SUMMARY REPORT OF THE 5th RISK ASSESSMENT NETWORK MEETING

Report: 2010/12

May 2010

INTERNATIONAL ENERGY AGENCY

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

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 Dr Ameena Camps of IEAGHG as a record of the events of that workshop.

The 5th international research network workshop on the Risk Assessment Network was organised by IEAGHG in co-operation with the Colorado School of Mines. The organisers acknowledge the financial support provided by IPAC-CO2 Research Inc. for this meeting and the hospitality provided by the hosts, the Colorado School of Mines, at the Calvary Episcopal Church.

A steering committee guides the direction of this network. The steering committee members for this network workshop were:

Tim Dixon, IEAGHG (Chairman)
Malcolm Wilson, IPAC (Co-Chair, Sponsor)
Dag Nummedal, Colorado School of Mines (Host)
Jerry Sherk, Colorado School of Mines (Host)
Grant Bromhal, NETL/DOE
Ameena Camps, IEAGHG
Rick Chalaturnyk, University of Alberta
Charles Jenkins, CO2CRC
Claudia Vivaldi, Schlumberger
Neil Wildgust, IEAGHG

COPYRIGHT AND CITATIONS

The report should be cited in literature as follows:

'IEAGHG, "5th Meeting of the Risk Assessment Network", 2010/12, May 2010'

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

IEAGHG, Orchard Business Centre,
Stoke Orchard, Cheltenham,
GLOS., GL52 7RZ, UK
Tel: +44(0) 1242 680753 Fax: +44 (0)1242 680758
E-mail: mail@ieaghg.org
Internet: www.ieaghg.org

Summary Report of
5th Risk Assessment Network Meeting

17th – 19th May 2010
Golden, Colorado

Organised by IEAGHG

Hosted by The Colorado School of Mines

Sponsored by the:

International Performance Assessment Centre for Geological Storage of CO_2 (IPAC-CO2)

FIFTH WORKSHOP OF THE INTERNATIONAL RESEARCH NETWORK ON RISK ASSESSMENT

Executive Summary

The fifth meeting of the IEAGHG Risk Assessment Network was held in Golden, Colorado in May 2010 and was hosted by the Colorado School of Mines. The workshop was well attended with over fifty attendees from industry, academia, government and research organisations, representing seven countries; which allowed for various in depth discussions.

The two day workshop was divided into eight sessions, opening with a welcome session and closing with the Outcomes and Recommendations discussion session. Presentations were held over six sessions, covering key topics: Regulatory Requirements, What can Risk Assessment deliver?, Risk Communication, Update from Real Projects, Induced seismicity/Geomechanics, and Long-term Risk Management; with twenty minute presentations on average and a minimum thirty minute facilitated discussion. All the discussion sessions were met with enthusiastic input from all participants, many of which continued into the coffee and lunch breaks, expressing the great interest in the workshop topics, and the importance of such an open forum for advancing knowledge in this topical field.

Presentations and discussions showed the advancement of regulatory requirements; however some concerns from the technical audience were raised which highlighted the need for researchers to take a proactive in informing regulators to ensure requirements are adequate for emerging needs; and to ensure they apply adaptive approaches to allow for the iterative process of risk assessment which was also highlighted in real project data.

Although projects have developed their own effective risk assessment methodology, including a novel approach of FEP analysis presented by Ken Hnottavange-Telleen of Schlumberger (see Session 4.4), the need for benchmarking and consistency was clearly evident; therefore guidelines such as those within the CO2QUALSTORE report will be useful for ensuring consistency (see Session 2.1). The need for terminology consistency was also expressed in the majority of sessions; expressing the important of the IEAGHG report 2009/TR7 which will meet a highlighted knowledge gap; as was the need to quantify and reanalyse the risk profile, as per the proposed risk curve presented by Kevin Dodds of BP (see Session 4.2). Additionally, the development of CO_2 storage voluntary/bi-national standards by the Canadian Standards Association (see Session 1.3), with the aim of developing such into International standards was seen as a positive step forward; as was the EU RISCS project with an aim to produce a guide for impact appraisal meeting the need for quantifying impacts for environmental impact assessments (see Session 2.5), and the US DOE Best Practices for Public Outreach and Education for Carbon Storage Projects (see Session 3.1). Induced seismicity remains an important topic for discussion, though is limited by a clear scarcity of data.

Discussions highlighted three main knowledge gaps: a need for more information on monitoring performance, a need to understand microbial response and geochemical changes, and the need for interaction between the IEAGHG Risk Assessment Network and the IEAGHG Monitoring Network. Participants also gave the following recommendations: there is a need for benchmarking between projects and for open knowledge sharing, it is important to use natural analogues to understand processes, there is a need for further research on metrics for quantification of risk, it is important to define terminology and ensure consistency, to encourage greater industry representation, be proactive to provide regulators with information and technical training, and for the research community to work together to avoid research overlaps.

This highly productive and informative workshop expresses the importance of such meeting at a time when the CCS community are actively developing methodologies and processes for project risk assessments.

Contents

Introduction

Welcome Session

Chaired by Tim Dixon, IEAGHG and Malcolm Wilson, IPAC-CO2

The meeting was opened by Tim Dixon of IEAGHG who welcomed all the participants to Golden, Colorado, and the venue for the workshop, the Calvary Episcopal Church. Tim Dixon thanked IPAC-CO2 as sponsors of the meeting; and thanked the Colorado School of Mines for hosting the meeting and for hosting the previous nights' evening reception in the Geology Museum.

Tim Dixon then welcomed John Poate, the Vice President for Research and Technology Transfer at The Colorado School of Mines, to the speaker's podium to provide the opening welcome address.

John Poate welcomed the workshop participants to Golden, and introduced the Colorado School of Mines.

> The Colorado School of Mines is a small school with a mission to understand the earth, energy and the environment. They have a graduate body of around 1200 and over 3000 undergraduates. Their undergraduates receive the highest starting salary of any other state school. They receive strong industrial funding which supports some of the strongest U.S. research in photovolteics, wind energy, nuclear energy, gas hydrates, and unconventional gas with the only fracking centre in the country.

John Poate concluded his welcoming address by stressing the importance of the workshop, with energy and the environment as a crucial scientific challenge, and highlighting his interest in receiving the findings of the meeting.

Tim Dixon followed the welcoming address by providing a recap of the risk assessment network, correcting the programme which had accidentally omitted Neil Wildgust's presentation at the end of the Welcome Session.

Tim Dixon discussed the IEAGHG programme, the various networks, and the specific objectives of the risk assessment network. He then presented the highlights from the previous network meeting which included groundwater impacts, risk communication, and risk insurance; and identifying knowledge gaps in brine movement and pressure front migration, induced seismicity and the scaling of risk. The 6th Meeting of the Monitoring Network was also discussed; highlighting one of the main points under discussion at this meeting: the risk profile of site characterization – raised by Susan Hovorka and Sally Benson, stating the risk profile of site characterization doesn't flatten out but keeps increasing during injection as the reservoir is further characterized as CO_2 migrates throughout the formation and the 'CO_2 illuminates' the subsurface.

Tim Dixon briefly presented the following programme, and introduced Koorosh Asghari of IPAC-CO2.

Koorosh Asghari of IPAC-CO2 provided the audience with a background presentation on the International Performance Assessment Centre for Geological Storage of CO_2 (IPAC-CO2).

IPAC-CO2 have recently announced the appointment of Dr Carmen Dybwad who is now the IPAC-CO2 Chief Executive, joining IPAC-CO2 from her previous role as Vice-President of the Canadian Energy Research Institute (CERI) in Calgary. IPAC-CO2 is funded by the government of Saskatchewan, Royal Dutch Shell, and the Government of Canada, totalling 14 million dollars. The Centre is an independent and objective R & D entity, with a board of directors to ensure objectivity, and it is an international organisation. IPAC-CO2 has a MoU with Saskatchewan Montana CCS Project, PTRC (who manage Phase I of Weyburn), and the University of Regina.

IPAC-CO2 aims to gain public and regulatory confidence in CO_2 storage as a sustainable energy technology and an environmental option, concentrating on practical rather than theoretical aspects, and focussing on risk assessment, complimenting commercial practitioners of risk assessment. Though based at the University of Regina, it has a global network of research centres for collaboration, and has developed a web-based 'Community of Practice' to facilitate knowledge sharing.

The Centre aims to establish high performance computer networks, provide global online access to software, models and available data acting as a benchmarking data repository for the IPAC-CO2 community. IPAC-CO2 has three main broad goals: capacity building, technology development and information and services to meet the needs of industry, regulators and the public.

Koorosh Asghari concluded his presentation by inviting workshop participants to join the community of practice and to assist IPAC-CO2 in the collation of data for their data repository, introducing Elsa Johnston as the communication contact.

Q. How does IPAC-CO2 plan to meet the main aims mentioned in the Technology Development goal, particularly the aim to improve subsurface assessment models?

A. Koorosh - IPAC-CO2 is not yet advanced enough to have met these goals, and hasn't yet addressed the true aims to improve storage models. IPAC-CO2 has started a benchmarking project which includes assessment of subsurface models, and has also begun to develop standards with the Canadian Standards Association. IPAC-CO2 acts as a facilitator linking the community.

Q. The initial start-up funding was mentioned, what is the ongoing funding? Have there been any projects submitted for review on risk assessment?

A. Koorosh - There haven't been any projects submitted for review in IPAC-CO2, but are currently in discussion with ongoing projects.

Malcolm – We are in a lot of discussions at the moment, which will hopefully develop and facilitate projects in the near future. IPAC-CO2 is a facilitator to ensure CO_2 projects move forward. In regards to the funding, we are currently about half way there in terms of financial requirements; and the 14 million set-up funds are divided into two periods: part over 4 years, and part over 5 years.

Q. You mentioned about making available high performance computing/software, who would need this given most professionals have their own computing power?

A. Koorosh – Most research organizations to have access to their own software; however not all organizations have all the programs they may require, so IPAC aims to hold all necessary geological storage relevant programs to enable organizations to access these directly. Additionally, if there are various models developed within the community on different aspects or risks, they can, as part of IPAC, share these models within the community to allow critical analysis and comment for further development.

Q. Will it be possible for people/members of IPAC to use the software/simulators through remote access?

A. Koorosh – Yes that is the eventual goal. Talk to Joe for further information on the community of practice. There are various levels of access, and IPAC holds a suite of models which can be accessed remotely once the remote access aspect is established.

Q. How does IPAC stay objective with various sources of funding, how do you eliminate the conflict of interest?

A. This is a very good comment which has been occupying IPAC minds. In general IPAC is non-for-profit, and is also open for industrial funding, but this industrial funding does not have any influence on IPAC: an aspect which is monitored by the board.

Following the IPAC-CO2 presentation Tim Dixon and Malcolm Wilson chaired a short discussion on the future of the risk assessment network and how IPAC-CO2 and IEAGHG can collaborate further. The first stage in progressing IPAC-IEAGHG collaboration was stated to be placing the report to develop a risk assessment standard; produced by Anna Korre of Imperial College, London; on the IPAC website. Additionally, the risk assessment network currently meets just once a year, and the IPAC online community hopes to engage the network on an ongoing basis. IPAC-CO2 are currently developing various access permissions on their website to allow a broad discussion. The discussion highlighted benchmarking as possibly the most powerful role of the IPAC community, and it was suggested this could be a key role with considerable investment. IPAC encouraged network members to engage with them on how benchmarking could be developed effectively. Joe Ralko also highlighted that only IEAGHG risk assessment network members will be invited to be able to access the IPAC password protected site.

