3rd MONITORING NETWORK MEETING

Report Number: 2007/5

Date: June 2007

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. The IEA fosters co-operation amongst its 26 member countries and the European Commission, and with the other countries, in order to increase energy security by improved efficiency of energy use, development of alternative energy sources and research, development and demonstration on matters of energy supply and use. This is achieved through a series of collaborative activities, organised under more than 40 Implementing Agreements. These agreements cover more than 200 individual items of research, development and demonstration. The IEA Greenhouse Gas R&D Programme is one of these Implementing Agreements.

DISCLAIMER

ACKNOWLEDGEMENTS AND CITATIONS

The IEA Greenhouse Gas R&D Programme 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 the IEA Greenhouse Gas R&D Programme as a record of the events of that workshop.

The international research network on Monitoring is organised by IEA Greenhouse Gas R&D Programme in co-operation with CO2CRC, BP, Australian Government and Department of the Environment and Heritage, Department of Industry, Tourism and Resources. The organisers acknowledge the financial support provided by Rio Tinto and Woodside for this meeting and the hospitality provided by the hosts CO2CRC.

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

Charles Christopher, BP (Chairman)
Rick Chalaturnyk, University of Alberta
Kevin Dodds, CO2CRC
Susan Hovorka, Bureau of Economic Geology
Nick Riley, British Geological Survey
Thomas Berley CO2CRC
Mark Bonner DEH-Australian Greenhouse Office
Kate Roggeveen DEH-Australian Greenhouse Office
John Gale, IEA Greenhouse Gas R&D Programme
Angela Manancourt, IEA Greenhouse Gas R&D Programme

The report should be cited in literature as follows:

IEA Greenhouse Gas R&D Programme (IEA GHG), "3rd Monitoring Network Meeting, 2007/5, June 2007".

Further information on the network activities or copies of the report can be obtained by contacting the IEA GHG Programme at:

IEA Greenhouse R&D Programme, Orchard Business Centre, Stoke Orchard, Cheltenham Glos. GL52 7RZ. UK
Tel: +44 1242 680753 Fax: +44 1242 680758
E-mail: mail@ieaghg.org
www.ieagreen.org.uk

Third meeting of the International Monitoring Network for Geological CO_2 Storage
October 30 – November 2, 2006

Meeting report

Organised by IEA Greenhouse Gas R&D Programme and CO_2CRC

Rendezvous Hotel, Melbourne, Australia

Report written by Jonathan Pearce
British Geological Survey
Keyworth,
Nottingham,
NG12 5GG,
United Kingdom

Monitoring and Verification Network Meeting
Melbourne, Australia
31st October 2006

1. INTRODUCTION

The third meeting of the monitoring and verification network met in Melbourne, Australia over 3 days in October and November 2006. The meeting's objective was to provide an integrated set of monitoring and verification (M&V) guidelines to encourage further public, regulatory and technical community discussion for wide scale deployment of CCS technology. The objectives were realised by addressing the questions:

- What is the framework of a Monitoring, Evaluation, Reporting and Verification (MERV) protocol for wide scale CCS deployment?
- How do we provide assurance of storage integrity through well, seal and containment monitoring technology?

The meeting brought together national and international government regulatory agencies, non-government organisations and Monitoring and Verification (M&V) technical communities in an intensive series of workshops. It was followed by a field visit by train to the site of the CO2CRC Otway Basin Pilot Project (OBPP) in South West Victoria.

The third Monitoring Network Workshop built on the material presented and discussed at the first two meetings held in Santa Cruz, California 2004 and Rome 2005. These meetings had a principle focus of bringing together, through presentation and discussion, both the regulatory groups involved in setting monitoring programmes associated with CO_2 storage and those projects that are implementing such programmes in different environments.

- The inaugural meeting of the Monitoring Network demonstrated that there is a large tool box of monitoring techniques that can be applied to both surface and sub-surface monitoring of CO_2.
- The second meeting focused on what were the monitoring requirements and how would they be defined with respect to risk and regulatory requirements.
- The third Monitoring meeting further enhanced the dialogue of regulatory and technical integration, with joint development of Monitoring, Evaluation, Reporting and Verification (MERV) guidelines.

2. WORKSHOP ATTENDEES

The meeting was attended by 62 delegates from 10 countries (Appendix 2). The delegates represented Australian and North American regulators, international industrial operators and geological researchers from Australia, Europe, Japan and North America.

3. WORKSHOP PROGRAMME

The programme and agenda for the meeting are included in Appendix 1. The meeting was preceded by a workshop on the regulatory needs for monitoring, evaluation, reporting and verification (MERV), which involved presentations from regulators and researchers and a facilitated discussion on the design of MERV protocols. The Monitoring Network meeting was divided into a series of sessions, which focussed on specific topics within the area of monitoring and verification:

Session 1 - Plenary

Session 2 - Monitoring Issues: Wells and Seals

Session 3 - Containment and Integration

Session 4 - The Latrobe Valley case study

Session 5 – Discussion

Session 6 – Otway Basin Pilot Project Site visit.

4. SESSION 1: PLENARY

4.1 Introduction of Minister – Peter Cook

Mr Theophanous is minister for energy industries and resources, and has been advocating clean energy technologies for many years.

4.2 Minister's opening address – The Honourable Theo Theophanous, Minister for Resources

Climate change is a political issue and requires political solutions – technical, economic and social solutions are not enough. Mr Theophanous welcomed delegates to the meeting and recognised the importance of the Otway Basin Pilot Project, both to Victoria and Australia, as well as internationally.

A regulatory and legislative regime will be needed for CCS implementation and Mr Theophanous welcomed the dialogue undertaken yesterday between network delegates and Australian regulators.

Australia produces 1.5% of global greenhouse gas emissions, although it has only 0.4% of global population. If countries such as Australia do not take the lead, we can not expect other countries, such as China, to act. The Stern Review is important because it places emphasis on the economic costs of climate change; £3.68 trillion was estimated as global cost of unmitigated climate change. Immediate action will cost only 1% of global GDP. Many impacts were outlined.

The Victorian government believes action should therefore be taken now. One action is investigating potential for CCS as one technical option, which could save 25% of global emissions. AUS$103.5 m has been allocated to R&D on clean energy technologies. Mr Theophanous was pleased to announce the AUS$5bn Monash project to transform brown coal into diesel with CCS – this is biggest of its type in the world.

How do we bring the technology to market? This requires a market for carbon. Victoria developed a model for an emission trading scheme, accessed via the web, a cap and trade model.

Renewable energy sources are important and Victoria is keen to introduce renewable energy, to grow from 4% current production to a target of 10%, including wind- and solar-based production.

4.2.1 Questions & answers

What impact would an Australian ETS have on the price of electricity? Model developed by all state jurisdictions excluding federal government. It included economic modelling, which predicted price increases of around AUS$30 pa for a typical household during first 10 years, increasing to AUS$50 thereafter. However this does not include external environmental impacts arising from climate change.

Do you think current stakeholder dialogue is enough or will more environmental impacts be needed before real action is taken? Debate has been more intense recently. Victoria's 10-year drought has helped to focus the debate and could be due to melting glaciers, which have shifted winds that have previously brought Victoria's normal rainfall. This is a symptom of climate change and an ETS could help to mitigate this. We can look to the international agreements on ozone protection and CFC reductions as a hope that such agreements can be achieved.

What do you see as the next step in 20 years for Victoria? If re-elected, we will move to implement the ETS at last on a state basis, if not at federal level and will address energy efficiency through mandating.

4.3 IEAGHG overview on network activities – John Gale, IEAGHG R&D

Congratulations were given to CO2CRC for taking the opportunity to gain benefit of the delegate's attendance for a peer-review of the Otway Basin pilot project.

An overview of IEAGHG's network support in six networks was presented, on both capture and storage (capture, oxyfuel, biofixation, risk assessment, monitoring and well bore integrity).

A large number of monitoring techniques have been developed and this has led to the online monitoring selection tool being developed by BGS.

Only a few CO_2 storage demonstration projects have been instigated so far but more research projects are coming. So far, no evidence of leakage has been observed. Selected projects Weyburn, Sleipner, Rangely (where CH_4 microleakage is biologically converted to CO_2) were briefly reviewed. It was concluded that we can not define a generic leakage rate.

