectable using the VSP technique.

As the VSP reprocessing did not show the observed changes, current research is looking at the raw data. With limited source points the imaging (using VSP-CDP and migration) is less clear, probably due to velocity heterogeneity. The data will be used to study repeatability, quantification and storage permanence.

Questions and Discussion

At Frio the anomaly is greater than during the earlier survey, so will there still be free phase? Yes, we still expect to have some free phase. The model showed that it would not have dissolved at all at that stage.

It appears that the 3rd survey is of higher quality. Not if you look at the entire dataset, where it is all pretty consistent. There are still a lot of changes in there.

Is there a reason why there is no difference map? There is an interval time shift in here, and so I don't want to arbitrarily apply it.

Not saying that the interpretation is not valid, but if you were looking for a leak and did not know where it was, this wouldn't be determinable from the data. Yes this is true, this interpretation of the results can really only show this as we know where the location of the leak was, otherwise we would need corroborating evidence.

Looking at the Nagaoka data on the dissolution slide, the lower resistivity area is getting thicker – is that real? You can see the blue colour at the top and bottom. Where the blue becomes narrower, it could be an increased density of the formation water, because of dissolution, but we do need further data and are planning to sample again to find out. (see Figure 1).

Session 6: Emerging and innovative monitoring techniques

6.1 Surface deformation forward modelling of InSAR data at In Salah – Kevin Dodds, BP

An accurate elastic earth model is necessary to calculate what surface deformation is caused by subsurface flow. The data can become complicated by atmospheric and soil changes, which will need to be corrected for. The modelling carried out by Lawrence Livermore shows the effect of the reservoir and fractures. Surface deformation is not very sensitive to the vertical extent of the fault, so it is hard to determine if the fault is in the overburden and reservoir.

The coupled geomechanical analysis indicates that the uplift is consistent with pressure-induced volumetric expansion of reservoir rocks within the 20 m thick injection zone and perhaps within the 100 m thick zone of shaley sands just above the injection zone. The partial pressure drop and slow subsidence after shut-in of KB502 is consistent with pressure-induced elastic volumetric changes in the reservoir rock. The double uplift lobe is consistent with lateral expansion of a jointed zone extending about 200 m up from the reservoir (i.e. to below 1600 m).

Questions and Comments

InSAR is sensitive to the pressure field, but this is not the same as the plume. Are people looking at that to try and map the plume? Yes, you can assume they are looking at that. From the graphs you can distinguish between the two fairly well.

6.2 Monitoring Ecosystem Impacts of CO_2 Storage – RISCS project – Sarah Hannis, BGS

This is a 4 year project, started in January 2010 with no results as yet, the ultimate aim is to produce a guide for impact assessment. The project will involve experiments and observations of natural analogues in both marine and terrestrial environments.

The guide for impact assessment aims to inform stakeholders on key issues:

- What to consider when appraising potential impacts in the event of leakage from a storage site.
- How to evaluate the potential impacts of storage project development: design stage, construction, operation, post-injection and to enable transfer of site liability to the competent authority.
- Options for directly assessing the potential scales (temporal and aerial, realistic leakage ranges (fluxes, masses)) and ecosystem responses.
- Options for identifying, predicting and verifying the nature of impacts.

Questions and Comments

The benefits could be as good as the detriments. Are they looking at this? Yes they are looking at any and all impacts.

If there is a leak, it might not arrive at the surface, so there would be non pure CO_2. Will they look at effects of the impure gas? In the experimental part of the project it will be only pure CO_2. The natural analogues will contain impurities.

6.3 Evaluation of Geoelectrical Crosshole and Surface-Downhole Measurements – Conny Schmidt-Hattenberger, GFZ

Geoelectrical monitoring along with seismic is intended to measure the migration of the injected CO_2. The vertical electrical resistivity array (VERA) has 45 permanent electrodes, with 15 electrodes per well, giving an electrode spacing of around 10 m across an installation depth of 590 to 735 m. The area covered was the same as that covered by the seismic survey, in order to be able to compare the results.

The VERA system has been successfully installed and operating for three years. The pre-injection resistivity model was built based on site-specific data relating Archie's law with standard sandstone parameters. It is a low-resistivity environment (few Ωm to below 1 Ωm), with a thin reservoir layer (max. 20 m) and small resistivity contrasts due to partial CO_2 saturation.