Grant Bromhal presented an overview of the Carbon Sequestration Leadership Forum Technical Group’s Risk Assessment Task Force (RATF), on behalf of George Guthrie who was unable to attend the meeting.

> CSLF is at a ministerial level, established in 2003, with 24 members, and has complimentary goals to IEAGHG with respect to risk assessment. The CSLF mission is to facilitate the development and deployment of CCS technologies via collaborative efforts that address key technical, economic and environmental obstacles.
>
> Phase I of the RATF has been completed, which aimed to examine risk assessment standards, procedures and research activities. The Recommendations were finalised

in 2009 and the report is available online. The General recommendations were: the link between risk and liability should be recognised and considered; the storage integrity goals (i.e. acceptable risk levels) for sites should be discussed; and risk assessment should be considered in the context of stakeholder outreach and communication.

Phase II has been initiated, with two main tasks: to perform a gap assessment of what specific tools and methodologies will be needed to support risk assessment, and a feasibility assessment of developing technical guidelines which can be adapted on a site to site basis, using the IEAGHG Risk Assessment Network gap for gap analysis to develop a RATF Phase II plan.

C. Risk Assessment doesn't stand as an individual component, but integrates many different disciplines and fields of expertise and needs to be able to identify the various data available.

A. CSLF is at a very high ministerial level, and therefore does not aim to instigate projects or data collection itself. Yes, there is a need to develop monitoring tools etc, but information such as this is fed into the CSLF RATF. This is just one task force of many and each taskforce feeds information into each other on various aspects.

Neil Wildgust of IEAGHG followed Grant Bromhal's presentation by providing a brief summary presentation on the last IEAGHG Modelling Research Network.

The IEAGHG 2nd Modelling Network meeting was held at the University of Utah, Salt Lake City, on the 16th and 17th of February this year. There were 60 participants and four sessions: modelling methodology and recent advances, integrated roles and objectives, real storage projects – case studies, best practice and modelling protocols. IEAGHG have had an offer from Australia for the next meeting, so next year's meeting may take place in Perth, Australia.

Break out groups identified the progress in recent research however the need for data was highlighted to enable calibration. The R & D priorities from Session 2 were identified as storage engineering, wettability, rates of dissolution in brines, efficiency of capillary trapping, coupling or processes or merits of modelling separate components to aid upscaling, use of realistic boundary conditions. Session 3 summary remarks from the panel discussion highlighted the importance of heterogeneity and clear modelling objectives, models need to provide a range of possible outcomes which can be refined with time and experience, initial pilot projects are crucial to obtain data for predictive models, the quality of input data is critical for the model accuracy, and positively expressing current models success in obtaining good estimations despite knowledge gaps.

The meeting concluded with a discussion about the network and the concept of providing recommendations for best practice. The meeting concluded that protocols emerging from the US Regional Partnerships Program and other international efforts could be placed in an international context at future network meetings.

To conclude Neil presented details of the Day trip on 18th February to Crystal Geyser in Utah which is a useful natural analogue to understand potential leakage pathways and mechanisms.

Tim Dixon closed the opening session by thanking all the speakers, introducing the next session, Session 1: Regulatory Requirements starting after the coffee break.

Session 1: Regulatory Requirements

Chaired by Kevin Doran, University of Colorado

1.1 Update on the Alberta Regulatory Framework Assessment for CCS

Bettina Mueller, Alberta Energy

Bettina introduced Alberta in Western Canada, presenting the Alberta CCS projects and the regulatory framework assessment currently being undertaken.

Following on from the Alberta government climate change strategy in 2007, Alberta is the first in North America to regulate industrial emissions, with three main focuses: conserving energy, implementing CCS and developing green energy.

Alberta has a CCS program which is actively persuing demonstration of CCS projects, committing 2 million dollars in 2008, and building public confidence by ensuring efficient regulatory framework. Alberta has four projects in central Alberta: The Quest Project which has stored 1-2 million tonnes of CO_2 to date; Swan Hills synfuels project, starting in 2015 which is a coal gasification project with 300 MW from syngas and carbon dioxide storage in a deep coal reserve; the TransAtla Project Pioneer which will be operational in 2015, and Enhance: connecting the Alberta industrial region to EOR projects via the Alberta Carbon Trunk Line, with an existing capture plant and the aim to transport 14 million tonnes of CO_2 per year via the Trunk Line (currently 5.5 million tonnes per year).

The Alberta government are currently undertaking a regulatory review, which examines the current regulatory framework, including the existing regulations for acid gas injection and EOR operations, and aims to implement the necessary changes (if any) to ensure processes are in place for risk management. The view is currently identifying key issues for consideration, including risk assessment, monitoring, liability etc, to ensure these have been addressed in regulations. Additionally, the review team are currently developing an international steering committee, producing results directly to the ministers of Alberta. This panel will guide the ongoing work, assist in this work, and review the produced results. Alberta Energy are coordinating the review and will produce the resulting documents. The work will commence in the 4^{th} quarter of 2010, with a final report in 2011, and to be completed by 2012.

Q. What is the current thinking on long-term liability?

A. We are currently looking at the CCS Act, and providing the necessary information to our ministers.

Q. When you are looking for individuals for the expert panels, will you only be looking in Canada?

A. We will be looking internationally. The only key criteria is does the individual have the expertise in the field they will be addressing.

1.2 The Development of EPA's Regulatory Regimes

Jason Deardorff, U.S. EPA Region 8

Jason explained the structure of the U.S. Environmental Protection Agency, with 10 different EPA regions. Though most of the work is coordinated from HQ in Washington, environmental regulations are implemented by the regional EPAs. He then went on to explain the Underground Injection Control Program (UIC).

The 1974 Safe Drinking Water Act, reauthorized in 1996, was established to ensure protection of underground drinking water. Underground Sources of Drinking Water (USDW) is defined as any aquifer or portion of an aquifer that supplies a public water system or is less than 10,000 mg/l Total Dissolved Solids (TDS) and of sufficient quantity to supply a public water system. The UIC Program regulates underground injection of all fluids: liquid, gas and slurry. In 1974 the UIC program created 5 well classes: Class 1 – hazard waste injection, Class 2 – waste for EOR, oil and gas, Class 3 – for dissolved minerals, Class 4 – hazard waste injection directly below the water, and Class 5 – any other. Class 4 has now been banned.

The EPA encourages states to develop their own regulations which are as stringent as the federal regulations. Figure 1 shows areas of the U.S. where injection is controlled by state, jointly with the EPA, solely by the EPA or jointly with Tribal nations.

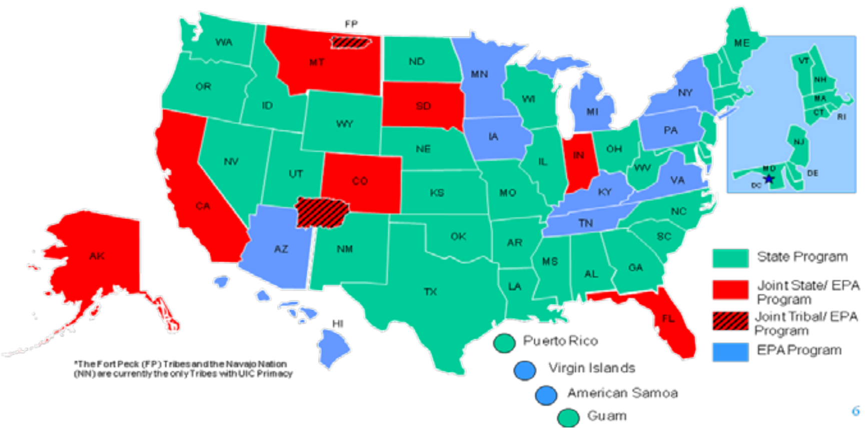

Figure 1. Map showing regulatory authorisation for injection in the U.S.

The EPA production of a draft rule for CO_2 storage aimed to build on EPA and State UIC experience, with an overall aim to ensure the protection of drinking water. In summer 2008, the proposed rules were signed, which included rules similar to those for Class 1 wells, such as injection must take place below the lowermost USDW, models must be used to determine the area of review; any new wells must be surface cased through to the lowermost USDW and well materials must be able to tolerate the corrosive nature of CO_2 plus water; there must be continuous monitoring of pressures in the well and there should be sampling and monitoring of the injection zone and confining system; injection must not exceed 90% of the formation fracture pressure, and there needs to be post-injection monitoring for 50 years.

In 2009 EPA published a notice of data availability with an aim to seek comment on US DOE regional project data and research findings, as well as the proposed injection depth. This received many comments, the most controversial topics being the injection depth. Industry felt the requirement would limit the capacity of storage reservoirs. DOE have also shown a high storage capacity in some areas limited by this requirement. EPA aims to have a waiver process to provide additional flexibility, which aims to accommodate injection into different formations at varied depth; to consider the concept that injection above and/or between the lowermost USDW, under specific circumstances, can be equally protective of USDWs, and to ensure consideration of community drinking water resources.

EPA is currently reviewing comments and responding to these, as well as preparing for rule finalisation, with the final rule due late 2010/early 2011.

Q. You mentioned the use of numerical models, what will be needed to be included in such models and who will assess them?

A. Multiphase flow modelling is required, including modelling of pressure front movement, geochemical models, and plume migration over the length of the project, which should show a timeline with the model development including after 10 years, 15 years and 20 years.

Q. What is the current thought on pore-space ownership?

A. States are currently involved in the pore-space issue, not EPA.

Q. Will EPA require a certain model or software package for simulations?

A. This will be decided by each office.

Q. The draft rule has explains the target formation to be one with sufficient capacity and with a confining layer free of faults or fractures. This appears to be a zero leakage scenario, so how does risk assessment feed into this as there must be a risk of leakage to be able to perform a risk assessment?

A (Wendy). The best that can be achieved is to examine the geology and provide confidence the site can confine the CO_2.

A (Jason). The rule does look at risk assessment, and certainly wouldn't provide a permit if the operators expected a leak, however, non-expected leakage is covered in the rule. Any risk assessment would therefore be performed for a non-expected leak.

1.3 The Geological Storage of Carbon: The Need for Standardisation

Kevin Boehmer, Canadian Standards Association

Kevin Boehmer explained the development of voluntary Canadian/bi-national standards for the geological storage of carbon dioxide, which is a new standardisation activity in collaboration with IPAC-CO2. The project will build on existing best practice guidelines and fill any gaps in such best practice, complimentary to developing and developed regulations, and developed through an accredited standards development process. The project will start as a Canadian project with U.S. participation, but is likely to feed into ISO in international standards. A technical committee will be formed, with industry, academia, researchers, NGOs, reaching out the international experts though networks etc. The project will be ran on a fast track timeline, to be published in early 2011 which will be followed by review and evaluation to move to ISO standards. The scope of the project includes site selection, development, operation, closure, post closure: occupational health, planning, greenhouse gas emissions, and monitoring and verification methodologies; based on industry practice.

Q. There is clearly a focus on geology, why are CSA not looking at capture and transportation?

A. CSA sees the need for capture and transport standards, but we are scoping out the process with the storage component as IPAC-CO2 are focussed on storage.

Q. One of the biggest performance based standards is zero leakage over different timescales, any idea how this can be approached for standards?

A. Policy or program neutral is standards key aim, and political decisions do not fit into the standards development process and has to work around them.

Q. How are standards developed in other industries, and how can we set standards before we understand the full process and how systems behave?