A storage facility should be designed for zero leakage. Wellbore integrity and performance assessments are being developed. Remediation strategies have been estimated to cost around \$0.1 per tonne, estimated from an IEAGHG study. Ecosystem impacts currently being reviewed by BGS.

IEAGHG will develop briefing papers, information sheets and topical reports – which aim to develop positive but unbiased messages on CCS safety and environmental impacts.

Charles Christopher, BP – CO_2 is less dense than surrounding fluids therefore wants to migrate upwards. It was recognised very early on that monitoring was very important. The CCP project had 2 aims: reducing capture costs and establishing safe storage. Therefore, technologies were reviewed. 4D seismic is a good method but has minimum detection limits reducing its usefulness for verifying stored volumes. Key issues are both technical and non-technical and include:

Technical issues:

- What are method sensitivities?
- Which methods do we use in what environments?
- How long do we need to monitor?

Non-technical issues:

- Who is the audience?
- Do they understand technologies?
- How does this understanding influence people's opinions of storage?

An example of gas storage was presented close to Houston and a project in California is planning to store CO_2 store under Los Angeles, including pipelines through LA.

Questions:

How do you address perceived risks within communities? Comparative risk assessments is very difficult. Difference may be due to voluntary nature of some risks.

4.4 CO2CRC Otway Basin Pilot Project Organisation – Peter Cook

An introduction to CO2CRC was provided: started research into CCS in 1998, now has a budget of AUS$140m over 7 years and 100 researchers, through to 2010. The need to implement clean energy technologies is increasingly being recognised by coal industry and power industries. Many government initiatives have been launched and CO2CRC is collaborating internationally e.g. Frio project. New Zealand part of CO2CRC (a Kyoto signatory). CO2CRC needs to engage more with power companies.

CO2CRC has three strands: capture, storage and pilots and demonstration projects, with the aim of assessing scope for CCS across the Asia-Pacific region and to encourage new commercial opportunities.

Several Australian projects were reviewed:

- Monash Project – AUS$5bn brown coal to diesel with CO_2 storage offshore.
- Hazelwood post-combustion capture will be retrofitted at brown coal power station.
- Zerogen project in Queensland to assess storage potential.
- Oxyfuels project
- Fairview CO_2 ECBM project.
- Gorgon project is a large LNG project with 4Mt CO_2 pa due to start in 2010 or later.

The Otway Basin Pilot Project was briefly introduced. The Gippsland Basin has forty years of oil production with an estimated 6Gt of storage capacity. In contrast, the Otway Basin is mainly offshore with limited gas resources, divided into a series of fault blocks, which contain a number of gas fields. One advantage of the Otway Basin is the availability of cheap CO_2. The storage target is a depleted gas field – both owned by CO2CRC. The original concept was to separate CO_2 from CH_4, but now planning to inject all the gas, though planned 97% CO_2 injection within 12 months. Baseline seismic and fluid geochemical surveys have been undertaken.

The management structure of the project was explained. CO2CRC Pilot Projects Ltd takes on liabilities for the injection and monitoring project. Participating companies have collectively agreed to underwrite the excess risks and provision operating committees.

The total cost for the Otway Basin Pilot Project is AUS$30m with an extra AUS$10m for the planned capture plant. An outline schedule was presented with a new well planned for February 2007 and injection planned for mid-2007.

Questions

How do you manage knowledge generated by such a large project? This is very challenging to get information published and a recognised area for future improvement.

Was the Site chosen for availability of CO_2 source rather than as a good CO_2 storage project? How good is the site for storage? Correct. It was never designed to be a future large-scale project. Faults are thought to be good sealing faults since they have retained natural gas and will be injecting into a depleted gas field. There is lots of focus on geomechanical issues.

Could Otway provide opportunities to study fault-controlled leakage pathways? Agreed but prefer that Otway didn't leak to build confidence. It does give opportunities to monitor across faults.

Did the field contain any CO_2 originally? No.

What phase is CO_2 in the mixed CO_2/CH_4 injection stream? CO_2 will be supercritical, based on phase modelling. It should be possible to monitor the CO_2 even with the presence of residual CH4.

5. Session 2 – Well-based monitoring

5.1 Keynote: Well-based monitoring – overview presentation of wells for monitoring – Rick Chalaturnyk

The purposes of monitoring are multiple, including fine-scale processes, operational issues and regulatory requirements. Well-based monitoring is a big component of many CO_2 EOR projects. Measurements include injection pressure and temperature, stream composition, and injection rates. Downhole pressure measurements can include: real-time gauges (electronic or low resolution), fibre optic systems, bubble tubes.

Well based geophysical logs can include – cement evaluation, saturation, resistivity, dual sonic, VSP, geochemical sampling and passive seismic.

To optimise monitoring one needs to be very aware of the specific well completions and geometries. Well geometries could include multilaterals in overlying aquifers. The locations and numbers of wells are very important.

Different monitoring levels can be recognised: operational, verification and environmental

Examples of deployment:

An example was presented of casing conveyed pressure and temperature measurements of reservoir and bottomhole pressures, in a horizontal well with both reservoir and internal production pressures. Sensors were cemented in place. Temperatures monitor cement hydration. Pressure tests can affect casing materials. During drilling through the end-plug, immediate communication between reservoir and internal production pressures can be observed.

An example of integrated permanent installations of geophones, pressure and temperature transducers and other monitoring equipment was presented. The Penn-West CO_2-EOR pilot project will inject 35tons CO_2 per day, in an inverted 5-spot well pattern. Remedial cement squeezing was required in a monitoring well. Three pairs of P-T gauges, 8 geophones and 2 fluid sampling ports were installed. Pressure sensors can monitor well completion processes. When the well pressures dropped below reservoir pressures, an influx of reservoir fluids occurred, which caused a small channel to form during cementing, which allowed fluid escape at 7litres per minute. Remediation involved a tubing punch, which could be monitored using the installed pressure gauges.

Questions:

Were there any issues during cementing around instrument cables? No, we used armoured cables and could reciprocate during completion to around half a pipe.

5.2 Overview of well-based monitoring approaches at the Frio2 project – Susan Hovorka

A search for a site to demonstrate storage within the Gulf of Mexico identified the Frio site. Principal objectives of Frio2 are to determine storage permanence (residual saturation, CO_2 solution), to evaluate post-injection monitoring and to develop novel monitoring tools (such as tubing conveyed seismic array).

At the end of the Frio1 project attempts to produce CO_2 when the well was opened did not produce any CO_2 due to residual saturation. The well was swabbed, and a weak gas lift with a water to gas ratio of 13,600 to 1 was achieved. CO_2 was produced at 0.17 tons per hour and it was therefore concluded that the risk of leakage was small.

An overview of the geology at Frio was presented: The reservoir comprises Oligocene fluvial & reworked sandstones with a porosity 24%, 4.4-2.5 mD. The reservoir is mineralogically heterogeneous which controls permeability. In Frio2, it is planned to maximise geochemical interactions rather than force breakthrough.

Reservoir modelling was used to design a monitoring programme but reservoir heterogeneity caused a lot of uncertainty in permeability prediction, with consequences for monitoring frequencies and durations. Injection and observation wells were 30 m apart with wells instrumented with U-tubes. Cross-well seismic was used to monitor fluid migration.

Fluid geochemistry in the monitoring well was observed during the injection well shut-in. Temperature variations also indicated CO_2 plume movement, which cools formation. Fluid sampling also identified CO2 breakthrough in the monitoring well.

Question: Was the lack of production at end of Frio1 due to CO_2 movement updip? No, CO_2 was residually trapped.

5.3 Early geochemical and geophysical results from Frio2 – Barry Friefeld

Instrumentation at Frio includes a seismic source in the injection well, hydrophones (7 above packer, 17 below top of packer, in and below the perforation interval) in the monitoring well, a U-tube sampler in both wells and P&T sensors. Not all hydrophones worked following installation.

Preliminary results indicate a 1.5ms delay in arrival time following arrival of CO_2. The seismic source and PT sensors interfered with each other. Very early travel time delays (much less than expected) were observed which enabled both spatial and temporal changes due to CO_2 arrival to be detected.