Studies incorporating multi-phase fluid flow modelling were performed. These indicated a significant dependency of apparent resistivity alteration to hydraulic conductivity within the reservoir (due to time-dependent CO_2 distribution). Inversion results are in good correspondence with current information from other monitoring systems (seismic, gas monitoring, RST and DTS) and contribute to the "big picture", although more detailed investigations need to be conducted.

Questions and Comments

Does how deep you measure, depends on the distance between electrodes? There is an advantage to being a shallow reservoir as what we have seen is not only noise. It is still limited and we could enlarge the area, by making the dipole larger at the surface, but then it would be mostly noise. 1000-1200 m should be the maximum depth. We were asked if this method can be applied for industrial wells, which it could, but it is necessary to use a complementary method as well.

If it was a commercial project, would the longevity of the fibre-glass casing be an issue? Possibly, and it is unsure how stable the system would be with a metal casing as the measurements would not be as good. It depends on what is planned for the wells, but it would likely need a compromise with steel, maybe using a textile casing.

6.4 Some Aspects of Seismic Monitoring at Otway – Milovan Urosevic, University of Curtin

This is a multi-injection plan into the Naylor reservoir. The first stage is 65 kt of 80:20 CO_2/ CH_4 transported and injected into one well, then the second stage is 10 kt of the same stream injected into a second well under the Huff n Puff method. The Naylor reservoir is a depleted gas field and is small, thin, relatively deep and heterogeneous making monitoring difficult, and so the most sensitive seismic techniques are needed.

The decision was taken to include time lapse 3D surface seismic in the monitoring plan. Although it is the least sensitive and repeatable, it provides coverage of the entire reservoir and is necessary for assurance monitoring. Also included is time lapse borehole seismic; 3D VSP with 3C geophones. This has improved sensitivity and resolution relative to surface data, improved repeatability and has increased the chance for direct CO_2 monitoring, albeit with limited coverage. Lastly there is 2D seismic monitoring with permanent sensors, which is potentially the most sensitive and repeatable technique.

Conclusions were:

- Good quality timelapse 3D surface data were acquired with Uni-crew.
- Base line seismic data recorded with free fall weight drop source, next two repeats with minivibroseis; very good (post-stack) repeatability achieved!
- Changes in soil saturation produce kinematic effects and different ground roll patterns
- CO_2 upward migration (“Leak”) would be readily detectable with 3D timelapse seismic.
- 3D repeatability much higher than 2D repeatability.
- Low signal to noise ratio and low NRMS can be improved with either strong source or high-fold.
- M&V of CO_2 storage in depleted gas fields could be achievable with high resolution 3D timelapse seismic. Analysis at Otway is ongoing
- Repeatability is important and may need to be determined ahead of timelapse seismic (NRMS is a function of S/N which is dependent on several variables)

Questions and Comments

An easy way to get repeatability is to take a legacy survey, take gathers, take out half of ray set then stack both halves, and compare. Unfortunately this won’t help with any seasonal repeatability problems. Most of the problems are with seasonal repeatability, though this method is better than nothing.

6.5 Effects of CO_2 Injection on Mineralogy - Ernie Perkins, AIFT

The Penn West monitoring program was completed in 2008 and the geochemical monitoring is ongoing. The mineral reactions were evaluated by direct observation of the core, predictive modelling and interpretation of fluid samples. The site had undergone water flooding before CO_2 flooding and changes caused by one were not able to be distinguished from the other.

General conclusions reached were that a significant amount of mineral reaction will only be observed in limited areas and that field chemical/ operational history may interfere with/ hide mineralogical (and fluid) changes.

Site specific conclusions were that core studies, geochemical modelling predictions and interpretation of monitoring data all indicate that mineralogical changes are small, that the impact of mineralogical changes on flow is minimal and that formation water chemistry is very a sensitive monitoring tool for monitoring mineralogical changes.

Questions and Comments

How does this relate to other reservoirs? Different reservoirs operate differently and the mineralogy is critical. Silicates react slower than what we are sampling for. Massive changes can be predicted if experiments are saturated and out of equilibrium. The water flooding process is destructive, because the minerals are dissolved then new water is introduced.