A. It depends on the intent of the standard. Of course I understand your point that standards can only be implemented when the system is fully understood however, standards can also aid technology development, and we probably know enough information about many aspects. With any new technology it is important to be careful to scope the project sufficiently before undergoing standards development.

1.4 Worldwide Regulations for the Geological Storage of CO_2

Jose Condor, IPAC-CO2

Jose introduced the concept of risk assessment, how the risk assessment process has evolved and adapted with time, and current international regulations and guidelines for the geological storage of carbon dioxide.

> There are various potential risks associated with CCS, including financial, public perception, technology failure and health and safety risks, identifying the need for one common policy and consistent verification system to produce new frameworks building upon current risk assessment frameworks. Capture and Transport risks can

be mitigated against and managed under existing frameworks, however risks associated with injection, storage and post-closure are challenging and require fresh thinking. Risk is strongly influenced by uncertainty, and as CCS carries a level of uncertainty the risk is currently higher than once we achieve a greater level of understanding after demonstration and wider-scale deployment.

There are developed international guidelines of OSPAR and WRI for risk assessment. OSPAR guidelines include the Framework for Risk Assessment and Management (FRAM). There are also CCS international regulations of OSPAR and the London Convention. In the EU, the EU CCS Directive includes risk assessment requirement, stating no injection can proceed without risk assessment and noted mitigation strategies, risk analysis of the CO_2 composition must be undertaken, and risk assessment is a requirement for storage permitting. In the U.S. there are various regulations at various stages of development including the American Clean Energy & Security Act which is yet to be approved by the Senate, and the EPA draft rule for CO_2 Geological Storage. There are also developments at the U.S. State level, such as the Kansas Carbon Dioxide Reduction Act. There are well developed EOR/EGR regulations in experienced regions in Canada, and considerable experience in regulating acid gas injection. In Australia there is the overarching Offshore Petroleum and Greenhouse Gas Storage Act, which has a risk assessment requirement with a need to detail risks and remediation strategies and to ensure this is included in the site plan.

Jose concluded his talk by describing the IEA CCS Roadmap recommendations with a need for full review of existing legal and regulatory frameworks by 2011 in OECD countries, and 2015 in all countries.

Q. What will be the final deliverable from your work?

A. IPAC is working in risk assessment, and doesn't want to re-invent the wheel, so we need to understand what is happening in other countries to share knowledge between projects.

C. Just to add some clarification, there was mention of WRI: these are guidelines not mandatory regulations.

Q. Do you have any idea what metric will be used to measure risk assessment?

A. No, not at this time.

1.5 Discussion Session 1: Issues Associated with Regulatory Implementation

Chaired by Kevin Doran, University of Colorado

Panel Members: Bettina Mueller, Jason Deardorff, Kevin Boehmer

Kevin Doran opened the discussion by asking the following question to the panel: Considering everything you discussed in your presentation, what are the key problems and questions, the key barriers to ensure success?

Bettina Mueller responded by highlighting that though aware of knowledge gaps such as accurate comparable predictive models on the migration and evolution of the CO_2 plume, it is currently too early in Alberta to be able to identify such.

Jason Deardorff explained the Rule is still a proposal until passed, and is still open to query therefore the draft Rule may change to some extent before it becomes legally binding. One area which remains to be answered is the different regulatory schemes developed by each state, particularly with concern to long-term liability and pore space. There are unknowns as to whether state laws will be as stringent as the EPA rule. Jason believes long-term liability to be one of the most probable uncertain areas.

Kevin posed a question to Jason: post-closure liability transfer is currently stated to be 50 years, yet with continuous monitoring programs operators may be able to prove long term containment before 50 years: will it be possible to shorten this time period?

Jason reinforced that the USDW must no longer be in danger. If it can be demonstrated the USDW is no longer in danger in less than 50 years the timeframe for post-closure liability transfer can be adjusted; however if the models show the reservoir still has brine movement then it is also possible to extend the 50 year guideline. Though 50 years have been chosen, it could take longer than this to be able to prove long term containment, which is largely dependent on pressure and proximity of the USDW. Studies have shown 50 years would be the optimum time.

Kevin Boehmer said this was different from a standards point of view. Standards are written to be used, so they need to find a consensus for public, industry and government to ensure they will be used.

Kevin Doran asked Kevin Boehmer: can you explain what consensus based is? Kevin Boehmer said Canadian Standards Association standards are similar to those of ISO which are formed when there is substantial agreement in comparison with disagreement, tested through voting procedures with agreement of a 2/3 majority.

Kevin Doran then asked Kevin Boehmer: there is an aggressive timeline to produce a standard, is this realistic, and is this as efficient as a longer period of time which would allow for greater stakeholder involvement. Kevin Boehmer answered: we have learnt how to do this quickly from previous experience of standards development. The development process will be a two stage process, with the first stage being a consensus based process to develop national standards, and the second stage will be to move this to international standards.

Kevin Doran asked Jason Deardorff if he could describe what is happening in EPA for a comprehensive federal and state regulatory process. Jason was unable to comment as he works at the local EPA offices, as opposed to the national head quarters who are working at that higher level of interaction.

Q. In Alberta, what is the expectation of long term performance assessment?

A (Bettina Mueller). Though I do not work in the regulatory department, my understanding is the current requirements for acid gas injection are considered adequate to cover these aspects. There may be additional information required, but we are not sure at this stage what this additional information will be.

C. I'm a little confused as to why some EPA regulations have very detailed needs for risk assessment, but the developing regulations for CCS does not appear to be as stringent for risk assessment of CO_2 storage.

A (Jason Deardorff). EPA have concentrated on drinking water as this is seen to be the primary risk. EPA believe if it is possible to contain the CO_2 away from drinking water sources, then the containment is sufficient enough to be covered for any risk of the CO_2 migrating to the surface.

Session 2: What can risk assessment deliver?

Chaired by Charles Jenkins, CSIRO and CO2CRC

2.1 CO2QUALSTORE report on quality audit & framework for operation

David Coleman, Det Norske Veritas (DNV)

David introduced DNV and CO2QUALSTORE (Guideline for Selection and Qualification of Sites and Projects for Geological Storage of CO_2) which is a joint industry project, started in 2008 and ending this year in 2010, with 13 partners including CLIMIT, Schlumberger, GASSCO, BG Group, BP, Statoil, Shell, Petrobras, RWE, Vattenfall, ARUP, DONG Energy and IEAGHG.

The overall objective of the project was to develop a unified, recognised and trustworthy approach to the selection and qualification of CO_2 storage sites: a methodology which identified one non-prescriptive structure for this process. The guidelines focus on screening, assessing and selection stages of operation, with project stages separated by decision gates, and developed to assist project developers to pass milestones whilst demonstrating compliance with regulations and stakeholder expectations (see Figure 3).

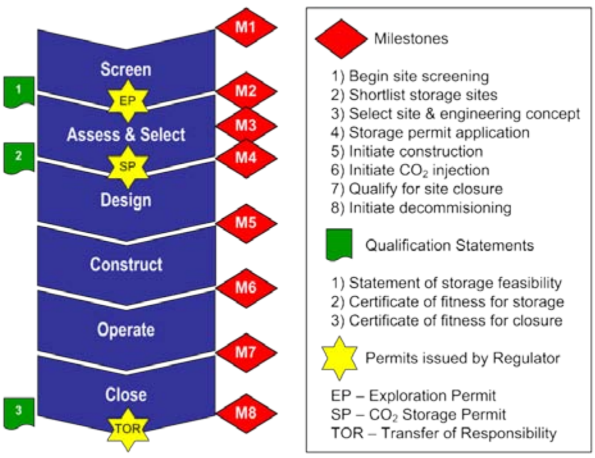

Figure 2. Project stages and major milestones in CO2QUALSTORE guidelines

The first stages are to find a site and ensure it is an efficient site. Once there are a few suitable locations identified, it is necessary to go through the stages of the risk assessment process. The Assess and Select stage will produce a development plan, characterising a storage site in sufficient detail to enable site and engineering concept selection and storage permit application. This development plan includes a characterisation report, an injection and operating plan, storage performance modelling, assessment and forecasting, a risk management plan, and a monitoring, verification, accounting and reporting plan. The model produces at this stage can be integrated with live data once injection begins. The practical application of modelling to actual formation response is key. As the project progresses the iterative process continues, as does site characterization and MVAR, field re-characterisation, and long term preparation for closure. During the closure, post-closure stages of the project the aim is to work towards liability transfer to a regulatory body by ensuring the risk is minimal as required by regulations.

Q. What have you done to advance the field of risk assessment and knowledge in this field?

A. We have attempted to develop guidelines which apply to as many of the existing regulations as possible, as well as those in other areas of subsurface work. In the U.S. there are 50 states with oil and gas experience. Regulators are looking at how to check the box, and these guidelines provide the tick boxes.

C. There are projects, such as the Gorgon project which have already been undertaking such a process, so this has been done before.

A. Many large companies are going through a focussed path, as they have competing budgets. Projects can use these guidelines or not, but the risk management approach used here will show the thought process and provide a guidance throughout the process.

2.2 Assessment for Geological CO_2 Storage – How experts work

Mike Stenhouse, INTERA Inc.

Mike began by providing an outline of his presentation, covering Weyburn Phase I risk assessment, reflections on such and recent initiatives.

Weyburn risk assessment started through a workshop in 1999. The assessment work scope was the proposal – assessing the performance of the Weyburn reservoir, with three parts to the project: systems analysis, modelling and interpretation. This large project had a considerable number of tasks, covering the geology, geophysical monitoring, and wellbore integrity (added into the project by the project managers), all feeding into long-term assessment of CO_2 storage (Task 5.5); with the main objectives being prediction, verification, EOR/storage performance and risk analysis. The project subdivided migration through natural pathways and artificial pathways, developing models for both. For natural migration pathways, the geological model took several years to build and was then incorporated into the Eclipse model, and a reservoir simulation model looked at the predictions of CO_2 migration with EOR operation. For artificial pathways a Unit cell model was developed, a numerical flow and transport model focussing on a single well, assuming zero concentration in the open borehole and assuming that as soon as CO_2 passed through the seal it would be available to the outside world.

The positives of Phase I Assessment were history matching benefitted predictions for reservoir simulations during the EOR period, benchmarking was successful but very difficult to set up, and there was good teamwork and integration within the project. It could have been improved by less emphasis on FEPs and by incorporating reaction transport. At that time there were no such assessment processes available, but now there are several, and there were limited modelling tools available in comparison to the large number available today. To support projects risk assessment should identify information and data to address uncertainties, ensure communication between the risk assessment team and the project team members, and should aid the decision making process by identifying what can and can't be quantified and identify what uncertain events can affect the performance of the project. Sensitivity analysis is crucial to identify variables which affect the uncertainties in models, to verify the performance of models, and to provide feedback to reduce uncertainties and risk. Data Value Analysis (DVA) is now being undertaken to aid decision making, which is a cost-benefit analysis of collecting additional information to reduce uncertainty in a specific decision-making context, as more information does not necessarily mean reduced uncertainty.

Mike Stenhouse concluded by discussing long-term performance of abandoned wells and the need for such to be a key component of risk assessment, the need for both detailed and simpler modelling tools to explore uncertainties, and the need for more projects to expand knowledge and experience.

Q. How many performance assessment calculations did you go through, and how did such change as the project progressed?

A. We performed several hundred simulations to produce the output. They were all done at one time, and we didn't continue to see how these changed.