A re view of the U-tube experiments was presented. The objective is to sample fresh fluids, both brine and supercritical CO_2 need to be sampled at in situ conditions (to minimise degassing) to quantify the gas: water ratio. Tracer experiments demanded almost one sample per hour. Wireline sampling was used for baseline and post-injection monitoring but was found not to be suitable for injection geochemical monitoring. Gas lift sampling was considered since it was difficult to recover downhole conditions, disturb flow-field and control sample rates. The U-tube technology was described. 52 litres of sample recovered with both phases recovered at a rate of 1 sample per 70 minutes.

Liquid samples were analysed for aqueous geochemistry, pH (showed a reduction to pH3.8), and tracers. Gas samples for CD_4 tracers and other samples. Results from Frio1 indicated some atmospheric contamination to gas compositions.

Tracer tests included CD4, perfluorcarbon, Kr Xe tracers. Xe, Kr tracers indicate rapid CO_2 solution since arrived at the same time as the CO_2.

Multi-function completions, and fibre optic based sensors will be important.

A distributed thermal perturbation sensor (DTPS) – distributed temperature sensor coupled with a heater was described. By comparing measured temperatures over time it is possible to see changes in heating as flow occurs.

Further refinements will include integration of monitoring technologies, with installation of duplicate U-tubes to sample both gas and liquid which will be engineered for simplicity and robustness.

Questions:

How do you factor in the reservoir heterogeneity in the interpretation of tracer arrival times? Geophysical measurements provide an "integration" along the flowpath.

Do you engage non-specialists? Yes, walk them through the whole process.

How do you communicate results to media? This requires careful management and coordination.

5.4 Logging techniques for CO_2 saturation and well integrity evaluation – Laurent Jammes

Performance and risk management are fundamental and requires a clear risk treatment plan. Risk management requires site characterisation and modelling. Risk treatment requires monitoring. Monitoring objectives are variable and include performance control and risk control (containment, contamination), as well as dynamic model calibration.

Well-based monitoring techniques were reviewed:

CO_2 saturation can be monitored using time-lapse density (gamma), based on photon emission, with measurement in a number of detectors. The sensitivity depends on the porosity and formation fluid density. Time-lapse neutron-neutron porosity, infers H_2 atoms from neutron scattering by H_2 in the pores, could be used for CO_2 saturation measurements with potential selectivity for CO_2/CH_4.

Neutron capture cross-section measurements (neutron-gamma), measuring gamma rays emitted following a neutron burst, are dominated by chlorine which measures the brine chlorine content. This was used at Frio1. In saline waters large differences are observed due to CO_2 concentration.

Neutron inelastic scattering, produced following fast neutron interactions with gamma rays, can be used to measure the C/O ratio. It is selective to CO_2/CH_4, CO_2/brine and possibly CO_2-rich phase and dissolved CO_2 (though the latter maybe too small).

Resistivity is also very useful: the well casing acts like a large electrode, with the current returning to the surface. It is sensitive to cement resistivity and dissolved CO_2 content. It involves two steps: measures current drop across the formation and then the casing resistivity is measured.

Cross-well electromagnetic surveys can be used to monitor the saturation distribution and monitor the injection front and CO_2 plume. Attempts at Frio were not successful, since the changes in resistivity were small and the wells were too close together and consequently, changes were below the signal to noise ratio.

Sonic logs are sensitive to the CO_2/brine ratio, although it is difficult to measure CO_2 saturations above 50%.

Downhole fluid analyser, based on IR gas analyser, are under development. H_2O and CO_2 peaks overlap in the near IR, so need to remove the water before analysis can take place.

Well integrity evaluations can be made using a variety of tools. Calliper measurements use a multifinger calliper tool with 24-60 fingers. Cement evaluation tools were identified since cement slurry displacement problems can occur for a variety of reasons. Sonic acoustic wave measurements are the classical method but recently ultrasonic tools are used. The key challenges for cement evaluation are being able to discriminate cement, liquid and gas, requiring an estimation of acoustic impedance behind the borehole wall. This works well with traditional cements but newer, lighter cements or contaminated cements have lower acoustic impedance which can be confused with water. To get around this, ultrasonic is combined with flexural impedance analysis of casing to distinguish cement density. Finally an isolation scanner can image the interface between the formation and cement to estimate casing eccentricity and cement debonding.

In summary, well measurements can complement other techniques and can provide accurate local measurements. However they need validation and demonstration in CO_2 environments. Additional possibilities when access to wells is available could include installing permanent sensors, sampling and cross-well and well-to-surface surveys.

When designing a monitoring programme it is important to answer the following questions:

- What do I want to monitor
- What properties can I measure?
- What variations can I measure?
- What techniques can I use?
- Sensor specification
- Location of sensors
- Measurement interpretation

Questions:

Can we install complex instrumentation and accurately locate your position? Possibly, but not too familiar with this.

5.5 Time-lapse well logging to monitor the injected CO_2 in Nagaoka Project – Daniji Tanase

The Nagaoka project is located at a gas field in a Miocene to Quaternary sequence with an anticlinal structure. Injection was into a 15° dipping target reservoir at ~1100m depth, in early Pleistocene sediments, at 2km from the crown of the anticline. A total of 10405 t of CO_2 was injected at an injection rate of 20-40t per day, with monitoring and simulations. Three deviated observation wells surround the injection well.

Site characterisation involved coring, cuttings analysis, logging, pump tests, step-rate tests and laboratory-based analyses of cores. Fluid samples were also taken.

A large earthquake occurred following well completion and subsequent FMI and CBL logging indicated no damage.

CO_2 was detected by cross-well seismic between the wells at various times during and following injection, and bottom hole P&T were measured in all observation wells. Continuous passive microseismic monitoring was performed.

Advanced well logging was repeated 31 times during the experiment. Changes observed include decreases in P-wave velocity, and neutron porosity and an increase in resistivity. Repeat surveys allow mapping of breakthrough with time. This can be combined with fluid sampling to calibrate logging responses to provide estimates of CO_2 saturation. Repeat borehole logging also allows comparison between estimates of porosity between different techniques (neutron and NMR). Spinner tests monitored flow within the borehole.

Future plans include continued post-injection monitoring, fluid sampling and logging of the injection well, and interpretation of 3D seismic. The simulations will be history-matched with this additional data.

Questions/comments:

This experiment provides an opportunity to identify data precision and accuracy with the repeated logging techniques used.

Did you use USIT for determining CO_2 effects of cement integrity? See presentation by Ziqui Xue in session 3 .

5.6 Discussion – focus on how well-based monitoring fits within the MERV discussion on Monday, its importance relative to injection phase and post-operational phase – Chair, Kevin Dodds

It was suggested that dynamic monitoring will be needed for CO_2 storage and is not often practised in the oil & gas industry.

Resistivity images are very powerful in showing the CO_2 plume. Ideally, permanently installed arrays of resistivity measurements would be very useful. But how would this be developed? This is an opportunity to bring additional groups who are using ERT for pollution studies. This needs more than one well which has significant cost implications and is therefore unlikely to be used widely for large projects due to costs. However, in a large project, observation wells may be more possible (for example, Gorgon has 2-3 observation wells).

Regulators would like to be able to monitor plume migration as this will be important to many communities.

It was suggested that if enough pilots are done, numerical simulations can be verified which will reduce the need for lots of detailed monitoring. It was countered that simulations will still need to be validated against monitoring data.

With commercial projects, we must have confidence that we can monitor where a CO_2 plume is located. It will not be possible to monitor plume migration in large commercial projects with wells. Imaging is useful to build confidence. In contrast, models have inherent assumptions and experience suggests that heterogeneities add a level of unknown complexity that is difficult to predict. The models need to be verified on a regular basis.

In Texas, for Futuregen projects, site selection is trying to avoid wells to minimise leakage risks. Public concern is focussed on water supply which requires monitoring of aquifers. Seismic may not be suitable for monitoring for leakage. In contrast in Alberta there are many wells so instrumentation is not a problem.

A new offshore well is AUS$50m in Australia, so need to maximise all existing wells and any instrumentation will require additional tubing and provides more risks for leakage. How can we extrapolate well data to the reservoir scale? Does this require future technological development? Some techniques can be upscaled already.