Is this typical? This is typical of silicate reservoirs as they have low reactivity and most of the reactions will take place at the front edge. Carbonates can be thought of as ‘fast’ reactors and amorphous iron oxides are much faster and it is possible to mobilise a lot of iron. Silicate reactions are slow enough that they will still be happening 10, 50 or 100 years down the line.

Is there any difference if there is fracture permeability? Yes, that is one inadequacy of the reservoir model. It is much different to matrix flow, because of the type of reactions.

6.6 Preliminary Electrical Resistance Tomography Results – Cranfield, Abe Ramirez, LLNL

ERT is a fairly robust system as there are no moving parts, it has a relatively low cost and can be operated remotely and continuously. The deepest ERT array is at 3200 m. There are 2 vertical cross-well electrode arrays 41 m apart and 10,000 measurements per day are collected.

The conclusions reached were:

- CO_2 produces a strong signal.
- ERT reconstructs basic plume details, but to a coarse resolution.
- Resistive anomaly appears associated with CO_2 movement in Lower Tuscaloosa formation with December 9, 2009 arrival at the F2 well.
- Significant positioning and resolution loss due to electrode damage in well F2, analysis continues.
- Conductive anomaly apparently due to work over fluids appears just after start of injection
- The system continues to remotely log ~10,000 ERT measurements/day (May 2010).

Lessons learnt from the experiment are that the robustness of electrode centralisers need improvement, the time required for cabling installation needs to be shortened while maintaining array robustness, for which the choice of electrical connectors may be very important and more well centralisers may be needed to protect wiring and electrodes.

Questions and Comments

Would it be possible to use surface current dipole with the sensors at that depth? No, as they would not have enough sensitivity.

The electrode is on fibreglass casing, could an insulator on steel casing be used? The electrodes need to be on outside of the casing, though other ways of insulating could be with epoxy paint.

Comment: That is what is used at Ketzin. If it is very shallow a plastic casing centralisers can be used.

Could another option be to have a dedicated well and cement it in? This is possible, but then the well is no longer multiuse.

It was pointed out that it is important to look at the completion costs compared to not completing it like this. At the Cranfield site a dedicated well would be $1.3 million, whereas this well with 'the works' was $1.6million. This means that lowering the pipe must be done slowly to avoid losing the hole. Pressure control is also important due to water flooding. A bigger hole of 12" had to be drilled rather than the normal 9.5".

In the CO_2 ReMoVe project, dedicated downhole electrodes were not used, but instead the whole metallic casing was used to inject the current. It was possible then to play with the frequency, though there were problems of resolution.

In Ketzin, there were 15 electrodes, at Cranfield only 7, which would severely limit the amount of information. If that can be fixed it would be a large step forward. Then you can bring in the other data to join the inversions.

Session 7: Conclusions

In the discussion following session 1, delegates were invited to suggest possible other workshops or ideas for joint meetings. A list of these were created throughout the meeting and then discussed.

Firstly it was noted that it is important not to reproduce what the other meetings are accomplishing, the ideas were:

Cement quality impacts on MMV: can we have missing/ bad cement affecting monitoring results. Permeability pathways don't work through coring very well. At the Michigan site the entire MMV program was changed due to some missing cement higher up.

Some MMV equipment installations (e.g. making casing non-conductive for ERT) can make it harder to get a good cement job. An idea is to put a geophone behind the casing, but would this compromise well integrity?

Microseismics: though there may be a lack of data so far.

Geochemical activity and induced seismicity, in terms of stress concentrations. This could look at InSAR as well.

It was also thought by many delegates that the network meetings could be more interactive. The best combinations were considered to be the monitoring network with the risk assessment or modelling networks. The most popular was to have the combination with the modelling network, because joint discussion as to why monitoring and modelling results do not always match up, and what the subsequent best course of action would be, was brought up during the panel discussion on uncertainty.

Key Learnings:

Projects

The speakers from CO_2 storage projects were asked to give a sentence summarising what is currently the most important aspect that is being worked on or needs to be worked on for their site.