2.3 The Long Term Risk Perspective of the Nuclear Storage Industry

Jim Conca, New Mexico State University

Jim Conca began by showing a NASA satellite image highlighting the distribution of global energy consumption.

The World currently uses 15 trillion kWhrs/year, which is predicted to exceed 30 kWhrs per year in 2040. Presently two thirds of the energy consumption is fossil fuel based, and we won't change fossil fuel usage to less than 10 kWhrs/year. 1.6 billion people currently have no access to electricity, 80% of them in South Asia and sub–Saharan Africa. 2.4 billion people burn wood and manure as their main energy source, and 3 billion more people will be born by 2040. Access to energy is essential to quality of life. China now has 500 million middle class citizens, yet still have 800 million in poverty.

Jim then discussed the minimum electricity demand considering global growth and continuing consumption and various energy strategies and the importance of nuclear energy as part of a global energy strategy. Jim went on to discuss the nuclear energy industry and problems faced within the industry.

There was incorrect but intentional association with nuclear weapons during the Cold War in 1945, and inaccurate and overly simplistic modelling of health effects of low radiation doses (LNT) (1959). There was also a general misunderstanding of the nature and amount of nuclear power waste which caused concerns. All the commercial nuclear waste in the world ever produced in history would fit in any high school football stadium. The Waste Isolation Pilot Plant (WIPP) in Carlsbard, New Mexico, stores nuclear waste in salt deposits; which have a very low diffusion coefficient; at 2150 feet below the subsurface. The salt exhibits significant creep closure, i.e., the salt completely closes all fractures and openings, even micropores, making the salt extremely tight, such that water cannot move even an inch in a billion years. During 10 years of operation over 100,000 loaded waste containers have been disposed of.

2.4 DOE's National Risk Assessment Partnership

Grant Bromhal, NETL/DOE

Grant Bromhal began by explaining the USDOE's NETL Carbon Sequestration Program, now in Phase 3 beginning injection of CO_2, and how the National Risk Assessment Program fits into this larger program.

NRAP has national goals of assurance of permanence, production of a best practice manual and a common assessment framework, with site specific goals of prediction of site performance, site-specific risk assessment, strategic monitoring and mitigation strategies. NRAP is a multi-lab risk assessment initiative to ensure success of large scale CO_2 storage projects, investigating processes and interactions both within and outside of the reservoir. NRAP is developing a science-based methodology to quantify risk profiles at storage sites, using integrated assessment models to link various subsystems at a storage site, with uncertainty handled by stochastic descriptions of subsystems; investigating hybridised sites to predict curves and comparing predictions with analogue case studies, coupling process models to the system model.

Q. Who is the customer you are focussing on? Could the regulatory authority look at evaluating storage reservoirs using such information?

A. We are focussed on industry and regulators and providing the information that addresses the scientific issues.

2.5 Assessing Ecosystem Impacts of CO_2: The RISCS Project

Ameena Camps, IEAGHG (on behalf of the Dave Jones, of the British Geological Survey and the RISCS project team)

Ameena began by explaining the RISCS project will be presented on behalf of the project co-ordinator, Dave Jones of the British Geological Survey and the entire RISCS project team, describing IEAGHGs involvement in the project in an advisory capacity.

Should any leakage occur from a CO_2 storage reservoir, there could be adverse effects on the environment and currently these are not well contrained. RISCS (**R**esearch into **I**mpacts and **S**afety in **C**O_2 **S**torage) aims to carry out research on impacts arising from known CO_2 fluxes in both marine and terrestrial environments and through experiments and field observations; providing key information which can be used for risk assessments and environmental impact assessments, for design of near surface monitoring strategies, for communication frameworks, and the ultimate goal is to produce a guide for impact appraisal.

RISCS is a four year project, starting in January 2010, and has already held its scenarios workshop for work package one. There are twenty four participants in the project, from many regions of the world including the UK, Greece, Italy, Norway, and outside the EU: Australia, Canada and the USA. There are also six industrial participants, one NGO, and an international organisation – IEAGHG.

The project is divided into six work packages, with work package two, three and four comprising of the experimental, field and modelling research. Work package one will develop a set of CO_2 impact scenarios for a variety of near-surface reference environments which will be a basis for following work packages. Work package two, Assessing impacts in the marine environment via field experiments and observations, involved OGL, PML and IMARES conducting research at a variety of scales in the laboratory and in the natural environment for field observations at Panarea in Italy. Work package three, Assessing impacts in terrestrial environments via field experiments and observations, involves effects and exposure experiments within laboratory experiments, at the controlled release site at UK ASGARD, and impact studies at natural release sites at Latera, San Vittorino and Montmiral. Work package four works to develop a marine system model and a terrestrial system model, synthesising results from work packages one, two and three; and aims to quantify CO_2 transport onshore and offshore in space/time and the associated chemical perturbation. All work packages will feed into work package five, which aims to produce a guide for impact appraisal to inform stakeholder groups, including regulators and policy makers.

Ameena closed by encouraging workshop delegates to contact the project coordinator, Dave Jones, with any queries about the RISCS project.

Q. Regulators assume a zero leakage scenario, so why is this project necessary if we assume zero leakage?

A. An Environmental Impact Assessment is a requirement of the EC Directive on the geological storage of carbon dioxide, and therefore investigation of potential ecosystem impacts is a requirement.

Q. Taking the nuclear industry experience, are we creating problems by analysing impacts when leakage is not expected?

A. It is a sensitive issue but analysing impacts is still required to inform risk assessments. Quantification of potential leakage rates and potential impacts has been identified as a key knowledge gap, by the EC as well as IEAGHG research networks including at an IEAGHG workshop held in 2008, hosted by the British Geological Survey, and today at this meeting. This project aims to fill this knowledge gap.

Also, natural analogue studies have shown limited impacts even for large volume releases of CO_2, therefore producing a positive message. The EPRI study in groundwater impacts is a similar case which informs monitoring requirements and remediation options, both of which are helpful in applying for a permit.

2.6 Panel Discussion: What does industry expect risk assessment to deliver?

Chair: Ken Knottavange-Telleen, Schlumberger. Panel Members: David Coleman; DNV; Mike Stenhouse, INTERA Inc.; George Bromhal, DOE/NETL; Jim Conca, New Mexico State University

Ken opened the session by asking each panel member the question under discussion. Jim Conca and Grant Bromhal both expressed their belief that industry expects risk assessment to determine future liability. Mike Stenhouse added that industry expect risk assessment to develop confidence in the technical aspects of a storage project for both regulators and the general public, and each company involved in a project wants to know the risk which risk assessment should be able to answer.

Grant Bromhal then discussed long-term liability which could be a show stopper for CCS, and risk assessment can deal with this issue of transference of responsibility. Grant also emphasised risk assessment can aid the development and design of a project, and a project will be designed around the aims of the project which in the case of CCS is containment of CO_2. The project will have to develop a monitoring program and risk assessment can aid the development of such by guiding when and where monitoring operations should focus.

Jim Conca stated that as risk assessment is quite developed now, risk assessment can iteratively drive the field on a regulatory prospective, and David Coleman highlighted the need for risk assessment throughout the lifetime of the project to enable efficient mitigation against risk.

C. We are in a relatively young industry, and we only have a few demonstration projects. If we perform a risk assessment thoroughly then we will learn a lot. We are going to learn what we need to do as well as what we don't need to do, which will reduce the costs eventually, so all risk work at the moment is relevant, even if information is duplicated.

C. Does risk mean just leakage from the ground or from other areas within the storage complex. It is important to define what part of the risk chain we are discussing.

C. An industry's reputation will be influenced by public acceptance of this new technology, and what is actually the issue is what regulations require and if these are feasible for industrial operators. Risk is very central to the process, and is well understood. We have considerable experience from the oil and gas industry for which we understand the risks involved.

Session 3: Risk Communication

Chaired by Jerry Sherk, Colorado School of Mines

3.1 US DOE Best Practice Guidelines
Sarah Wade, AJW Inc.

Sarah began by introducing the Phase II RCSP Program, showing the regional partnerships, their distribution, and the outreach coordinators for each regional partnership.

The USDOE Best Practice Guidelines are now the first draft, which will be revised over time. A best practice manual is an approach, providing a framework for planning and implementation, building on experience from the RCSP. As a first draft, the manual may change in the future, perhaps removing certain steps and perhaps adding others, but most importantly is to integrate the research and management.

It is important to start by thinking about the community you are going in to, and to approach it community engagement activities accordingly. For the storage reservoir, geologists and engineers will characterise the geology and predict CO_2 movement within the reservoir. Site characterisation can also be used to design effective public outreach to suit local conditions, for example, by characterizing the economic drivers, local concerns, perceived community benefits (Figure 3).

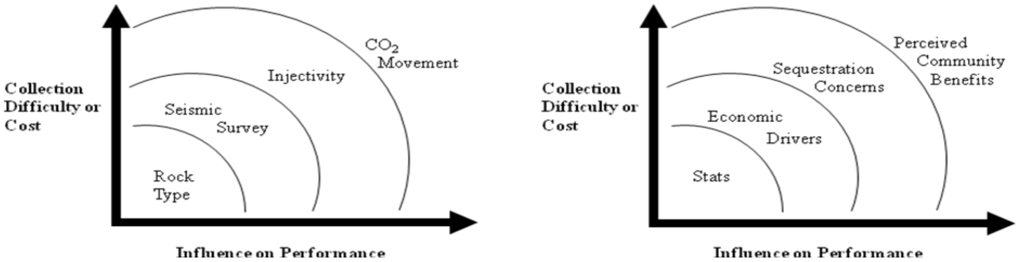

Figure 3. Site characterisation from a storage perspective and a social perceptive

The guidelines provide various stages for public outreach. 1. Integrate Public Outreach with Project Management, 2. Establish a Strong Outreach Team, 3. Identify Key Stakeholders and 4. Conduct and Apply Social Characterization. 5-7 work to develop the communication plan, key messages and outreach materials and 8-10 are to implement, assess and refine, especially as at these stages knowledge and experience will be gained and it will be necessary to monitor how opinions change with events, and adapt accordingly.

The key challenges for communication are the timing as the public really wish to know the answers before the project starts, uncertainty with problems to describe probabilities and the implications of a probability, fear of the unknown – 'how do you plan for unanticipated events' and 'how do we know you've thought of everything?' and, independent verification – how to prove responsible behavior.

Q. What about mis-information? For example, wrong information provided to the public by anti-CCS campaigners, how do we address that?

A. We have to be careful about our definition of what is wrong. There could be things they are discussing which we need to consider. We need to have a dialogue, both with the people providing the information, but also with the community. If trust is built with the community with open dialogue wrong information will be automatically discredited.

Q. Slovics work on fear and dread, do you think such work is useful for CCS to deal with unknowns?

A. IEAGHG have helped us to develop a social research network, and within this network we have had interesting discussions about how to translate history. Once demonstration projects are up and running, the dread and fear will naturally reduce.

Q. What are your approaches to how you deal with unrealistic probabilities?

A. Some of our work deals with trust. If you build trust you won't need to discuss probabilities. Even if a probability is just above zero, a community will still pick up on that small probability if they don't trust the operators.

3.2 Ethics and Communication of risk
Roel Snieder, Colorado School of Mines

Roel opened by introducing his background, including his participation in many outreach activities in regards to energy, stressing that he is in fact a CCS sceptic.