We need to determine the workflow between EOR and industrial scale CO_2 storage projects. Different monitoring tools must be integrated to minimise costs as industry doesn't want to continually shoot 4D seismic. Costs are not likely to be an issue since previous estimates indicate that costs will be very small per tonne of CO_2 captured.

There is probably an issue of education for regulators who will have a mindset that comes from, for example, landfill. Would some sentinel wells that monitor pressure be sufficient? In Class 1 wells in US, and acid gas injection in Canada, the only required monitoring is for annular pressures for well integrity. All other issues are covered by modelling and simulations. If monitoring data matches modelling, then this is probably sufficient. However, at Frio, still got breakthrough slightly ahead of expectation based on reservoir modelling.

Regulators posed the following questions:

- What are we trying to protect?
- How do we monitor to show these are being protected?
- What are the performance monitoring techniques – these will go in guidelines.
- Also monitoring for risk management will not be mandated but will be for operators to decide.

Differences should be recognised between demonstration and commercial projects. Early demos will require more monitoring. Large commercial projects may require more than one well, which could be designed to act as monitoring wells in the future.

Monitoring depends on the structure: a closed trap could be much simpler (a single monitoring well could be enough) than dipping aquifers with heterogeneity, which would require more monitoring.

Regulators commented that we are funding demonstration projects that are supposed to develop monitoring techniques. What do we want to do? We can't provide monitoring to demonstrate no leakage over 1000 years. No performance standards have been defined in terms of leakage rates. We can not define leakage rates for a specific site. Regulators should be flexible and try to match different demonstrations techniques to appropriate projects.

We should separate performance standards for accounting from local HSE. These will require different monitoring and modelling projects. If you can quantify leakage below the discount rate being applied in Canada, then this is a way of paying for monitoring.

It was concluded that we need to define zones and need guidance from regulators as to what we have to protect, so we can design appropriate monitoring programmes.

6. SESSION 3: MONITORING FOR CAPROCK INTEGRITY

6.1 Overview of issues or mechanisms at play in seal integrity and identify monitoring processes or techniques that may play a role in assessment managing caprock integrity risks – David Dewhurst, CSIRO

Why do seals fail? Two types of failure were defined: capillary failure, where buoyancy pressure is greater than the capillary entry pressure and mechanical failure (fracturing faulting and reactivation). Two types of seals can be identified: cap seal and fault seal.

To calculate the seal capacity (or height of trapped column) we need to constrain wettability (contact angle) at reservoir conditions.

Seal capacity issues include: the sample size – which requires a regional geological approach and the seal geometry and lateral extent – which can introduce lithology changes, sequence stratigraphy, seismic resolution.

Characterisation of fault seals need to consider juxtaposition, seal capacity and reactivation. Fault zone properties include: cataclasis, diagenesis, clay smears and grain sliding which can influence fault strength. The juxtaposition of shales with reservoirs is important.

Fault rocks can be cemented, and can be graded by phyllosilicate content. At >40% phyllosilicate smears develop, which can have very low permeabilities, <500nD. These can be predicted by the shale gouge ratio (SGR) by estimating shale proportions from gamma logs. At SGRs greater than 20%, the fault will seal. If the framework models are inadequate then subsequent fault sealing assessments are useless. Issues requiring further study include: FSA's only account for geomechanical properties, and exclude diagenesis. Sealing is assumed to be due to clays which may not be true. Gamma ray is not very accurate. CO_2 wettability is poorly constrained.

Fault reactivation includes 3 types of shears, shear failure, extensional and intermediate differential stresses, depending on orientations to principal stresses. Reactivation risking can be mapped onto 3D seismic to identify those faults at greatest risk of reactivation.

How to account for changes in pore pressure during injection? Geomechanical modelling can be coupled to flow modelling to estimate stress changes. Passive seismic can be sued to monitor and evidence presented suggests events cluster on lager fault planes. 4D seismic can be used to monitor flow by monitoring pressure changes.

In summary, many techniques have been developed but there remain several key issues. Knowledge gaps include wettability, diffusivity, reactivation and poroelasticity. Geomechanical modelling must be integrated with microseismics and 4D seismics.

Questions

When taking pore pressures higher than lithostatic, what measurements could be needed? One idea could be leak off tests for minimum horizontal stresses

6.2 Using geochemical techniques for monitoring seal integrity – Ernie Perkins, ARC/CO_2CRC

The following definition of a seal was proposed: A very significant decrease in porosity or permeability that minimises fluid migration. Why do we need to monitor across or above the seal? To demonstrate a seal is effective.

It is a concern that CO_2 could affect seals: while this is correct, longer term reactions could prevent solution. High rock/water ratios minimise reaction, preventing CO_2 migration into the seal. Some seals are not reactive.

How to monitor seals? Look for tracers, changes in composition, isotopic fingerprinting, and reactive components. Demonstration projects and analogues can constrain these reactions. Case history of Weyburn was presented with gas composition and isotopic data.

Monitoring domains can be defined and some domains will be monitored for public confidence assurance reasons. For example, the Otway Basin Pilot project undertaking atmospheric, soil gas and monitoring in shallow wells (constrained by location). Penn West used fluid chemistry both in the reservoir and above the aquifer to provide assurance.

To determine the sampling frequency is difficult but the approach is to assume how the fluid migrates, determine migration volume and rate, and then calculate if a technique would see a leak.

Key issues are:

- How big a signal do we need?
- Where and when?
- What types of monitoring?
- Closer to storage the more spatially restricted the sample locations and the more difficult it is to obtain samples.

Questions:

The Kharaka et al paper on Frio caprock stated that buoyant force will bring CO_2 into contact with seal and that there is not enough rock to buffer the pH change. Most reaction occurs on the plume front, with little reaction within the plume due to a lack of water. Diffusion is a very slow process.

Are atmospheric and soil gas sampling offshore possible? See presentation by David Etheridge in Session 4.

6.3 Reservoir simulation and coupled geomechanics to calculate pressure and stress changes that feed into monitoring design – Lincoln Patterson, CO2CRC/CSIRO

Equations of multiphase flow were explained. Saturations and pressures are calculated. Biggest uncertainties in the simulations are porosities and permeabilities. Key monitoring therefore is pressure and saturation.

Examples of modelling approaches presented including the field at the Otway Basin Pilot Project. Modelling can be used to help define locations of monitoring and estimate velocities of migration. Modelling can be used to guide monitoring programme, including the choice and location of monitoring techniques. Modelling can be used to interpret monitoring data.

Does it matter if models are slightly different to monitored data, as long as containment is maintained?

6.4 Discussion/seals & MERV: Focus on how monitoring fits within MERV discussion from Monday, its importance relative to injection phase and post-operational phase: Chair Rick Chalaturnyk

Fault seals are a big focus in Australia but not addressed in the US. Dept of Energy is risk averse and do not want to hear about failure. Should we have projects that deliberately look at fault migration? We have analogues that can provide some answers; for example, gas storage projects in Otway and upstate New York are against faults with no evidence of leakage. However, there are some gas storage faults that are leaking. It should be recognised that there are considerable differences between CO_2 storage and natural gas storage.

How could monitoring help avoid blow outs due to fault reactivation? Techniques could include microseimics, tiltmeters and Differential GPS. To measure stresses requires well access in faults which are unlikely to be located in these areas. Strain measurements have been obtained for some North Sea fields but this is embryonic. It was felt that accuracies should be OK for stress measurements.

Fluid extraction can create microseismic events and cause ground movement and therefore by analogy CO_2 storage could create similar events. Does USDOE monitor for microseismicity? Not sure but a small number of projects can be attributed to creating microseismicity. Within UIC this is specifically addressed. Microseismic monitoring at Weyburn indicated only a few events with large pressure gradients– but this may be due to pressure relief from oil production.

Questions posed:

Should we base monitoring on risk predictions modelling?

Should fault reactivation and pathway migration be actively studied?

CO_2 acidification can cause mobilisation of metals.

Brine displacement into potable waters could be an issue. The volumes of displacement may not be significant.

How do you monitor in a large plume footprint? Utilise other wells as far as possible.

Laboratory work may be needed to study effects of pH on clays – some evidence from clay liners in landfill sites.

What is the worst case scenario? Hard to get significant leakage along fractures. 7 blowouts have occurred in EOR floods in Texas and in Wyoming.