Aquistore: Key drill and instrument injection well.
Weyburn: Well integrity – program of wells exposed to CO_2 – special tool.
HARP: Data well and baseline monitoring.
Fort Nelson: injection commencing.
PCOR: Injection commencing.
MGSC: Developments and baseline monitoring and maybe injection.
SECARB: Anthropogenic site: permit and install wells. Integrate geophysical and geochemical data – time lapse gravity.
WESTCARB: 2 wells, 1 in Arizona, 1 in north California – start drilling to 14k.
MRCSP: Phase II monitoring – best practice.
SWP: Site characterisation and drafting a monitoring plan (using the RA) started.
Lacq: Results from passive seismic monitoring.
Gorgon: Cross-well evaluation and phase IV EM.
Ketzin: Further data matching / data integration.
Otway: Do residual trapping Huff-and-Puff experiment (leave for 1 week) and integration for timelapse post-injection surface seismic and VSP. Follow up HnP with a permanent installation of geophones along the service well.
Nagaoka: Coupling modelling and monitoring for the post-injection phase.
Sleipner: Gravity CSEM – interpret it.
In Salah: Fracture analysis and microseismics.

Monitoring in an evolving political environment

The politics of regulations is evolving, and for each new site, it may be useful to see what is being mandated, in terms of monitoring, by regulations at other sites.

The new EPA rule is in the discussion phase until 11th June and involves mandatory reporting for geological storage projects, with elective requirements for EOR and R&D projects. EPA requirements for storage sites are a risk assessment and a strategy to quantify leakage, but are non-prescriptive on techniques. Monitoring is required until plume stabilisation.

Injection of mixed gases is going on at some sites. There needs to be more thought about well installation and design and integration with injection. The practicalities of moving from small scale to large scale need to be thought of as it will not be possible to stop injection to carry out monitoring on a commercial project.

Public perception needs to be discussed for each site as it can be a ‘showstopper’. Talks on public outreach have shown how this is being addressed. The programs discussed are comprehensive and highly geared to information transfer. It is important to see how this can be reproduced elsewhere.

A comment was made that it could be useful to speak on outreach on a particular project, though it was agreed that this would be more appropriate for the social research network. However, it was considered useful to have a talk on outreach, regarding the interaction with monitoring and that it could be useful to have one at each network meeting, but in a way that would be appropriate for each meeting.

Uncertainty

A major issue is that there is such a broad spectrum of what people think of as uncertainty and it may be necessary to define how we are using it and address that.

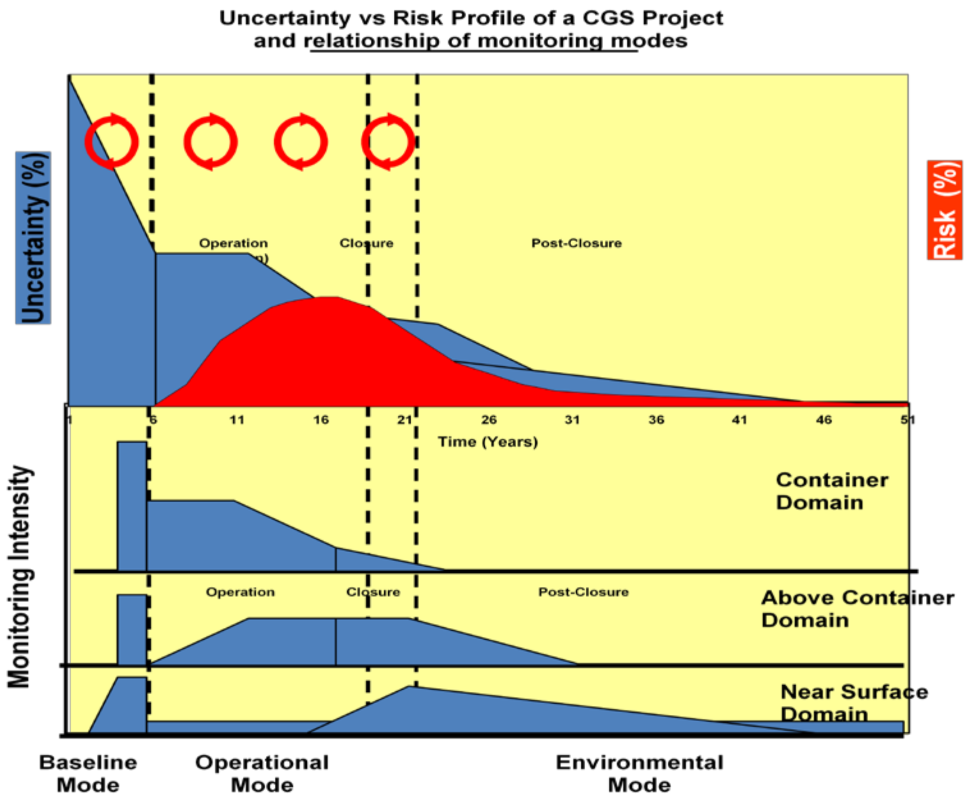
There are measurement related uncertainties and uncertainties related to modelling results, which will never completely match the monitoring results. A large part of dealing with uncertainty is recognising when a mismatch is significant.

