SUMMARY REPORT OF THE 6TH IEAGHG RISK ASSESSMENT NETWORK WORKSHOP

Report: 2011/**

December 2011

INTERNATIONAL ENERGY AGENCY

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DISCLAIMER AND ACKNOWLEDGEMENTS

This report was prepared by Dr Ameena Camps of IEAGHG as a record of the events of the workshop.

The 6th IEAGHG Risk Assessment Network Workshop was organised by IEAGHG in co-operation with BRGM. The organisers acknowledge the financial support provided by BRGM and International Performance Assessment Centre for the Geological Storage of Carbon Dioxide (IPAC-CO_2) for this meeting; the hospitality provided by the hosts, BRGM, at the Le Palais Beaumont, Pau, France and, for the hospitality provided by TOTAL during the site visit to the Lacq-Rousse project.

An International Steering Committee guides the direction of this network. The International Steering Committee members were:

Ameena Camps, IEAGHG (Chair)
Olivier Bouc, BRGM (Co-Chair; Host)
Tim Dixon, IEAGHG (Co-Chair)
Hubert Fabriol, BRGM (Host)
Adrian Bowden, URS
Grant Bromhal, USDOE/NETL
Rick Chalaturnyk, University of Alberta
Kevin Dodds, BP
Charles Jenkins, CSIRO and CO2CRC
Angeline Kneppers, GCCSI
Jerry Sherk, IPAC-CO2

The International Steering Committee also wish to acknowledge Pauline D'Armancourt of BRGM for all her work in organising the logistical aspects of the meeting; Claudia Vivalda for her expertise and advice during programme discussions, and Samantha Neades of IEAGHG for her organising prowess.

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'IEAGHG, "Summary report of the 6th IEAGHG Risk Assessment Network Workshop", 2011/**, December 2011'

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Introduction

The 6th IEAGHG Risk Assessment Network Workshop was held from the 21st to the 23rd of June in Pau, France hosted by BRGM; sponsored by BRGM and International Performance Assessment Centre for the Geological Storage of Carbon Dioxide (IPAC-CO_2). 54 participants attended the workshop from 15 different countries.

The three day workshop highlighted the latest international CO_2 storage risk assessment developments, discussing communication and regulatory developments, risk and incident management, potential induced seismicity, monitoring performance, understanding potential groundwater impacts, risk assessment methodologies, key outcomes and identified knowledge gaps which need to be addressed in future research. Participants were fortunate to visit the TOTAL Lacq-Rousse project on the 3rd day of the workshop, including the oxy-combustion capture site and the storage site in the afternoon, with a TOTAL sponsored lunch.

The agenda and presentations from the meeting are available in the network members' area of the IEAGHG website (www.ieaghg.org). The previous workshop agenda, presentations and report are also detailed on this website.

Session 1: Risk Communication & Regulatory Developments

Chaired by Tim Dixon, IEAGHG

Suzanne Brunsting of ECN presented **lessons learnt from risk communication of the Barendrecht project** in the Rotterdam area of The Netherlands, cancelled in 2010 following public opposition. A survey conducted in Barendrecht concluded the majority of the population were aware of the project; however there was little knowledge of the technology itself with 80% of those surveyed believing the decision-making process was unfair. Primary concerns were related to safety and very little appears to have been communicated to allay these concerns. The project highlights the importance of risk communication to discuss uncertainties and provide trusted information, having a dedicated public outreach team and an independent mediator, facilitating public participation as part of a formal risk assessment.

Since the last Risk Assessment Network (RAN) Workshop, **the Canadian Standards Association have been developing a CO_2 standard**, bringing together the best practices and guidelines for a standard up to the transfer of liability. Rick Chalaturnyk of Calgary University presented an update on the development process with an aim to enable an International standard. The final EU Guidance Documents to support coherent implementation of Directive 2009/31/EC on the geological storage of

carbon dioxide have been published. Raphael Sauter of the European Commission discussed the **CCS Directive and the Guidance Documents**, presenting the CO_2 Storage Life Cycle Risk Management Framework and relevant risk aspects including: guidance for a monitoring plan to be risk based, scope and format of corrective measures plans and integration with the EU ETS. An EC report on the transposition of the Directive will be available in May 2012.