7. Session 4: Containment and Integration

7.1 Susan Hovorka (chair) – Review of day 2

Review of key messages from Day 1

Looking forward to recommendations at the end of this workshop:

- What constitutes validation?
    - Affirmative data to validate model predictions,
    - Direct measurement of protected resources
    - What are we trying to quantify?
    - IPCC statement:

      It is very likely that the fraction of CO_2 retained is more than 99% over the first 100 years

      It is likely that the fraction of CO_2 retained is more than 99% over the first 1000 years
    - Protective of HSE criteria
    - Best possible practice: ALARP
    - Value of looking at retention not by percent
        - By mass
        - With time, by area, with pressure

- What retention can be predicted?
    - By natural analogues
    - Modelled – inputs from lab data, extrapolation of small scale observations, statistical approach
- What retention can be verified?
    - Accounting procedure
    - Point measurements
    - Integrated measurements

- Selecting the tools
    - Fit for purpose, all sites unique, select from MMV tool kit
    - Check up analogues
    - A procedure to follow that tailors test program for each site: Gateway process

- How do we set performance standards
  - Thresholds – what is action?
  - Issues of sensitivity, precision, accuracy, false assurance, false positives, need validated methods to provide public confidence

7.2 European CO_2GeoNet Research Network – Interim report: Nick Riley

The aims of the network are to integrate within the European Research Area with a joint research portfolio focussing on CO_2 migration and leakage mechanisms and impacts.

Why study leakage? Leakage is the main issue of concern amongst public, NGOs and regulators. HSE, ecosystem protection, resource & property damage, carbon credits, public & regulatory acceptance, efficacy & risks of CCS need to be compared to other climate change options.

As industrial sites are not designed to leak, we need to use natural analogues and field-based experiments.

The concept of source to pathway to target to resource was introduced.

We need to understand what is measurable. We need to be able to monitor storage security and defend unfounded leakage claims and we need be able to recognise leakage.

Terrestrial impacts: An overview of work at Latera, a collapsed caldera, was presented. Investigations of natural seeps, microbiological, invertebrate and mineralogical/geochemical responses to both CO_2 and H_2S are being undertaken. Testing of airborne remote sensing techniques raised the issue of false positives. Open-path laser trials have been undertaken.

Collaboration with University of Nottingham ASGARD facility is being undertaken to conduct experiments on plant responses to CO_2. Epidemiological and sociological studies at Ciampino are being undertaken to begin process of determining how populations may respond to natural CO_2 seeps.

Aquatic impacts: aquatic systems are more sensitive to CO_2 changes. An overview of the Laacher See region and microbiological studies was presented. Benthic chamber experiments via collaboration with RITE in a Norwegian fjord were reviewed.

Panarea video was shown which provides an introduction to shallow volcanic offshore seeps. This area will form a PhD thesis for a student at University La Sapienza Roma.

In summary, the leakage issue is a key concern for many stakeholders and should be addressed with transparency, honesty and openness. The evidence base is required to build confidence. Governments and regulators need evidence to develop appropriate regulatory framework.

Questions:

How many anomalies in remote sensing data are really due to CO_2? Still working on this but many, if not most, identified anomalies are not related to CO_2.

7.3 Walkaway VSP for CO_2 Monitoring at the Penn West Pilot, Alberta – Marcia Couelsan Crewes

The Penn West CO_2-EOR Pilot is injecting into the Cardium Formation, a sandstone and conglomerate reservoir with a potential for up-scaling to full commercial production. Approximately 70,000 wells are located within the region. CO_2 will be injected into two deviated wells at 70 tonnes per day at 20Mpa. For comparison, the average Canadian produces about 5 tonnes per year. The dominant fracture trend is NE-SW and the expected sweep will be along this trend. Although the Cardium is poor P-wave reflector but this is not a problem since looking for differences in 4D surveys.

The monitoring well is equipped with and array of 8 geophones. A review of the Vertical Seismic Profile (VSP) process was presented. Advantages of VSP include higher frequency bandwidth than surface seismic, which leads to increased resolution, provides correlation between the surface and depth, and provides indexed well logs. VSP can be used to improve surface seismic processing (velocities, Q estimation and anisotropy), and allows for passive seismic. A comparison of VSP with surface seismic with higher resolution and corresponding well indicates S waves are more sensitive to pressure changes and could be a useful future data source.

VSP is used in a time-lapse mode to monitor flood and look for leakage in the overburden. The first survey was acquired in December 2005, and the second is planned for early 2007. A change in P-wave velocity and fluid composition is expected to increase the Cardium Formation as reflector. There are several challenges to time-lapse VSP. One example is non-repeated shots which can introduce very strong artefacts in difference datasets. Finite difference models were used to investigate the effects on non-repeated shots, and repeatability issues. Seismic noise can be caused by geological heterogeneities. Increases in amplitudes in the Cardium Formation were observed in the models as a result of the CO_2 flood. Travel time increases at the base of the reservoir show a systematic increase of 0.2 ms.

In conclusion, shot repeatability is very important. P-wave amplitudes have increased and comparisons of datasets indicate excellent repeatability. Walkaway and 3D VSP are critical to imaging thin reservoirs and formations where surface seismic does not show any changes.

Based on the experiences at Penn West, a proposed approach for monitoring would be:

- Instrument entire wells with geophones to monitor overburden
- Install geophone arrays in several wells
- Potentially instrument in production and injection wells
- Increased integration between geophysical and geochemical monitoring.

Questions:

Did amplitudes increase below Cardium? Effects of data processing (cross-equalisation processing was not done) introduce artefacts.

Are there advantages of a seismic source generating fewer S-waves? Possibly, but not sure how available these are.

Need a baseline shot at fixed location? Yes, need to ensure exact repeat locations are used.

Repeatability can be affected by weather conditions? Yes see a static shift due to frozen ground or wet ground.

Is aspiration to ensure similar ground conditions as it will change waveform? Yes need to be careful with this.

Is cross-equalisation almost essential for looking at subtle effects? Yes, this is very important.

How much CO_2 was injected by the time of the repeat surveys? ~15000-25000 tonnes can be estimated.

7.4 Field investigation results after the Mid Niigata pref. Earthquake at the Nagaoka injection site – Ziqiu Xue

Main objectives of this study are to detect CO_2 breakthrough and CO_2 movement through formation pressure monitoring. Time-lapse well logging was reviewed.

Following the start of injection on July 7th, 2003, an earthquake occurred on October 23rd, 2004, after ~9000 tonnes of CO_2 had been injected. The epicentres were very close (~20km) to the site with magnitude 6.8 recorded at 10 km. Following the earthquake, CO_2 injection was stopped and pressure systems automatically shutdown.

No damaged was observed in any of the site infrastructure including the liquid CO_2 tank, injection and observation wells, and pipelines. Some damage was sustained on the access road. Some sand liquefaction and small fractures were observed at the surface close to observation wells.

Following the earthquake, cement bonding, induction, sonic and neutron logging and cross-well seismic (comparing differences in waveform), formation water by Cased hole dynamic tester (CHDT) were all performed. No difference was observed in the pressure decay curves indicating no additional fracture reactivation or formation damage. No correlation between injection rate and microseismics was observed. CBL logging indicated no damage to cements above and below the formation. SUIT also confirmed no damage observed at formation level. No anomalies were observed on sonic, induction or neutron logs. Similarly cross-well seismic tomography indicated that no CO_2 leakage into the caprock had occurred.

Cased hole dynamic tester (CHDT) detected changes in resistivity in specific strata within the Zone 2 injection zones. The biggest changes were due to high (99%) CO_2 concentrations displacing the water, below this zone large amounts of CO_2 have been dissolved into the water. Concentrations of Ca, Mg and Fe also increased in waters in this zone.

In summary, no differences in drawdown curves indicate the integrity of reservoir was maintained following the earthquake. Cement bond logs and detailed well logging indicated that well integrity had been maintained. Cross-well seismic also confirmed CO_2 containment.

Question:

In Japan, are there any design requirements built-in to well design? Ideally should select a safe site, but in Japan this is unavoidable. Therefore this is always considered in project designs.

7.5 Assessing the efficacy of CO_2 storage by atmospheric monitoring – David Etheridge

Why do we need to monitor the atmosphere? To verify containment and complement subsurface monitoring since the atmosphere is where greenhouse gas climate change takes place and where health and safety impacts are likely to be seen if a leak should occur.