There is also a difference in the uncertainty relating to unexpected events and the broad probability and uncertainty ranges on parameters.

Uncertainty is critical for risk assessment processes and updating monitoring information. Uncertainty and risk over time are interactive but not dependent on each other.

It was put forward that the injected CO_2 illuminates the subsurface, by increasing the area of contact and providing new data on the subsurface. This leads to further knowledge, but also further uncertainty, so that the risk profile may not plateau after a certain point, but continue to increase until injection is ceased (Figure 2).

Figure 2



Dodds, 2010

Post-Injection

Monitoring is required for the long-term and required over many years and so we need a strategy to deal with that. If it is over a long time, then it will need to be cheap and effective. There will need to be data integration of geochemistry, geophysics and modelling.

In the USA, the EPA perspective is that each site needs to be monitored until plume stabilisation.

It was also agreed that some 'mythbusting' may be necessary. Stakeholders want monitoring for 50 years, but it is necessary to be realistic about what can be observed and what can go wrong.

A note from Charles' talk on the risks of monitoring, highlights dealing with what happens when you get data that looks like something that isn't something (false positives). It is necessary to deal with this situation before it happens, by deciding what you are monitoring for as you cannot just remove a data point. A communication plan is needed to explain a false positive to the public.

Emerging and Innovative Monitoring Techniques

It was found to be useful to compare the same technologies used at different sites, as this helps to show some of their limitations as well as benefits.

An idea was a master class or invited reviews for emerging technologies, but at the stage where a lot of potential technologies would have been ruled out. There could possibly be a keynote on technology opportunities, which is not project specific.

Key Outcomes and Learning Points

There is a big shift in the breadth and quality of work being done. There are more details, more knowledge and more projects from which to learn.

There needs to be more data integration of geochemical and geophysical and modelling work, as well as more research on permanent installations and microseismics.

Recommendations on future network combinations

Networks	**Joint Meeting Topics**
Risk & Monitoring	Integration process Risk-Monitoring -Mitigation
Monitoring and modelling	• History matching. How close? • Geomechanical interpretation of induced microseismics • Faster iterations between model and data
Well integrity	• Cement quality impact on MMV • Integrity and MMV with perforations
Permanent monitoring	1. Stress concentration 2. Instrument wells 3. Did monitoring result in negative outcome?

All the presentations are available on the web site:
http://www.ieaghg.org/index.php?/2009112020/monitoring-network.html

The next meeting Monitoring Network meeting will be hosted by the GFZ, Potsdam, Germany in 2011.

6th Monitoring Network Meeting

6th-8th May 2010
Natchez, Mississippi, USA

Organised by

IEAGHG and Bureau of
Economic Geology at the
University of Texas

Hosted and sponsored by
Gulf Coast Carbon Centre at the Bureau of
Economic Geology at the University of Texas

6th May 2010 Day 1

08.30 to 09.00 Registration

Session 1: Report from previous Meetings Chair - Tim Dixon; IEAGHG & Susan Hovorka; University of Texas

09.00 to 09.20	Welcome Address: Susan Hovorka; University of Texas & Tim Dixon; IEAGHG
09.20 to 09.40	Summary from the last Monitoring Network Meeting: Kevin Dodds; BP
09.40 to 10.00	SEG CO_2 Update: Don White; NRCan
10.00 to 10.10	2010 Modelling Network Meeting Summary: Millie Basava-Reddi; IEAGHG
10.10 to 10.30	**Discussion**