The Session discussion focussed on **decision 7** of the Sixteenth Session of the Conference of the Parties to the UNFCCC/Sixth Session of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (**UNFCCC COP 16/CMP 6**). This decided CO_2 capture and storage in geological formations is eligible as project activities under the Clean Development Mechanism (CDM) provided issues identified are addressed and resolved. Discussion aimed to carry forward RAN points and recommendations to the upcoming technical UNFCCC workshop on modalities and procedures. Delegates highlighted the importance of focussing on the objectives of risk assessment rather than the methodology used, questioning the terminology used in the decision text; questioned whether consideration of non-GHG issues was relevant for the CDM; noted the iterative nature of risk assessment, hence process throughout the lifetime of a project is important and recommending the use of an expert panel or network of experts to support the UN system.

Session 2: Understanding Potential Groundwater Impacts

Chaired by Ameena Camps, IEAGHG

There are several challenges in predicting potential groundwater quality impacts; including heterogeneity and rate limited chemical reactions. These highlight a time scale issue; which to understand requires the integration of laboratory and field data. Elizabeth Keating of Los Alamos National Laboratory presented results from **field, laboratory and modelling studies at a natural analogue site Chimayo in New Mexico, USA**: a shallow sedimentary aquifer where there are a lot of trace elements in the water and soil. Beneath the shallow water aquifer which is highly dissected by faults with CO_2 flowing up-dip; is a carbonate layer with brackish water. Trace elements have been found to be associated with the brackish water; in-situ mobilisation is negligible; and CO_2 entrains the trace metals from the deeper layer bringing them to the surface not mobilising the trace metals; showing the system is dominated by reactions below the aquifer and brine displacement is more important than reactions in the shallow aquifer.

Julie Lions presented the results of the **IEAGHG study: Potential Impacts on Groundwater Resources of Deep CO_2 Storage**, a review summarizing the current knowledge and identifying research priorities. GIS-approach has been used to determine possible over-laps/conflicts between freshwater aquifers and deep saline formations with potential for CO_2 storage in Europe and North America; however hydrogeological data used does not contain depth data therefore site specific information in required. Areas with potential deep saline formation storage overlain by aquifers include: onshore in Germany and the Paris Basin and should be further considered. There are limited analogue and experimental studies, and in the field there is no impact directly observed on fresh groundwater in the CCS context, with large variability in modelling results. Hydrodynamic models show the effect of pressurisation to be much larger than the area associated with the plume; however brine displacement was found to be only over a very small distance and unlikely to affect groundwater resources. The study considers mitigation methods. Careful design of storage operations will minimise risk.

GCCSI established a thematic group in 2010 on the theme of **Managing impacts of CO_2 storage on groundwater** which held its first workshop in May 2011 focussing on Australian flagship regions. There are four main regions including the proposed Collie Hub project, Perth Basin; Wandoan, Surat Basin and CarbonNet, Latrobe Valley all at varying stages of development; and the existing Otway project in the Otway Basin which has groundwater monitoring stations in place demonstrating no change has occurred between pre-and post-injection. The workshop identified there is a poor level of knowledge about deep saline formations and their interaction with other water bodies, convergence of 3D modelling between groundwater and resources is required, unnecessary prescriptive monitoring should be avoided. Angeline Kneppers concluded future research should establish deep groundwater

baseline data for the flagship projects, consider how to avoid excluding groundwater bodies that could be considered unsuitable for CO_2 storage but are not potable and ensure consistent communication.