Atmospheric monitoring can be continuous, unattended, non-invasive, with integration across multiple point and diffuse sources.

Monitoring should be able to detect CO_2 concentrations, attribute to the stored CO_2 (by using isotopic signatures or tracers) and quantify the leaks (using transport and dispersion, CO_2 fluxes). The literature suggests that we need annual leakage rates lower than 0.1% globally, to ensure sustainability of storing large amounts of carbon. Dispersion modelling shows that such leakage would cause small CO_2 changes compared to background atmospheric variations.

Historical variations in baseline CO_2 (i.e. unaffected by local natural or human sources) and other gases at Cape Grim (NW Tasmania) were reviewed. Here seasonal effects dominate CO_2 variations and long-term trends show increases. In the local atmosphere, backgrounds can show very large variations against which we need to be able to detect leaks. This can be achieved through adding tracers or using natural tracers, determine or model natural fluxes, and employ strategies based on temporal variations.

Tracers can be naturally occurring (isotopes, trace gases) or introduced (e.g. SF_6, CF_4). CO_2 and tracers require continuous high precision in situ analysers or flask air sampling that must be analysed in laboratories.

At Otway, baseline (ocean-sourced air) CO_2 is modified by biospheric exchange over 4km fetch from the coast. Biospheric exchange can be measured either from flux tower or using flux chambers, which are mature technologies.

It is important to predict how potential plumes are dispersed in the atmosphere using transport models.

In conclusion, atmospheric monitoring may be a regulatory requirement. Acceptable atmospheric leakage rates are just detectable with the sensitivity depending on setting and the amounts of CO_2 injected.

Questions:

What are the comparative costs to analogue well logging? This could be done (cf: Benson report) but atmospheric monitoring is likely to be relatively cheap, since it utilises mostly existing monitoring techniques and doesn't require boreholes etc.

How is the leakage rate defined? It is a constant leakage rate relative to the original amount injected.

How does precipitation affect atmospheric concentration? Yes it does affect soil gas permeability and biosphere and microbiological productivity.

Could ozone be used? This would be very challenging.

The target scenario is to assume a fault leakage scenario. The site comprises a 100m perforated pipe at 2.8m depth in glacial till. Background data such as wind direction and speed, with variable wind direction was collected. Background CO_2 eddy covariance fluxes have been measured. Energy inputs were determined. The influence of low-permeability silt layers to horizontal migration was investigated. Soil textures were characterised.

Vertical injection tests were described. Soil gas sorption tubes were used to monitor tracer distribution. Large fluxes were observed over an area of 2m diameter. Ground-based hyperspectral imaging to monitor plant stress proved less useful due to the late season and lack of chlorophyll but some plants may be better suited for longer injection tests.

Resistivity measurements may be able to monitor the CO_2 plume. Isotopic measurements indicate shifts in isotopic signatures both in chambers and canopy air. A LIDAR system is being developed to monitor atmospheric CO_2 concentrations.

Conclusions are that concentration and flux measurements are probably less sensitive than ^{13}C measurements. Soil moisture and temperature are important to soil flux. Depending on the geometry of the underground source, surface fluxes may be measurable.

7.7 Wellbore integrity at Sheep Mountain: Charles Christopher

Brief updates of the experiments at the Sheep Mountain CO2 production facility were presented. Wells have been in place since the 1970s and have been exposed to wet CO_2. Tubing that was pulled after 18 years showed no corrosion. Five side wall plugs were taken, including from both formation and caprocks. CO_2 movement was observed with minor cement alteration (red colouration).

7.8 Discussions: Seismic and atmosphere monitoring and MERV requirements

Soil gas and atmospheric monitoring suggest CO_2 could migrate horizontally a along way from the injection point. This means that near-surface site characterisation is very important to define where monitoring should be placed. Atmospheric monitoring provides opportunities to monitor large areas. For example at Gippsland, site characterisation and modelling shows that CO_2 can migrate 10's km. This is a familiar problem to regulators.

Should early demonstrations bother with near-surface conditions directly above the reservoir, when CO_2 could leak a long way horizontally? This confuses people that this is where CO_2 could leak.

Soil gas measurements can also be used to identify potential migration pathways as part of site characterisation and this can contribute to an understanding of migration pathways. Analogues of gas movement in shallow subsurface exist. Near surface monitoring can also be used to determine background fluctuations and show that the CO_2 is not from the reservoir.

Atmospheric monitoring should be done in conjunction with ground-based measurements.

At ZERT, they are developing open-path lasers for permanent installation.

8. SESSION 5: LATROBE VALLEY CASE STUDY

8.1 Review of Monday Regulatory Outcomes – Mark Bonner

The regulator's role is still in its infancy and a need to build this capacity was recognised. Researchers need to educate and inform regulators. There is a need to focus the science to answer regulatory requirements. Which regulatory analogues are relevant? We will need to use existing legislation as far as possible. Regulators are sceptical about safety in an industry with a poor environmental record.

Key issues

- Key values need to be protected
- How can risks be managed or mitigated?
- What is the role of MERV?
- What is the role of standards-based MERV systems?
- What is the most chronic risk of incidents, what options are there for mitigation, remediation and/or rehabilitation?

Principles of regulation are based on; inter alia, Equity, Efficiency, Dependability, Independence, Transparency, Flexibility, and Consultation

Political realities

- It is a political judgement that ultimately defines the term "dangerous climate change".
- Scientists provide evidence for political judgements to be made.
- Many uncertain tipping points.
- We need to deliver CCS to a public that is still wondering how it all works.
- Politicians want numbers even if they are not understood.
- Key to success is the maintenance of integrity of public confidence.
- Much angst over who accepts long-term acceptability.
- Important to understand private sector risks.
- CCS intuitively offers greater benefits than disbenefits.
- Least developed countries need to slow rate of emissions growth

Our generation is focussed on stabilisation, while the next generation will be seeking absolute reductions. Low or high rates of deployment will impact other options and it should be remembered that CCS is 15-20% of required reductions. If it is going to fail, we need to know sooner rather than later. Proponents disparage other options, which should be avoided. Plenty of tools are available but we need to focus on the real needs of monitoring.

Economically, the cost of getting CCS wrong will be huge. We need to protect the integrity of emission caps for both market and environmental reasons.

There are many analogous activities from which to draw guidance in establishing regulatory approaches. However, there remains considerable confusion amongst policymakers and regulators around key issues of knowing how much knowledge is enough, monitoring capabilities, permitting of long-term storage, monitoring and liability transfer, and management of failure.

Possible approaches to standards, from political, business and social standpoints were highlighted.

The urgency of needing regulatory frameworks now was emphasised.

In conclusion, dialogue is as important as addressing the technical issues, the design basis is crucial and the regulatory approach should be flexible. Transparency and openness are very important. Learning by doing is an appropriate way forward. The long term concepts of storage are challenging for non-experts. Politicians will demand numbers and there needs to be a quantifiable end state. Are we monitoring for a market or environment – if both, compromises will be inevitable.

8.2 The Latrobe Valley CO_2 Storage Assessment

Catherine Poole outlined the Latrobe Valley feasibility study. The delegates broke out into groups to discuss issues raised by the Latrobe Valley assessment.

8.3 Breakout results: Risk evaluation and regulatory recommendations

It was identified that the locations of well, drilled in 70s, was poorly understood and that well integrity could be an issue.

Plume migration is a clear uncertainty due to a lack of existing data. This has required several modelled scenarios to be investigated, which will need verification. The controlling influence on baffles could require verification. Opportunities exist to improve models during drilling of the injection well. 3D seismic considered most appropriate monitoring tool despite trying to exclude it.

The ultimate operator is unknown – smaller operators have less familiarity with CO_2 injection and mid-size operators have more experience but less interest in storage.

Injectivity could be an issue, though current evidence indicates permeabilities are more than sufficient. Fault reactivation was identified as a possible issue.

Regulatory issues: Protecting existing oil and gas resources is currently the biggest concern for existing operators, but the overlying Kingfish field is likely to be depleted before injection starts. Currently the London Convention would exclude this project, as it is storage in an offshore saline aquifer not associated with oil and gas production.