10.30 to 11.00 Coffee Break

Session 2: Results from International Monitoring Projects Chair - Don White; NRCan

11.00 to 11.20	Ketzin Project; Conny Schmidt-Hattenberger, GFZ
11.20 to 11.40	The Lacq Rousse Project (France): Hubert Fabriol; BRGM
11.40 to 12.00	ETI Review Outcomes and CCP Projects: Kevin Dodds; BP
12.00 to 12.20	EPA-CCP Study: Susan Hovorka; University of Texas
12.20 to 12.40	Gorgon CO_2 Monitoring & Verification Planning: Adi Widyantoro; Chevron
12.40 to 13.10	**Discussion**

13.10 to 14.10 Lunch

Session 3: Results from US and Canadian Monitoring Projects Chair Susan Hovorka; University of Texas

14.10 to 14.30	Overview of US Partnership Projects: John Beyer; Lawrence Berkeley National Laboratory
14.30 to 14.50	Phase III SECARB Project Cranfield: Susan Hovorka; University of Texas
14.50 to 15.10	Overview of the PCOR Partnership's Phase II MVA Activities: Steve Smith; EERC

15.10 to 15.50 Coffee Break with Poster Session

15.50 to 16.10	MMV Planning WESCARB and DOE's National Risk Assessment Partnership (NRAP): Tom Daley; Lawrence Berkeley National Laboratory
16.10 to 16.30	Microseismic Monitoring of CO_2 EOR in the Aneth Oil Field: Jim Rutledge; Los Alamos National Laboratory
16.30 to 16.50	Monitoring Activities under MRSCP Phase II Field Demonstrations: Neeraj Gupta; Battelle
16.50 to 17.10	Status of Canadian Projects: Don White; NRCan
17.10 to 17.40	**Discussion**

Close Day 1
Evening cocktail reception (cash bar) and hoer d'oerves Dunleith Plantation and Historic Inn

7th May 2010 Day 2

Session 4: Monitoring in an Evolving Regulatory and Political Environment Chair -Tim Dixon; IEAGHG

08.30 to 08.50	Overview of US EPA's Mandatory Reporting of Greenhouse Gases Rule: Injection and Geologic Sequestration of Carbon Dioxide: Barbora Master; US EPA
08.50 to 09.10	Aquistore Project: Kyle Worth; PTRC
09.10 to 09.30	CO_2 Surveillance During CO_2 EOR and CCS Policy Progress in the US: Steve Melzer; Melzer Consulting
09.30 to 09.50	Overview of the PCOR Partnership's Phase III Field Demonstration: Spectra Energy's Fort Nelson CCS Feasibility Project: Steve Smith; EERC
09.50 to 10.10	Monitoring and Outreach: Carbon Storage Outreach and Education with STORE: Hilary Olsen; University of Texas SECARB ED: Southeast CO_2 Sequestration Technology Training Programe: Kimberley Sams; SECARB

10.10 to 10.40 Coffee Break

10.40 to 11.00	How do we Deal with the Question of Uncertainty? Andy Chadwick; BGS
11.00 to 12.00	Panel discussion: How do we deal with the question of uncertainty? Chair: Andy Chadwick; BGS Panel members: Kevin Dodds; BP, Hubert Fabriol; BRGM, Charles Jenkins; CSIRO, Susan Hovorka; University of Texas

12.00 to 13.00 Lunch

Session 5: Post-injection Monitoring Chair –Andy Chadwick; BGS

13.00 to 13.20	Otway and the Risks of Monitoring: Charles Jenkins; CSIRO
13.20 to 13.40	Post-injection Monitoring at the Nagaoka Site: Saeko Mito-Adachi; RITE
13.40 to 14.00	Post-injection Monitoring at Frio: Susan Hovorka; University of Texas and Tom Daley; LBNL
14.00 to 14.30	**Discussion**

Session 6: Emerging and Innovative Monitoring Techniques Chair –Charles Jenkins; CSIRO