Potential impacts on microbial populations and implications for groundwater was highlighted as a knowledge gap at the 5th RAN workshop and Julia West of the British Geological Survey was invited to present research results in this field. Microbes will exist in geological settings relevant to CCS. Nutrient and energy supplies for microbial growth, as well as microbes themselves, may be introduced into the deep subsurface through CCS activities, and each CO_2 migration scenario will impact on indigenous microbial populations. Microbes are unlikely to survive in supercritical CO_2 environments, however many will survive and thrive in contact with CO_2 gas or dissolved phases generating biofilms. CO_2 can act as an energy source by methanogens which can impact on the oxidation of minerals. Resulting physical impacts from microbial activity on the reservoir includes the alteration of porosity impacting injectivity (as seen at Ketzin due to not adding a biocide on injection); and chemical impacts include change in pH, mineral formation or degradation and mobilisation of trace elements. Models to understand microbes and groundwater do not consider microbes which catalyse geochemical processes. Microbial effects may be small or undetectable in initial period of storage but is site specific and the effects of CO_2 injection needs to be evaluated.

Session 3: Methodologies

Chaired by Rick Chalaturnyk, University of Alberta

Matt Gerstenberger of GNS Science discussed the results of a project examining various **risk assessment methodologies for CCS**. Risks can come from anywhere in the system and are not independent; hence an integrated system assessment will highlight greatest risks. It is important to identify what we know and how well we know it for risk assessment. Much of our knowledge comes from modelling which is insufficient for risk assessment; expert judgement will almost always be required. Uncertainty can be dealt with through expert elicitation to help guide the process, to further understand probabilities and draw components of risk assessment together. Structured expert elicitation guidelines are available, including the Cooke methodology, providing an iterative process, a workshop environment with weighted group response though the questions posed are key for an effective weighted response. Future risk assessments should consider the development of conditional probabilities, structured expert elicitation, weighted expert judgement and open methodologies.

Developing a common rational and operational Methodology of ANAlysis Unified and management of risks for CO_2 geological Storage within the French context, Yann Le Gallo of GeoGreen presented preliminary results of **MANAUS.** The projects final output will be a methodological guide, providing a review of tools and methods for risk analysis, functional analysis for storage, risk scenarios, uncertainty management and impact potentials. Commercial flow and geochemical models and software for uncertainty analysis have been examined with comparison studies of high level functionalities of models. Models have been ranked for suitability, and some proved unsuitable for CO_2 storage. Strengths and limitations of methods and tools for analysis have also been considered.

Adrian Bowden of URS presented **Biosphere and Geosphere risk assessment** process using the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage project as an example. Many technical inputs are considered in geosphere risk assessment and the outputs identify what risk events, and the likelihood of such, may move CO_2 from the geosphere to the biosphere. Biosphere risk assessment then identifies the risks to biosphere assets with ranking and severity, applying EIA methodology to CCS. Community engagement is then used to ascertain what the community believe are pertinent considering valued assets. At Weyburn wells were identified as the key risk issue, and community valued assets included camping areas and native prairie habitats. A workshop forum can be used to bring together technical studies on risk components and identify required expertise with each specialist providing a summary of key findings. A consequence table can be used to estimate potential impacts. It is important to engage at all levels and involve a different expert network.

Max Watson of BP presented the new BP concept and tool, integrating dynamic changes in CO_2 storage system relative to leakage risk mechanisms through time and space: **Quantitative Risk**

Through Time (QRTT). This uses the inclusion of dynamic aspects such as the degree of trapping, the pressure, and what are these attributes in time. Risks will change as the CO_2 storage reservoir evolves with time i.e. once the plume reaches the trapping structure there will be seal risks, once in chemical trapping phase the risks drop significantly. Monitoring will be based on the risk plan and to the project design will aim to reduce risk. As injection begins, the model can be used to match performance with time, identifying the level of risk with time. QRTT has been successfully demonstrated on In-Salah but requires further demonstration.