8.4 Breakout results: M&V evaluation – Latrobe Valley recommended technologies using IEAGHG M&V tool.

The Latrobe Valley study was used as a case study to evaluate the monitoring and verification tools that could be deployed to address various MERV aims. The delegates broke out in to small groups and were asked to use the IEAGHG Monitoring Technique selection tool to facilitate their discussions.

Breakout group 2:

The following techniques were thought to be appropriate:

Well integrity: CBL, seafloor (sparker/boomer, biological) for abandoned wells

During injection, could use annular pressure and mechanical integrity.

Faults: seismic, downhole-pressures, falloff tests, microseismicity, history match in post-injection phase.

The group thought the tool was helpful but in some areas the group disagreed with the findings (e.g. downhole pH in post-closure abandoned wells).

Breakout group 3:

Quantification and storage efficiency aims were not selected. Pre-injection monitoring requires regional surface seismic to test repeatability and validate model predictions, and early repeat surveys would be needed due to the high injection rates. If the seismic survey was good, then a permanent array could be installed.

Multibeam echo sounding was selected for surface characterisation.

Discussions centred on the use of a monitoring well for microseismic monitoring – issues of location on plume path required. VSP, passive seismic, downhole chemistry could all be employed in a monitoring well.

Breakout group 4:

Issues over biological impacts on whales of repeat 3D seismic surveys were recognised.

Other identified tools included downhole fluid chemistry (may not be needed due to hydrodynamic trapping), geophysical logs, microseismic monitoring to allay fears of earthquakes with the installations of ocean bottom seismographs. Additional existing wells could be used for fluid chemistry monitoring.

The need for financial assurances was discussed.

Regarding the selection tool itself, the question was asked who was this tool meant for – do we expect the public to understand the tool? It is likely they will find and use it so the clickable explanations are very useful.

Breakout group 1:

In addition to those already listed, a need was identified to include flow rates at the wellhead. A baseline benthic survey was required. 3D seismic survey could be acquired for the baseline survey with follow-up 2D surveys which were cheaper.

Comments on the tool included the definitions of aims sometimes varied from what was assumed, for example ‘leakage’ and ‘plume’ vs. ‘migration’.

9. FINAL MEETING WRAP-UP

Thanks were expressed to Kevin Dodds for the excellent organisation of this meeting. The delegates also thanked Charles Christopher for his guidance which was instrumental in setting up the network and he was wished a happy and profitable retirement.

The next meeting will be in Edmonton, with an opportunity to see Penn West and Weyburn plus many other active industry practitioners.

10. APPENDIX 1: AGENDA

Day 1 - Monday 30 October, 2006		
Regulatory Guidelines for Monitoring, Evaluation, Reporting and Verification (MERV)		
08.45 to 09.00	Introduction/Housekeeping:	Gerry Morvell, Assistant Secretary Energy Futures, Department of the Environment and Heritage.
Session 1–Keynote and NGO Perspective; Chair Gerry Morvell		
09.00 to 09.45	Keynote speech: The Climate Change Context for CCS:	Howard Bamsey, Deputy Secretary, Department of the Environment and Heritage.
09.45 to 10.15	An NGO viewpoint on CCS, Regulation and Monitoring:	Greg Bourne, CEO WWF Australia.
10.15 to 10.30 Break		
Session 2 – Further Perspectives; Chair John Gale		
10.30 to 11.00	US EPA Underground Injection Control programme: experience:	Elizabeth Scheele - US Environment Protection Agency.
11.00 to 11.30	A perspective on MERV for Australia:	Gerry Morvell, Assistant Secretary Energy Futures, Department of the Environment and Heritage
11.30 to 12.00	Insurance industry perspective:	Peter Sengupta, Zurich Global Energy.
12.00 to 12.30	Another country's experience with MERV:	Steve Cornelius, UK Department for Environment, Food and Rural Affairs.
12.30 to 13.30	Lunch	
Session 3-Technicians Upate: Chair John Gale		
13.30 to 14.15	IEA Monitoring Tool:	Andy Chadwick, British Geological Survey.
14.15 to 14.45	Goals of the OBPP monitoring programme + summary of other projects:	Kevin Dodds, CO2CRC.
14.45 to 15.00 Break		
Session 4-Facilitated Discussion on Design of MERV Protocols; Chair Gerry Morvell		
15.00 to 16.00	THEME - how to design and establish a suite of generic MERV protocols for CO_2 storage:	
Facilitated discussion: within the context of some agreed MERV objectives (which may include): • for accounting purposes within national emission inventories; • protect health, safety and environment (HSE) - existing or new regulations? • recognition within emissions trading schemes (accounting for capture, transport and injection); • assurance that sites perform effectively (frequency); • verify CO2 remains trapped in short term; and • provide a basis for predictions about behaviour in the very long term basis.		

<table>
<tr><td colspan="3">Session 5-Facilitated Discussion On Where To From Here;Chair Gerry Morvell</td></tr>
<tr><td>16.00 to 17.30</td><td colspan="2">THEME - what are the next steps to help expedite MERV arrangements and so assist in the widescale implementation of CCS?:</td></tr>
<tr><td colspan="3">Facilitated discussion: within the context of supporting the early trialling and eventual widescale deployment of CCS:
• managing MERV arrangements within a CCS integrated system (pre injection (3-5 yrs); injection (5-50 years); post injection (50-200 years); and
• post closure (>200 years)
• MERV arrangements for RD&D today (what are the minimum regulatory arrangements for pilot projects; pre-commercial);
• MERV arrangements for commercial scale projects (what are the minimum regulatory arrangements);
• MERV arrangements for onshore and offshore storage (consistency?);
• MERV arrangements for allowing realistic market expectations (insurers/reinsurance/financiers - risk premiums); and
• How to strike a balance between regulator; technology and market.</td></tr>
<tr><td colspan="3">Close Day 1</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Dinner-Guest Speaker, Dr. Graeme Pearman-Climate Change: Risk and Opportunity. Dinner sponsored by Woodside Energy</td></tr>
</table>

<table>
<tr><td colspan="3">Day 2 - 3rd Meeting of the Monitoring Network - Tuesday 31 October, 2006</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>08.15 to 08.30</td><td>Welcome and, fire briefing/safety issues;</td><td>John Gale, Kevin Dodds.</td></tr>
<tr><td colspan="3">Session 1</td></tr>
<tr><td>08.30 to 08.40</td><td>Introduction of Minister;</td><td>Peter Cook CO2CRC.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>08.40 to 09.00</td><td>Minister's Speech:</td><td>The Honourable Theo Theophanous, Minister for Resources.</td></tr>
<tr><td>09.00 to 09.10</td><td colspan="2">Question and Answers for Peter Cook and Minister.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>09.10 to 09.25</td><td>IEA GHG Views;</td><td>John Gale IEA GHG.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>09.25 to 09.40</td><td>CO2CRC Views;</td><td>Peter Cook CO2CRC.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>09.40 to 10.00</td><td colspan="2">Setting stage for monitoring network discussions during Day 1 and Day 2 relative to the Regulatory Meeting on MERV. Provide overview comments about how structure and agenda for the next two days relate to MERV discussions on Monday; Rick Chalaturnyk, U.Alberta.</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>10.00 to 10.30 Break</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Session 2- Monitoring Issues: Wells and Seals</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>10.30 to 11.00</td><td>KEYNOTE1: WELL BASED MONITORING</td><td>Rick Chalaturnyk, U.Alberta.</td></tr>
<tr><td>11.00 to 11.30</td><td>Overview of Well-Based Monitoring Approaches at the Frio 2 Project;</td><td>Susan Hovorka.</td></tr>
<tr><td>11.30-12.00</td><td>Compatibility and Early Results of Geochemical and Geophysical Well-Based Monitoring from Frio 2;</td><td>Barry Friefeld</td></tr>
</table>