14.30 to 14.50	Surface Uplift at In-Salah: Kevin Dodds; BP
14.50 to 15.10	Monitoring Ecosystem Impacts of CO_2 Storage– the RISCS Project: Sarah Hannis; BGS
15.10 to 15.30	Geoelectric Monitoring at Ketzin: Conny Schmidt-Hattenberger; GFZ

15.30 to 16.00 Coffee Break

16.00 to 16.20	Some aspects of Seismic Monitoring at Otway: Milan Urosevic; Curtin University
16.20 to 16.40	Effects of CO_2 Injection on Mineralogy: Ernie Perkins; AIFT (Formerly ARC)
16.40 to 17.00	Preliminary Electrical Resistance Tomography Results -Cranfield: Abelardo Ramirez; LLNL
17.00 to 17.30	**Discussion**

Session 7: Key Outcomes form Meeting Chair –Kevin Dodds; CSIRO

17.30 to 18.30	Outcomes and recommendations from the 6th monitoring Network Workshop Panel members: Kevin Dodds; BP, Susan Hovorka; University of Texas, Tim Dixon; IEAGHG

Close Day 2

Site Visit to the Cranfield Injection Site - Saturday 8th May 2010

08.30 Bus departs from the Natchez Convention Center for Cranfield

16.00 Depart Cranfield for Natchez Convention Center

Steering Committee

Tim Dixon, IEA GHG (Chair)
Millie Basava-Reddi, IEA GHG
Susan Hovorka, University of Texas (Representative of the hosts and co-Chair)
Andy Chadwick, BGS
Charles Jenkins, CSIRO
Don White, NRCan
Hubert Fabriol, BRGM
Julianna Fessenden, LANL
Kevin Dodds, BP
Hilary Olson, University of Texas
Ziqiu Xue, Kyoto University

The Gulf Coast Carbon Centre at the Bureau of Economic Geology at the University of Texas is supported by

ATTENDEE LIST

6th Monitoring Network Meeting

6th-8th May, 2010 Natchez, Mississippi, USA

Millie Basava-Reddi, IEAGHG
Adnand Bitri, BRGM
John Henry Beyer, Lawrence Berkeley National Laboratory
Bob Butsch, Schlumberger
Andrew Chadwick, British Geological Survey
Charles Christopher, BP Alternative Energy
Marcia Coueslan, Schlumberger
Tom Daley, Lawrence Berkeley National Laboratory
Tim Dixon, IEAGHG
Kevin Dodds, BP
Hubert Fabriol, BRGM
Neeraj Gupta, Battellle
Sarah Hannis, British Geological Survey
Susan Hovorka, Gulf Coast Carbon Center, Bureau of Economic Geology
Charles Jenkins, CSIRO
Robert Kiker,
Keigo Kitamura, RITE
Don Lawton, University of Calgary
Barbora Master, US EPA
Franz May, BGR
Tip Meckel, Gulf Coast Carbon Center, TX BEG
Steve Melzer, Melzer Consultants
Saeko Mito-Adachi, RITE
Modesto Montoto, Fundación Ciudad de la Energía

Nobumichi Morishita, Japan NUS Co.
Jean-Philippe Nicot, Texas Bureau of Economic Geology
Hilary Olsen, University of Texas
Jennifer Owens, St Francis Xavier University
Ernie Perkins, Alberta Innovates—Technology Futures
Guillemette Picard, Schlumberger
Albelardo Ramirez, Lawrence Berkeley National Laboratory
Richard Rhudy, EPRI
Kaylene Ritter, Stratus Consulting Inc.
Will Roadarmel, Pinnacle
Katherine Romanak, University of Texas
Jim Rutledge, Los Alomos National Laboratory
Kimberley Sams, SECARB
Sohei Shimada, RITE
Conny Schmidt-Hattenberger GFZ
Steven Smith, Energy & Environment Research Center
Nobukazu Soma, AIST
Daiji Tanase, J-Power
Robert Trautz, EPRI
Kirk Trujillo, Halliburton
Milovan Urosevic, Curtin University
Hans-Dieter Vosteen, State Authority for Mining, Energy and Geology
Don White, NRCan
Adi Widyantoro, Geological Survey of Canada
Kyle Worth, Petroleum Technology Research Centre