> New technology projects are often closed down before they have begun. A geothermal energy project was stopped in 2009 in Switzerland due to concerns about induced seismicity, as was a similar project in California, and many of us have been aware of public opposition to Vattenfall's underground CO_2 storage project which have stalled regulation development. Before such projects go forward we should be thinking about how we are dealing with the public, and the ethical aspects of what we are doing.
>
> There are different approaches to working with the general public. One option is to ignore the people: a communist and unbridled capitalism approach. Utilitarian ethics works upon the principle of the greatest good for the greatest number of people (maintaining awareness that you cannot cater for a small number of people who are concerned). Principle based ethics works by mitigating against the effects and compensating those affected, and virtue ethics is inclusive where the local population is a stakeholder in the project, has a share in the benefits and has a voice in the decision making (however, with such the population needs to want to listen).
>
> Perceived risk = probability x consequences + emotional concern + lack of control.
>
> There are a number of past approaches to risk communication: 1. Just give them the numbers, 2. Just explain the consequences of not taking action, 3. Just explain that they have accepted similar risks in the past (however there is a difference between voluntary risks and involuntary risks), 4. All we have to do is show then it's a good deal. An alternative approach is 'All we have to do is to make them partners'.

Roel summed up by providing the audience with a number of recommendations including to identify and communicate the ethical basis, to partner with communication experts, invest in education and outreach, admit uncertainties, build trust and make the public a stakeholder in the project.

Q. You are now head of communication at BP, what do you do?

A. I would first explain the need to go into deep water, and then I would ask BP about their compensation strategies.

C. At Otway we have a full time person who lives in the area, communicating with the local community and keeping his ear to the ground to listen to any concerns which may arise.

3.3 Public communication for the geological storage of CO_2
Joe Ralko, IPAC-CO2

Joe introduced himself as an accredited business communication expert, working as a journalist for a number of years, a specialist on crisis reporting, and who assisted with the promotion of IEAGHG Weyburn Phase 1.

> When addressing a communication plan you have to determine who your target audience is, and there is no such thing as the 'public'. People have different views due to different backgrounds. Determine your key messages. If you cannot communicate these key messages to people within your organisation, you will not be able to communicate these messages externally. Keep these messages simple, and begin by asking a child in grade 8 and adapt according to their response. Opposition to a technology will largely be based on two axioms: is it safe? and not in my back yard. Your messages must suit the audience, whether this audience is the general public or investors in the project for example, and your communication strategy will be dependent upon the audience. Measure your communication efforts to determine what worked and what didn't work. Following on from a meeting on Community Engagement Guidelines at the World Resources Institute in Washington we will be creating and administering a Community of Practice Pod, which will be a secure on-line community where we can share best practices as well as the opportunities for improvement based on our real life experiences in communicating with various audiences.
>
> Educate the media to avoid false reporting. People fear the unknown and fact cannot beat emotion. All news is local, and the internet is now the number one source of information, so news crawlers can be your friend and a news release can be sent everywhere in very little time which is an extremely powerful tool.

C. I would like to see a central coordination group to tap into responses when something happens within the media, as each media outlet is aimed at a different target audience. Industry needs to think about media training.

A. I agree. Each media outlet is for a specific audience, and there should be some cross comparison and coordination for communication.

Q. Should all media be treated equally?

A. Yes, it is important to treat them all with respect, even if they treat you unfairly. The worst you can do is shut them down. Ask their questions and build their trust by being approachable.

3.4 Managing Communication Risk at the Illinois Basin-Decatur Project

Sallie Greenberg, Illinois State Geological Survey

Sallie began by introducing the Illinois Basin-Decatur Project: part of the Midwest Geological Sequestration Consortium (MGSC), which is one of seven of the regional partnerships.

The Phase III project in the Illinois Basin uses CO_2 from an ethanol production facility, and will store at 7200 ft, and is planning to inject 1 million metric tons of CO_2. The injection period will be for three years, with post closure monitoring and on-going outreach. The project has undergone two rounds of FEP analysis: round 1 looking at the surface, near surface and deep subsurface; and round 2 focussed on the facilities, legal aspects and communication.

One of the major focuses has been to address risk through communication, drawing on every major player in the project to form a communication team. This communication team has undertaken considerable research to understand the social context of the community, undergoing regional work to tie in to specific projects. The team consist of representatives from the MGSC, Schlumberger Carbon Services, Archer Daniels Midland, and the US DOE/NETL.

In the local area, the MGSC research team is well known and respected by the community, and the industrial partner, ADM, is strong in the community. There has also been economic slowdown with industry jobs lost, in the area for the last 25 years, therefore there appears to be economic benefits to having the project in the region.

The project has a focussed communication plan. The challenges of putting the plan into practice were different than developing the Plan. This plan helped establish the lines of communication among the project team members. All staff on the project; including the Communications Team; are required to sign a cover sheet to show they have read the Plan and will abide by the guidelines it establishes. Another important part of the communication plan has been the name of the project. Even with a well-defined name and policies in place for name usage, the Illinois Basin – Decatur Project continues to be referred to with different names making it very difficult to communicate about. The multiple name usage can be misleading by implying there are several projects where in fact there is only one. The project has a select group of people trained to speak with the media. Only media-trained personnel are permitted to speak on behalf of the project to ensure the project message is consistent.

The communication plan has also led to the development of a crisis plan. The crisis plan was determined a necessary item as a result of the project risk assessment and addresses questions such as, how will the project team respond in the event of a major crisis, and what would be the type of risk scenarios in which the crisis plan will be enacted. With this crisis plan in place, response under crisis conditions has been thought out prior to such an event and following the plan makes it easier to deal with by assigning responsibility and removing stress.

Key messages have been developed; including geological sequestration as a potential climate change mitigation technology, combining sequestration and biofuels production, balanced energy and environment portfolios. There are various words which mean very little to the laymen, and should be used with caution such as ‘fate’ of CO_2 or ‘supercritical’ ‘cavern’ storage saline ‘formation’ or ‘aquifer’. Using animations and images helps to get the message across quickly and easily.

Communication is a two way process. The public have many misconceptions and so providing useful information for them is important. Explaining commonly used terms such as porosity has proven to be very important. A lot can be conveyed very well or very poorly. Collaboration is essential, and it is important to listen to people. One challenging or poorly conducted CCS project can impact the future of CCS projects.

C. It wouldn’t be a good idea to share the sensitivities you mentioned in the terms used today, as is takes people a few seconds to sign into their iPhone and search the internet. We need to openly talk about these things and not skirt around the issues as people can find information on anything they wish to.

Q. What do you think is best: storage or sequestration?

Open Discussion: The majority raised their hands to use storage, though some still preferred sequestration. Sallie stated she uses both terms.

Q. Perhaps to get the community involved you could encourage brighter high school students to undertake sampling, and pay them for doing this. This would have an educational and practical engagement benefits.

A. We have a site where there is limited access and therefore monitoring in this way would not be possible. Sure, if this was done well it could be great, however if not it could be problematic, especially if sampling is done for regulatory purposes and/or required to be processed in specific manners.

Q. You can only lose your reputation once: do you think the IPCC has lost its reputation?

A. The IPCC problems don't seem to have been a problem, there has been more of a concern over the effects of climate change.

A. If 50% don't believe in climate change, there is always the other 50%. This tends to be related to the economy, so if the economy picks up people will be more interested in investing in the environment. The last 6 months is irrelevant, we need to think about the next 40 years.

3.5 Panel Discussion

Chair: Jerry Sherk, Colorado School of Mines. Panel Members: Sarah Wade, AJW Inc., Roel Snieder, Colorado School of Mines, Joe Ralko, IPAC-CO2 and Sallie Greenberg, Illinois State Geological Survey

Jerry opened the discussion by mentioning a report on the radio he had heard this week, which was talking about the use of Xrays at the airport, and the risks of these Xrays, asking the question to the panel: is this risk communication or risk opposition?

Joe Ralko stated if he had communicated the topic of discussion on the radio, he would have said the risk was terrorism and the xrays mitigate against this risk.

Jerry then asked, is there too much information out there? and Roel answered by expressing that he is not concerned with the quantity of information, as everything can be put on the internet, however the content of this information is important, and we should be careful when scrutinising such information.

Sarah Wade argued that what is missing is access to academic papers and translating these key papers so people can easily understand them. We should identify the key papers and make them available, and we should also translate the regulations so the general laymen can understand them. Guides to the information are important to make the information easily accessible and reduce misinterpretation. The need for such was widely agreed upon in the discussion, and Sallie reiterated the need for good information, especially for the younger generation who appear to believe all available information is true.

C. We need to be more agile and proactive in providing good information. Too much information is not the problem; it is the quality of the information.

Q. Gould relates cancer diagnosis and being exposed to a substance. His risk went from 10^{-14} to 10^{-12} and the media still didn't understand this. How can you package the information so it is not misleading?

A. What has happened in the media has been catastrophic. The media have become technological geeks and are no longer intelligent purveyors of news, so we need to make sure our message is clear when they ask questions.

C. Though be aware - they will still get it wrong.

Session 4: Updates from real projects

Chaired by Claudia Vivalda, Schlumberger

4.1 Weyburn Phase II Risk

Rick Chalaturnyk, University of Alberta

Risk introduced the phases of the Weyburn project and the themes within the project, highlighting that the primary objectives changed a little during the project.

In the 'Final Phase' of the project a different approach was undertaken, this reflected that the environmental and ecosystem impacts were knowledge gaps and one of the major challenges. The full field risk assessment's primary objective changed a little to include three things: biosphere risk, containment risk, and effectiveness risk. The RISQUE method was used (work done by URS) which has also been applied at other sites, including the Gorgon project. The containment risks are fairly standard though it is important to note Weyburn is an EOR operation and therefore will be different than geological storage of CO_2.

The risks changed throughout the project, and it was possible to determine CO_2 loss rates by calculating flow and injection rates. In 2008 one of the highest containment risks was the natural seismicity in the region, as there was very little data available; however with increased knowledge in 2009 the risk quotient reduced significantly. Of course containment risks are not the only risks to consider. Effectiveness risks are also important, which include a change in the economics: particularly important for an EOR project, and if it remains economically viable the site may never switch to a storage site.

A meeting was held with the local community to discuss the risk of leakage to determine what they would be the most concerned about. Their concerns were where the CO_2 will go, will the reservoir be effected by earthquakes, and the effect on the reputation of the area i.e. if there were to be a leak people would no longer wish to move to/or visit Weyburn. The risk assessment process also incorporated linguistic variables: personal attitudes to risk and the consequences of risk which is important to consider for assurance.

Rick closed his presentation by highlighting how pleased he was to hear people are beginning to populate numbers on the shallow environmental impacts, which was highlighted at the early stage of the project as a major challenge and key knowledge gap.

Q. It is an oil and gas field, and as methane is a greater greenhouse gas, why haven't you assessed the possibility of methane leakage?

A. This is a good question. The research has started to assess the site for CO_2 storage, but clearly the movement of other gases is important.

Q. When you went to the community, how did you define a leak?

A. The unintended movement of CO_2 to the biosphere. There was no discussion of the criteria used as it is appropriate to discuss what the quantity of the leak will be, and it is up to them to discuss what aspects they would be worried about.

4.2 Demonstrating Iterative Risk Assessments Using In-Salah Experience
Kevin Dodds, BP

Kevin introduced his presentation as a high level exercise, with many hidden processes which would not be included in the phases shown in the diagrams of operation stages.