12.00 to 13.00	Lunch	
13.00 to 13.30	An overview of logging techniques for CO2 concentration measurements and well integrity evaluation;	Laurent Jammes, Schlumberger.
13.30 to 14.00	Time-lapse well logging to monitor the injected CO2 in Nagaoka Project;	Daji Tanase SEC Engineering Advancement Association, Japan.
14.00 to 14.30	Facilitator Discussion-Focus on discussion is how well-based monitoring fits within MERV discussion from Monday, its importance relative to injection phase and post-operational phase, etc.	
14.30 to 15.00	Report back and general discussion on well-based monitoring technologies.	
15.00 to 15.30 Break		
15.30 to 16.00	KEYNOTE 2:MONITORING for SEAL or CAPROCK INTEGRITY;	Dave Dewhurst, CSIRO.
16.00 to 16.30	Using geochemical techniques for monitoring seal integrity;	Ernie Perkins, CO2CRC
16.30 to 17.00	Reservoir simulation and coupled geomechanics to calculate pressure and stress changes that feed into monitoring design;	Lincoln Paterson, CO2CRC
17.00 to 17.30	Facilitated Discussion/Seals &MERV	
Focus on discussion is how monitoring fits within MERV discussion from Monday, its importance relative to injection phase and post-operational phase, etc.		
17.30 to 17.45	Discussion and preparation for Day 2;	Kevin Dodds, CO2CRC
Close Day 2		
Dinner sponsored by Rio Tinto		

Day 3 - 3rd Meeting of the Monitoring Network - Wednesday 1 November 2006		
Session 1-Containment and Integration		
08.00 to 08.30	Introduction review Day 2 plan fro Day 3;	Susan Hovorka, Bureau of Economic Geology, Austin
08.30 to 09.00	European "CO2 Geonet" Research Network on the geological storage of CO2-interim progress report relative to monitoring verification, ecosystem protection/responses, health and safety regulation and public perception of underground CO2 storage;	Nick Riley, BGS
09.00 to 09.30	Walkaway VSP for CO2 Monitoring at the Penn West Pilot;	Marcia Coueslan, U.Calgary.
09.30 to 10.00	Field investigation results after the Mid Niigata Pref. Earthquake at the Nagaoka injection site;	Ziqiu Xue, Research Institute of Innovative Tech for the Earth, Japan.
10.00 to 10.30 Break		

10.30 to 11.00	Assessing the long term efficacy of CO2 geological storage by atmospheric monitoring;	David Etheridge, CSIRO.
11.00 to 11.30	Design and Preliminary Data for a New Facility for Testing Near Surface CO2 Detection;	Lee Spangler, ZERT and Montana State University.
11.30 to 12.00	Discussion/Seismic and Atmosphere	
12.00 to 13.00 Lunch		
Session 2-Latrobe Valley Scenario Introduction and Break-out Sessions		
13.00 to 13.30	Review Day 1 Regulatory Outcomes;	Mark Bonner, DEH-Australian Greenhouse Office
13.30 to 14.00	The Latrobe Valley CO2 Storage Assessment;	Catherine Gibson-Poole, Australian School of Petroleum.
14.00 to 14.45	Breakout-Risk Evaluation and Regulatory recommendations;	Latrobe Valley Key risks and regulatory issues to be address by MERV.
14.45 to 15.15	Report Back Discussion	
15.15 to 15.45 Break		
15.45 to 16.15	Breakout M&V Evaluation: Latrobe valley Recommended technologies using IEA GHG M&V tool.	Session Chair: Kevin Dodds,CO2CRC.
Session 3		
16.15 to 16.45	Report Back Discussion	
16.45 to 17.00	Wrap up	
Close Day 3 IEA Dinner (1MB Adobe Acrobat pdf)		

Travel to Warrnambool

Day 4 - 3rd Meeting of the Monitoring Network - Thursday 2 November 2006
Otway Basin Pilot Project (OBPP) Site Visit

Bus tour of Otway site
This will include:
• Visit and presentation of OBPP implementation
• Geological overview of CO2 containment with reference to local outcrops
• Visit to locations of the volcanic source of the OBPP CO2
• Tour of local gas storage project
• Visit to the magnificent cliffs and coastline nearby the OBPP

Delegates will be returned to Melbourne by bus leaving 1500-1630 Nov 2nd for 3 hour travel time back to Melbourne.

11. APPENDIX 2: ATTENDING DELEGATES

No	First Name	Last Name	Organisation	Country
1	Kevin	Dodds	CO2CRC/CSIRO	Australia
2	John	Gale	IEA GHG	UK
3	Tony	Espie	BP Alternative Energy	UK
4	Nick	Riley	British Geological Survey	UK
5	Lee	Spangler	ZERT and Montana State University	USA
6	Alistair	Jones	Woodside Energy Ltd.	Australia
7	Dave	Dewhurst	CSIRO Petroleum	Australia
8	Sandeep	Sharma	CO2CRC	Australia
9	Christian	Bernstone	Vattenfall Research and Development AB	Sweden
10	Geoffrey	Ingram	Schlumberger carbon Services	Australia
11	Elizabeth	Mackie	Shell	Netherlands
12	Hirokuyi	Azuma	OYO Corporation	Japan
13	Mark	Williamson	Environmental Protection Agency	Australia
14	Ian	Wilson	Environmental Protection Agency	Australia
15	Jiro	Watanabe	Geophysical Surveying CO.Ltd.	Japan
16	Darren	Gladman	Dept. of Sustainability & Environment	Australia
17	David	Etheridge	CSIRO Marine and Atmospheric Research	Australia
18	Kate	Roggeveen	Australian Greenhouse Office	Australia
19	Anthony	Sheehan	Australian Greenhouse Office	Australia
20	Julian	Turecek	Origin Energy	Australia
21	Mark	Payne	Australian Greenhouse Office	Australia
22	Koji	Kano	Engineering Advancement Association of Japan	Japan
23	Ziqiu	Xue	Research Institute of Innovative Tech for the Earth	Japan
24	Don	White	Geological Survey of Canada	Canada
25	Daiji	Tanase	SEC, Engineering Advancement Association	Japan
26	Ernie	Perkins	Alberta Research Council	Canada
27	Andy	Chadwick	British Geological Survey	UK
28	Wendy	Hadley	Zurich Global Energy	Australia
29	Peter	Sengupta	Zurich Global Energy	Australia
30	Toshiyukki	Tosha	Geological Survey of Japan (AIST)	Japan
31	Jonathan	Pearce	British Geological Survey	UK
32	Elizabeth	Scheehle	US Environmental Protection Agency	USA
33	Alex	Zapantis	Rio Tinto Ltd.	Australia

34	Donald	De Vries	CanSyd Australia Pty Ltd.	Australia
35	Gerry	Morvell	Department of the Environment & Health	Australia
36	Simon	Race	Benfield Corporate Risk	Australia
37	Damon	Jones	EPA Victoria	Australia
38	Stephen	Cornelius	Defra	UK
39	Shiro	Ohkawa	Japan Petroleum Exploration Co., Ltd (JAPEX)	Japan
40	John	Frame	EPA Victoria	Australia
41	Bruce	Dawson	EPA Victoria	Australia
42	Susan	Hovorka	University of Texas at Austin	USA
43	Richard	McDonough	Primary industries & Resources SA	Australia
44	Cassandra	McCarthy	Australian Coal Association	Australia
45	Ian	Duncan	Bureau of Economic Geology	USA
46	Marcia	Couesaln	University of Calgary	Canada
47	Namiko	Ranasinghe	Department of Primary Industries	Australia
48	Max	Watson	CO2CRC	Australia
49	Thomas	Berly	CO2CRC	Australia
50	Peter	Cook	CO2CRC	Australia
51	Rick	Chalaturnyk	University of Alberta	Canada
52	Barry	Freifeld	Lawrence Berkeley National Laboratory	USA
53	Ashish	Datey	Schlumberger	Australia
54	Mark	Bonner	Australian Greenhouse Office	Australia
55	Clement	Yoong	DITR	Australia
56	Tim	Moore	Solid Energy	New Zealand
57	Charles	Christopher	BP	USA
58	Lincoln	Paterson	CO2CRC/CSIRO	Australia
59	Bill	Koppe	Monash Energy	Australia
60	Scott	Hargreaves	Monash Energy	Australia
61	Carmel	Anderson	CO2CRC	Australia
62	Catherine	Gibson-Poole	CO2CRC/ASP	Australia

MERV

- Pressure/Flow/Temp
- Baseline benthic survey
- 3-D surface seismic (for baseline)
- Multi-beam echo/geophysical logs/fluid chemistry
- Follow on seismic work 2-D seismic