In Salah is a flagship project, which will demonstrate different risk assessment processes to develop best practice. Prior to drilling a risk register was produced to identify the key risks and actions needed to reduce uncertainties associated with these risks. A URS RISQUE was commissioned in 2008, also applied to CO2CRC ESSCIs, Otway Pilot Project and Weyburn; which allows comparison with other projects, following In Sar surface deformation observations. Further high resolution seismics were used to evaluate the effects of fractures in the subsurface and near surface. A seismic data update is planned in 2010.

The monitoring programme was developed to be able to identify problems should they occur, including injection well problems, migration out of the storage domain, wellbore leakage and early CO_2 breakthrough. We injected tracers to help identify the CO_2 flow, an important part of the monitoring operations. To monitor for well problems there has been ongoing pressure monitoring, through-casing logging, step rate tests, pressure fall-off tests and production logging, and for migration out of the storage domain a suite of seismic, satellite imagery, observation wells, microseismic and, shallow aquifer monitoring.

A certification framework was developed as part of the project, and it was important to perform a top down approach very early in the project to identify what you do know to validate the process. The certification framework aimed to develop a simple framework for evaluating leakage risk for certifying operation and decommissioning of geological CO_2 storage systems. Within this framework, five compartments were identified: Emission Credits and Atmosphere, Health and Safety, Near-Surface Environment, Underground Source of Drinking Water, Hydrocarbon and Mineral Resources, with two main conduits or leakage pathways: wells and faults and fractures. Once compartments are identified it is then possible to evaluate the probability of one leakage pathway crossing a domain/compartment. It is necessary to have an acceptable containment measure to compare with other projects, and for InSalah this was 99% of the injected volume over 1000 years. The identified potential containment risks were categorised as seal, fault, wells, regional over-pressurization, out of closure leakage, and exceeding spill point, and each were quantified according to their risk quotient.

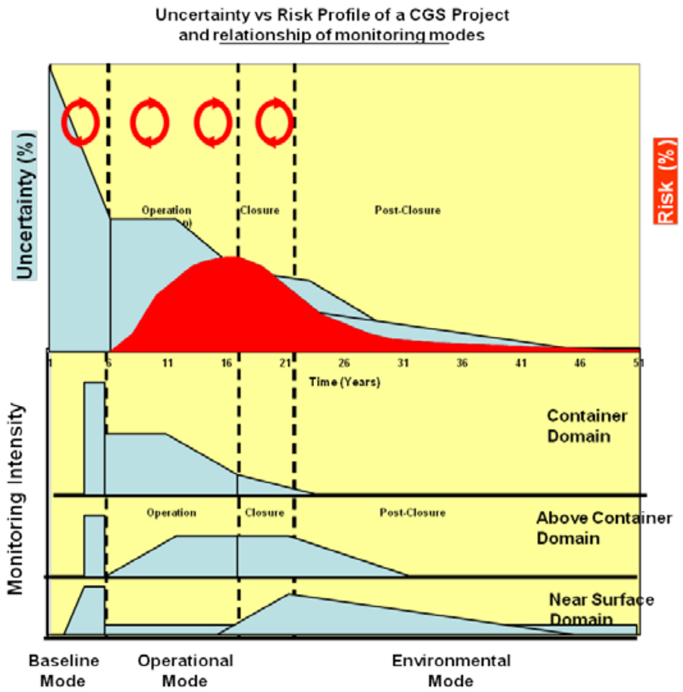

Figure 4. Proposed Risk Profile by K. Dodds, BP

The gained uplift knowledge identified a need to reassess the risk profile, as this highlighted the need to update information on fractures and barriers which may have been causing the uplift; hence increased knowledge doesn't necessarily reduce the uncertainties. It is important to note that if there are any alterations to the site, such as a new borehole drilled, then the risks would need to be re-calculated.

Kevin closed his presentation by discussing the BP risk analysis process, with expert groups for the URS QRA, the CF and the more technical internal risk assessment map which removed bias from the expert group analysis; and the proposed risk profile which differs from the Sally Benson curve (Figure 4).

Q. Didn't the decrease in uncertainty reduce the risk?

A. The risk still remains, though we may know more information and have an increased chance of mitigation. The risk may in fact increase with increasing information.

4.3 Otway and the risks of monitoring
Charles Jenkins, CSIRO & CO2CRC

Charles began by introducing the fact that nowadays nothing is hidden, and everything you do is potentially something which can be made public.

> Monitoring is generally undertaken for assurance; however, the more you measure, the more likely it is that you will have to explain something. In particular you are likely to have "false alarms" because of measurement error or natural variability, and it should be clear in advance what qualifies as a false alarm on statistical grounds. The difficulty is then that a conservative false alarm level also means that the measurements lose sensitivity to real anomalous events. This is a familiar trade-off in experimental design.
>
> Examples from Otway: The Otway monitoring program involved near surface soil gas monitoring, and each time the soil gas was measured it had to be taken at a different site due to access problems and weather conditions. Head space gas in water boreholes is something required by regulators. In both cases the statistics of the measurements are poorly understood and it is impossible to apply rigorous principles of experimental design. Other examples: an anomaly was seen is the sulphate levels of groundwater, and also in SF6: a tracer added to the injected CO_2 stream. In both cases it turned out that the notion of "anomaly" was ill-defined because the statistical properties of the data has not been accounted for; but defining the false alarm level rigorously after the fact is not satisfactory and could attract accusations of meddling with the data, as has been seen in other climate-related controversies recently.

Charles concluded by highlighting the importance of taking care when interpreting results.

C. I regularly make groundwater measurements and don't perform statistical analysis. I feel statistics are not necessary, and rather more data is required to eliminate erroneous results.

A. It has taken a very long time to get the measurements we have, and in any case, any scientific result has to have an error bar associated with it. This requires statistical analysis.

C. If you are taking groundwater measurements you need a groundwater model, so I don't understand why you are rushing in to take measurements without a conceptual model.

A. We do have a conceptual model, but it doesn't help much. The aquifer is shallow, unconfined, and strongly affected by rainfall and extraction.

C. I don't understand why a drop in sulphate concentration would be an issue with only a handful of measurements.

A. It is not an issue if what qualifies as an anomaly has been defined in advance. It is an issue if the notion of an anomaly is subjective as the results of assurance monitoring need to be crystal clear to all stakeholders, even hostile ones.

C. This is very interesting. You have discovered something which has been known for a long time, and need a way of analysing sampling error and analytical error.

A. Indeed I have been describing the well-known Neyman-Pearson formulation of hypothesis testing.

4.4 From Decatur to Denver: Progress in Information Capture for CCS Risk Assessment

Ken Hnottavange-Telleen, Schlumberger Carbon Services

Ken introduced his talk by explaining that he will discuss a methodology for collecting risk assessment data which starts very early on in the project for project design and early risk management.

> The risk assessment process evaluates the risk associated with a FEP, quantified by identification of the likelihood and the severity, focussing on scenarios related to the FEPs to efficiently generate risk reductions. Throughout the Illinois Basin Decatur Project very few aspects of the risk assessment process has changed, though some aspects have, for example there is now one working group as opposed to six in the beginning, which ensures everyone hears the same discussion and to minimise bias. The facilitators also now use a wireless keypad to capture data immediately, providing instant feedback, speeding up the process.
>
> The main instruments for risk assessment are very similar to those presented by Kevin Dodds, though the maths are a little different. The likelihood and severity levels are plotted onto a risk matrix, where black indicates a high risk, and blue indicates a low risk. Moving across the table from left to right increases the likelihood, and moving down increases the severity; labelled 1 to 5 from very likely to very unlikely and light impact at -1 to severe at -5. This may need to be expanded to include the probability. It is then possible to include specific project values to define the impact, including health and safety, environment, financial, storage security and social acceptance impact. There are three FEPs which have the most consistent risk levels when performing risk evaluations: schedule and planning, geology: additional confining formations [besides primary seal] and social actions and reactions: local.

Ken then performed a live demonstration of the wireless keypad devices used to instantly evaluate FEP analysis, by collating live data on a number of key questions. These questions included: What is the best-guess or mean severity of potential negative impacts to project values in schedule and planning, where not very severe is one, and severe is five? which collated an audience mean of 3.15, and What is the best-guess or mean severity of potential negative impacts to project values in local social actions and reactions? which resulted in a mean of 4.68.

So, according to the poll, the results indicate schedule and planning has a medium severity, social actions and reactions are a high risk, and confining seals are a low risk. As well as these, there are five very specific risks which are the least consistent: Site setting: boreholes, Geology: fractures and faults, Groundwater contamination by CO_2, Site setting: community characteristics, Injection effects: Induced seismicity. Of these, Groundwater contamination by CO_2 and Injection effects: Induced seismicity have been separated into technological risk ranking and public perception risk ranking, highlighting that the perception of these are much higher than the technological aspects. There are many different opinions on risk and a consistent opinion and approach is needed.

C. The spread of the values is as important as the mean.

A. Yes, absolutely. The ranking of the risk is important.

Q. Do you see a difference in an outcome when comparing an audience such as this, and one formed of the general public?

A. Yes, at the beginning of each risk workshop we go through a number of questions where each is asked to inform us of their area of expertise as pertinent to each FEP. We don't know enough yet, but from the workshops we do show a difference between expert comments and those of non-experts, so we are aware of a difference.

Q. What is your opinion about mixing technological and perception aspects? As in the current format the question doesn't define which aspect we are considering, and we may be thinking differently?

A. Yes, it is of course important to clearly define the question, but there will still be different thought process despite clear definition.

4.5 Research and application of CCS in China

Lidong Wang, North China Electric Power University

Lidong introduced the global CO_2 emissions per country and energy consumption in comparison with that of China, highlighting the percentage of coal in China's energy mix and the quantity of such used for electricity; therefore highlighting the need for CCS. Lidong then provided an overview of research in both carbon capture and carbon storage, and international cooperation on CCS through Near Zero Emissions Coal (NZEC), Cooperation Action within CCS China–EU (COACH) and the China Australia Geological Storage Project (CAGS). The capture demonstration projects were described, on the Beijing power plant which captures 3000 tonnes per year, the Shidongkou power plant with between 100,000 and 160,000 tonnes captured annually, and the Shuanghai power plant capturing 10,000 tonnes per year, all of which using MEA as the capture method. EOR pilot projects were also discussed including the Jilin oil field, the Daqing oil field and the Shengli oil field; and a coal bed methane project in the South Qinshui basin, injecting 192.8 tonnes of CO_2 to increase methane production from 2.8 to 15; concluding by discussing whether or not CCS in China is ready for commercial demonstration.

Q. Has anyone in China looked at pelletized iron to capture CO_2?

A. Yes, there are some researchers looking at liquid iron to capture CO_2, but there are many problems including regeneration of the absorbent.

Q. Is there any activity in terms of advancing CCS with industry/power companies?

A. There are no large scale projects, though there are small scale demonstrations.

Session 5: Induced Seismicity/Geomechanics

Chaired by Dag Nummedal, Colorado School of Mines

5.1 Induced Seismicity and its implications for CO_2 Sequestration Risk

Matthew Gerstenberger, GNS Science and CO2CRC

Matthew introduced the presentation by discussing the aim of the research undertaken, which was to determine the probability of induced seismicity with injection projects, including water injection, by evaluating existing data.

> There is very little consistency within the collected data, such as the injection pressure, and there seems to be considerable bias with a need for more data. Within the data the majority of the events are small events which wouldn't be felt on the surface. The datasets were analysed to determine whether there were any correlations, and there appears to be a directly proportional relationship with the volume of fluid injected and the magnitude of the event; however the pressure is inconsistent and more data is needed to conclude whether this correlation is appropriate. For three sites the majority of events occurred prior to the end of injection. Additionally, the largest events are likely to occur within 5km of the injection site.

These are preliminary results, and there is a bias towards higher magnitude events, plus the depth information may not be relevant to CO_2 injection. The spatial component needs further work for clarification. We also need to consider further work in terms of risk.

C. There may be induced seismicity in secondary water flooding in EOR operations, but it hasn't been seen in CO_2 injection, so it is important to constrain what is injected and at what phase of the operation.

A. Yes, we do have this information, and we can display this in further work.

Q. It is important to screen whether projects have exceeded the fracture gradient. What about natural tectonic activity and what affect this will have on a project?

A. For Otway we have performed a seismic study, which will have the same risk as seismicity in this research; however it will be different with differing infrastructure etc and relevant information is limited.

C. We really need to know whether the events you presented are due to natural seismicity, and the data needs to be presented with more details and in context to the specific operations.

A. Yes, there was work done to screen some values which identified some which were due to natural seismicity, but we really need more data to eliminate bias presented here.

5.2 Risk Assessment Tools in Geomechanics
Vaughan Griffiths, Colorado School of Mines

Vaughan introduced his talk by discussing the increase in the use of probabilistic tools in geotechnical engineering, ranging from simple established techniques to more complicated advanced tools, for example using finite element methods.

Risk assessment is inherently quantitative, with an aim to attach a number on things such as trying to determine reliability or the probability of failure. When using the traditional approach of probability of failure and factor of safety, a safer approach may actually have a higher probability of failure; which does not occur when using a probabilistic approach (Figure 5).

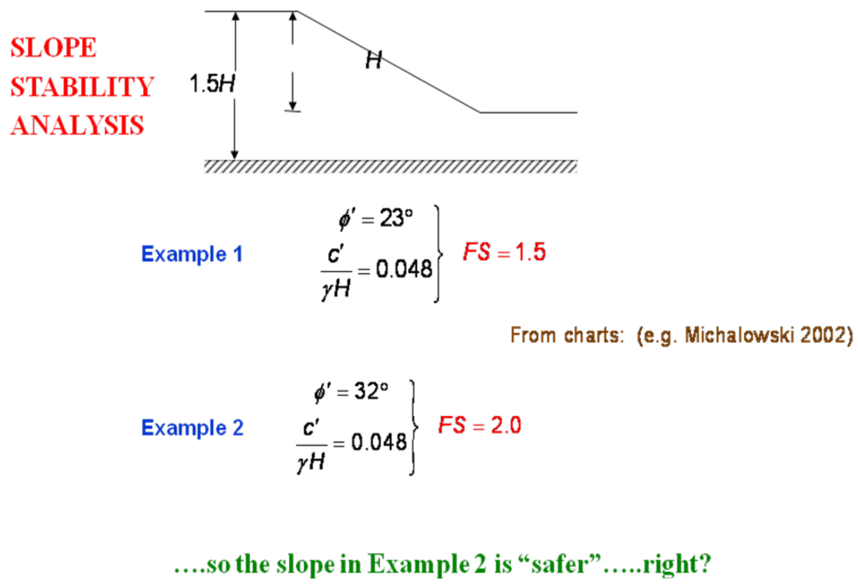

Figure 5. Traditional calculation of slope stability factor of safety

There are three levels of probabilistic analysis of risk assessment: 1. Event trees, 2. First Order Reliability and 3. Random Finite Element Methods (RFEM). Event trees rely on an expert panel, case histories, local site experience and engineering judgement; first order reliability methods uses readily available optimization tools and delivers an estimate of design reliability index, and RFEM uses random field theory and Monte-Carlo simulations, explicitly accounting for spatial variability and correlation though can be computationally intensive. The high order level RFEM produces an infinite number of combinations to identify risk of failure.

Vaughan concluded by highlighting the variability of soil and rock in their natural state, and this variability is usually coupled with a paucity of data. Risk assessment methods provide an essential tool to assess engineering performance and it is better to be probably right than exactly wrong.

Q. Random fields is a strong assumption – how well constrained are these random fields?

A. We are in need of good quality data, and we are looking at various papers to get a handle on how variable rocks and soils are, but at this stage we can only approximate a range, and cannot provide specific constraints.

C. Some of us are working on this in CCS, using geostatistical methods, so thank you for highlighting its relevance.

A. Great.

Q. You talked about geomechanics in dam design: do you think the knowledge was advanced enough in the 1930s?

A. The Hoover dam was extremely heavy, and nowadays this would not be built.

Session 6: Long-term Risk Management

Chaired by Malcolm Wilson, IPAC-CO2

Panel Members: Rick Chalaturnyk, University of Alberta; Kevin Dodds, BP; Kevin Doran, University of Colorado; Mike Stenhouse, INTERA Inc.

The panel discussion opened with a short presentation from each of the panel members. Kevin Dodds began by asking: how do we quantify the risk profile? and is the long term risk decrease too simplistic, referring to his previous presentation's proposed revised risk curve. He also stated monitoring emphasis should switch to the near surface domain with time and long term risk is never zero and will always have a finite value.

Mike Stenhouse discussed long term risk management with the use of two presentation slides, one displaying the Framework for Risk Assessment and Management (OSPAR) and the second displaying escape mechanisms from the IPCC (2005) special report. Mike highlighted that some experts argue post closure monitoring, or long term monitoring, isn't needed as operators are required to prove the CO_2 is contained; however, there is still a need for long-term monitoring. Sites for nuclear waste disposal are well characterised and can be accessed immediately, as opposed to CO_2 storage sits which have large uncertainties. The nature of the risk profile is site specific, so the risk assessment should work to characterise this profile for each site, and monitoring is an important part of the risk assessment process and long-term plan.

Kevin Doran opened by addressing the need to characterise what risk we are actually discussing, whether this is operational, geological, financial, liability or climate change. REPRA allows for the ability to sue if there is a danger to the environment, which could provide liability if CO_2 was to be listed as a hazardous waste, similar to hydrogen sulphide injection. SURPLA, allows joint, retroactive liability, which would be limited to damages directly related to the leak of hazardous waste. There are also State statutes which are designed to manage risks, and common law which could be used for risks associated with negligence or trespass. It is important to consider all risks in a project, particularly liability which is a big unknown at this stage in the CCS chain. It may be appropriate to phase the transfer of liability to the State, and have appropriate risk assessments before each phase.

Rick Chalaturnyk began positively by arguing that on most levels, the CO_2 storage community are able to conduct an efficient risk management plan; however operational risks may still be a problem. Rick expressed his belief that tight management of operational risks is the key for long-term risk management, alongside the integration of continuous monitoring data with evolving simulations to ensure detailed knowledge of the site.

C. Kevin Dodds. It is about demonstrating that you can contain the stored CO_2 for a long period of time. Operation risks are different.

C. Mike Stenhouse. I agree with Rick's optimistic view. Operational risk is similar to those of existing projects, such as EOR operations. The injection phase is when you need a lot of feedback about what is going on in the reservoir. This knowledge will assist in the long-term phase. We need to be paying attention to the long-term phase.

C. Kevin Doran. Most of the risk is in the operational phase. Perception of risk is going to be hugely important. We can describe it technically, but you have to be able to describe it effectively to the public and regulators.

C. There is a good saying. What we know we don't know, and what we don't know we don't know. We don't know what process will appear in 50 years time, either about bias or what is happening in the reservoir. Sometimes the scientist is the wrong person to ask about risk and what we know. The public are constantly bombarded with confusing information, where scientists report one thing one time, and it changes with future research. This raises the level of uncertainty in the public's mind. In Texas there are formation fluids leaking to the surface from wellbores affecting agriculture, so the public logically have genuine concerns. Things may crop up, and we need to ensure operational excellence through all phases.

C. Kevin Doran. It will be this generation's perception of long-term risk which will determine regulations and operations, not future generations.

C. It would be wise to remove processes from scenarios. People are not stupid, and they want you to be earnest about what you do. A lot can be done. Don't short change the data needs you have, and give the regulators clarity. Don't wait for them to come to you.

C. Kevin Dodds. We have to start somewhere with a preliminary model, but then need to continually adapt and adjust the model with time. There will always be uncertainty, but we have to build a program and make informed decisions.

C. On the health and safety side of things, people are going to need assurance.

C. Mike Stenhouse. We have results from Weyburn on leakage, and have asked what this means in terms of health and safety by identifying how much CO_2 would be needed to make an impact.

C. The risks you're evaluating aren't just technical. It is important to base the potential consequences on the basis of how much can leak from a storage site.

C. If you are working to create an effects based risk profile this will be very different than an operational risk profile.

Session 7: Outcomes and Recommendations

Chaired by Malcolm Wilson, IPAC-CO2 and Tim Dixon, IEAGHG

Panel Members: Kevin Doran, University of Colorado; Charles Jenkins, CSIRO and CO2CRC; Jerry Sherk, Colorado School of Mines, Claudia Vivalda, Schlumberger and Dag Nummedal, Colorado School of Mines

Each of the session chairs prepared a one slide presentation of key messages from their session, and these were presented and agreed upon by the workshop participants. The following lists the key messages from each of the sessions.

Session 1: Regulatory Requirements

The adequacy of existing regulatory frameworks needs to be addressed, and there is a need for adaptive approaches. Aggressive timelines may need to be reconsidered, and process and substance is important. There also appears to be terminology confusion, and it is important to address what Risk Assessment means.

Session 2: What can risk assessment deliver?

Risk assessment is an iterative process, and has an important role in operator long term liability. There is a hierarchy of risk at different levels in operation. It is important to avoid overcomplicating things and develop regulations that work, building in lessons learnt from nuclear waste industry.

Discussion: What does industry expect risk assessment to deliver?

Risk assessment needs to deliver a statement of a project's liabilities, provide guidance for risk management to establish procedures, guidance on a projects design, information to satisfy regulators/permitters and stakeholders, information to provide assurance, and lastly not numbers, but arrows to guide the projects management plan forward.

Session 3: Risk Communication

There is a need to express risk using terms and images that can be understood by the public, especially given the trend toward increased public participation. A need to learn to work with both print and electronic media to "get the story told" correctly; to develop the capacity (a) to separate the chaff from the wheat and (b) to counter misinformation; and a need for candor over time; "you can only lose your reputation once." We exist in a climate of fear: to counter that fear we need to take care to follow the above. Also a database of key papers transcribed in laymen's language would be very useful for risk communication.

Session 4: Updates from real projects

There were four key areas highlighted: Metrics, with a need to identify reasonable acceptability levels; Benchmarking, with a need to compare methods to ensure consistency, and to exchange lesson learnt with upcoming projects. Interpretation of data: how do we ensure reliability and efficient interpretation to feed into risk assessment? and the Value of information and over simplification**:** care needed to ensure do not omit relevant information in effort to simplify.

Session 5: Induced seismicity/geomechanics

There is a lack of available data, bias needs eliminating; and care must be taken when communicating research outputs: must be communicated in context.

Other relevant messages

Monitoring is crucial to understand the storage reservoir and predict CO_2 behaviour. There is a need to validate models, and there appears to be three big unknowns: geomechanic responses, geomicrobiological, geochemical and mineralogical changes. We need more field measurements to understand the kinetics.

Session 6: Long-term risk management

There is a need to quantify the risk curve, and the risk curve may differ from the previously assumed curve. It is crucial to give the regulators clarity – don't wait for them to tell you. Both operational risk and long-term risk needs consideration: differing opinions on relative significance. It is important to continuously reassess risk profile and management plan as the project progresses and knowledge increases; and of course public perception is key, the public will demand monitoring. Start off as you wish to continue.

These key messages were then brought together in an open discussion to identify recurring learnings from all of the sessions. These were identified as:

- ***There is a need to address the adequacy of existing and emerging regulations. Take an active role and provide regulators with information.***
- ***It is extremely important to build trust with the public, and care should be taken when using terminology which should be consistent.***
- ***How can acceptable levels of risk be defined? This needs to be answered in the near future.***
- ***There is a growing need for data from more demonstration projects to improve understanding of risk profiles, and knowledge sharing should be encouraged.***

Drawing from all the sessions, the key knowledge gaps were highlighted as:

- ***There is a need for more information on monitoring performance***
- ***There is a need to understand microbial response and geochemical changes***
- ***Interaction is needed between the IEAGHG Risk Assessment Network and the IEAGHG Monitoring Network***

Finally, the important recommendations from all the participants of the 5th Risk Assessment Network Workshop:

- ***Avoid research overlaps***
- ***Further work is needed on metrics for quantification of risk***
- ***There is a need for benchmarking between projects and open knowledge sharing***
- ***Important to use analogues to understand processes in addition to models***
- ***Define terminology and ensure consistency (as per the IEAGHG report)***
- ***Encourage greater industrial representation at Risk Assessment Network workshops, and strengthen links.***
- ***Provide information for regulators and in depth training***

ieaghg

5th Risk Assessment Network Meeting

Evaluating technology options to mitigate greenhouse gas emissions

17th-19th May 2010
Denver, Colorado, USA

Organised by

IEAGHG and
Colorado School of Mines

COLORADO SCHOOL OF MINES
EARTH ENERGY ENVIRONMENT

Sponsored by
IPAC-CO2

IPAC CO2 International Performance Assessment Centre For Geologic Storage of CO2

17th May 2010 Day 1

08.00 to 09.00 Registration

Welcome Chair Tim Dixon; IEAGHG

09.00 to 09.10	Welcome Address: John Poate, Vice President for Research and Technology Transfer at The Colorado School of Mines.
09.10 to 09.30	The IEAGHG Risk Assessment Network: Tim Dixon; IEAGHG
09.30 to 09.50	The International Performance Assessment Centre for the Geological Storage of Carbon Dioxide (IPAC-CO2): Koorosh Asghari; IPAC-CO2
09.50 to 10.05	Future Network Discussion: Chairs: Tim Dixon; IEAGHG and Malcolm Wilson; IPAC-CO2
10.05 to 10.20	Carbon Sequestration Leadership Forum Update: George Guthrie; NETL/DOE

10.30 to 10.50 Coffee Break

Session 1: Regulatory Requirements Chair Kevin Doran; University of Colorado

10.50 to 11.10	Update on the Alberta Regulatory Framework Assessment for CCS: Bettina Mueller; Alberta Energy
11.10 to 11.30	The Development of EPA's Regulatory Regimes: Jason Deardorff; US EPA
11.30 to 11.50	The Geological Storage of Carbon: The Need for Standardisation: Kevin Boehmer; CSA
11.50 to 12.10	Worldwide Regulations for the Geological Storage of CO_2: : Jose Condor; IPAC-CO2
12.10 to 12.50	Discussion: Issues Associated with Regulatory Implementation: Chair Kevin Doran; University of Colorado Panel Members: Bettina Mueller; Alberta Energy, Jason Deardorff; USA EPA, Kevin Boehmer; CSA, Jose Condor; IPAC-CO2

12.50 to 13.50 Lunch

Session 2: What can risk assessment deliver? Chair Charles Jenkins; CSIRO & CO2CRC

13.50 to 14.10	CO2QUALSTORE Report on Quality Audit and Framework for Operation: David Coleman; DNV
14.10 to 14.30	How Experts Work—Then and Now: Mike Stenhouse; INTERA Inc.
14.30 to 14.50	The Long Term Risk Perspective of the Nuclear Storage Industry: Jim Conca; New Mexico State University
14.50 to 15.10	DOE's National Risk Assessment Partnership: Grant Bromhal; NETL/DOE
15.10 to 15.20	Assessing Ecosystem Impacts of CO_2: The RISCS Project: Ameena Camps; IEAGHG
15.20 to 15.50	Discussion: What does Industry Expect Risk Assessment to Deliver?: Chair Ken Knottavange-Telleen, Schlumberger. Panel Members: David Coleman; DNV, Mike Stenhouse; INTERA Inc., Jim Conca, New Mexico State University, Grant Bromhal; NETL/DOE

15.50t o 16.10 Coffee Break

Session 3: Risk communication Chair Jerry Sherk; Colorado School of Mines

16.10 to 16.30	US DOE Best Practice Guidelines: Sarah Wade; AJW Inc.
16.30 to 16.50	Ethics and Communication of Risk: Roel Snieder and Jen Schneider; Colorado School of Mines
16.50 to 17.10	Public Communication for the Geological Storage of CO_2 : Joe Ralko; IPAC-CO2
17.10 to 17.30	Managing Communication Risk at the Illinios Basin-Decatur Project: Sallie Greenberg; Illinois State Geological Survey
17.30 to 18.00	Discussion

Close Day 1
18.30 –19.30 Reception at the Golden Hotel 19.30 Dinner at the Golden Hotel

18th May 2010 Day 2

Session 4: Update from Real Projects Chair Claudia Vivalda, Schlumberger

08.30 to 08.50	Weyburn Phase II Risk: Rick Chalaturnyk; University of Alberta
08.50 to 09.10	Demonstrating Iterative Risk Assessments Using In-Salah Experience: Kevin Dodds; BP
09.10 to 09.30	Otway and the risks of Modelling: Charles Jenkins; CSIRO & CO2CRC
09.30 to 09.50	From Decatur to Denver: Progress in Information Capture for CCS Risk Assessment: Ken Hnottavange-Tellen; Schlumberger
09.50 to 10.15	Research and Application of CCS in China: Lidong Wang; North China Electric Power University
10.10 to 10.40	Discussion

10.40 to 11.10 Coffee Break

Session 5: Induced Seismicity/Geomechanics Chair Dag Nummedal, Colorado School of Mines

11.10 to 11.30	Induced Seismicity and its implications for CO_2 Sequestration Risk: Matthew Gerstenberger; GNS Science and CO2CRC
11.30 to 11.50	Risk Assessment Tools in Geomechanics: Vaughan Griffiths; Colorado School of Mines
11.50 to 12.30	Discussion

12.30to 13.30 Lunch

Session 6: Long-term Risk Management Chair Malcolm Wilson, IPAC-C02

13.30 to 14.30	Discussion: How do we manage long-term risk?: Panel Members: Rick Chalaturnyk; University of Alberta, Kevin Dodds; BP, Kevin Doran; University of Colorado, Mike Stenhouse, INTERA Inc.

Session 7: Outcomes Chair Tim Dixon, IEAGHG

14.30 to 15.20	Discussion: Outcomes and recommendations of the 5th Risk Assessment Network workshop Panel Members: Session Chairs
15.20 to 15.30	Closing Comments: Tim Dixon; IEAGHG, Dag Nummedal; Colorado School of Mines, Malcolm Wilson; IPAC-CO2

Close Day 2 and Coffee

Site visit Rangley

16.00	Travel to Rangely via Coach. The coach will pick up from the Golden Hotel and The Table Mountain Inn before departing Golden
C.18.30	Dinner at the Glenwood Canyon Brewing Company, Glenwood Springs (www.glenwoodcanyon.com)
C. 23.00	Overnight accommodation at the Blue Mountain Inn (www.bluemountaininnrangely.com)

19th May 2010

Rangely Site Visit

08.00	Breakfast at the Blue Mountain Inn
09.30	Arrive at the Chevron Rangely Facility
12.00	Lunch at the Chevron O&M building, catered by Giovanni's Italian Grill (www.giovannirangely.com)
15.00	Depart the Chevron Rangely Facility
C.18.00	Dinner en route
C.21.30	Arrive in Golden

Chevron Rangely Facility tour, hosted by Dag Nummedal, Colorado School of Mines, including:Overview

- Overview presentation, Jeff Roedell
- Leak detection study, Ron Klusman
- Safety briefing, Jeff Roedell
- Site visits of the CO_2 compression plant, production collection station and injection wells

5th Risk Assessment Network Meeting Steering Committee

Tim Dixon, IEA GHG (Chair)
Malcolm Wilson, IPAC-CO2 (Co-Chair, Sponsor)
Dag Nummedal, Colorado School of Mines (Host)
Jerry Sherk, Colorado School of Mines (Host)
Grant Bromhal, NETL/DOE
Ameena Camps, IEA GHG
Rick Chalaturnyk, University of Alberta
Charles Jenkins, CSIRO and CO2CRC
Claudia Vivalda, Schlumberger.

ATTENDEE LIST

5th Risk Assessment Network Meeting

17th-18th May, 2010 Denver, Colorado, USA

Nwachukwu Anywmele, University of Texas
Koorosh Asghari, IPAC-CO2
Olivier Bouc, BRGM
Kevin Boehmer, Canadian Standards Association
David Borns, Scandia National Laboratoy
Grant Bromhal, US DOE/National Energy Technology Lab.
Jim Bryant, IPAC-CO2
Robert Buxton, GNS Science
Ameena Camps, IEAGHG
Richard Chalaturnyk, University of Alberta
John Choptiany, Dalhousie University
Sigrid Clift, University of Texas
David Coleman, DNV
Jim Conca, Mexico State University
Jose Condor, IPAC-CO2
Tim Dixon, IEAGHG
Kevin Dodds, BP Alternative Energy
Kevin Doran, University of Colorado at Boulder
Carmen Dybwad, IPAC-CO2
Lori Gauvreau, Schlumberger Carbon Services
Matt Gerstenberger, GNS Science
Sallie Greenberg, Illinois State Geological Survey
Vaughan Griffiths, Colorado School of Mines
George Guthrie, National Energy Technology Lab.
Ken Knottavange-Telleen, Schlumberger Carbon Services
Charles Jenkins, CO2CRC
Joe Ralko, IPAC-CO2
Ronald Klusman, Colorado School of Mines
Anna Korre, Imperial College London
Pradeep Kumar Dadhich, TERI
James Lepinski, Headwaters Clean Carbon Services LLC
Cameron McQuale, Geogreen
Bettina Mueller, Govt. Of Alberta Dept. of Energy
Dag Nummedal, Colorado School of Mines
Hilary Olsen, University of Texas
Rajesh Pawar, Los Alamos National Lboratory
Stan Pence, Consulate General of Canada
Richard Rhudy, EPRI
Kaylene Ritter, Stratus Consulting Inc.
Jen Schneider, Colorado School of Mines
George Sherk, Colorado School of Mines
Mike Stenhouse INTERA Inc.
Koichi Takizwaw, RITE
Atsuko Tanaka, AIST
Robert Trautz, EPRI
Claudia Vivalda, Services Petrolier Schlumberger
Peter Wyant, IPAC-CO2
Sarah Wade, AJW Inc.
Lidong Wang, North China Electric Power University
K. Udo Weyer, WDA Consultants Inc.
Steve Whittaker, Petroleum Technology Research Centre
Neil Wildgust, IEAGHG
Malcolm Wilson, University of Regina
Kyle Worth, Petroleum Technology Research Centre
Jason Deardorff, US, EPA
Roel Snieder, Colorado School of Mines
Joe Ralko, IPAC-CO2

Evaluating technology options to mitigate greenhouse gas emissions