Presenting on behalf of Grant Bromhal of US DOE/NETL, Elizabeth Keating of Los Alamos National Laboratory highlighted the latest developments of the **National Risk Assessment Partnership (NRAP)**, specifically associated with long-term quantitative risk profiles. NRAP is using an integrated assessment model approach to predict site performance, including a model for risk profiles in groundwater systems calculating the dynamic evolution of risk proxies such as pH and Total Dissolved Solids (TDS), using a wellbore-release model to calculate potential CO_2/brine leakage rates based on pressure and saturation, and a reservoir model to predict pressure and saturation at the reservoir-caprock interface. Results have identified preliminary risk profiles showing recovery initiates after injection ceases and impact probability decreases with distance from release. Following focus on quantification methodology and tools, in the next two or three years the US DOE will focus on the science base to reduce uncertainty then integration of monitoring and mitigation strategies.

To examine measurements of meaning and question uncertainty, Ken Hnottavange-Telleen of Schlumberger Carbon Services discussed how we identify sources of risk, subdivide risk and apply a quantitative estimation of how we understand that risk, given there is no **'completeness' in risk identification** so thoroughness is the best we can achieve. New conception of risk may be the product of applying metathinking to identification of risks, assisting in the thoroughness of risk assessment.

Discussion reiterated the importance that though the methodology used for risk assessment of a project should be traceable, selection of a methodology should be specific to a project and, rather than examining or attempting to compare methodological approaches the verification of communication should be the main focus. Risk Assessment should provide guidance for decision makers.

Session 4: Risk & Incident Management

Chaired by Angeline Kneppers, GCCSI

Presenting and discussing the **IEAGHG Weyburn Midale CO_2 Monitoring and Storage Project's response to claims of a CO_2 leak**, Rick Chalaturnyk of the University of Alberta; on behalf of Norm Sacuta from PTRC; highlighted the history of testing at the Kerr farm from initial water testing by Saskatchewan mines and energy to the Petro-Find claim of a shift in the isotopic concentrations in soil gases. With the detailed monitoring program and knowledge of the injected isotopic concentration, PTRC response shows there is no evidence for a change in isotope concentrations in soil gas due to the project, and all values are within the range of naturally occurring CO_2 in soils in Saskatchewan; hence the phenomena observed can be explained by near surface processes. Further investigations are underway. This highlighted a process for management, including development of communication tools such as key messages, establishing a point of contact and the production of an official response; in addition to reinforcing the importance of baseline measurements.

Thomas Le Guenan of BRGM presented **GERICO, a database for geological CO_2 storage risk management** which aims to be a communication tool for risk treatment measures, similar to the IEAGHG Monitoring tool, following recognition of the importance of more emphasis needed in risk treatment. The database orders risk mitigation measures according to causes and consequences of a top event. The tool or database is in development and once the first version is finalised it will be made available online in French and English, potentially linking with the IEAGHG Monitoring tool.

DNV have developed a new guideline – **CO2WELLS** - during a joint industry project, supplementing the CO2QUALSTORE guideline. The guideline provides guidance on the risk assessment of active and abandoned wells during the initial screening of a candidate storage site and the qualification of

these wells for continued use or modified use. Though primarily for existing well stock this risk management framework can also be used as a basis for new well stock qualification. Mike Carpenter of DNV presented and discussed the new guidelines which are consistent with current emerging regulations and the ISO31000 international standard for risk management.

Discussion raised the importance of further consideration of the EC requirement for data access on transfer of responsibility and difficulties which may be encountered for a data repository; for example in accessing data for wells outside the zone of the plume or legacy data for risk assessment purposes.

Session 5: Induced Seismicity

Chaired by Adrian Bowden, URS

Joëlle Hy-Billiot of TOTAL presented the Lacq-Rousse pilot project in France and **results of micro-seismic monitoring at the Rousse storage site**. The storage site is a depleted gas reservoir, a fractured dolomitic reservoir, with a depth of 4500m and initial pressure of 485 bar, overlain by 200m caprock with carbonates and shales. Monitoring aims to answer identified potential risk scenarios through pre-injection, injection and 3 years of observation. Microseismic monitoring network consists of one deep array, seven subsurface arrays in shallow wells above the reservoir with one surface seismometer. Baseline was carried out in 2009 with only the subsurface network. Injection began January 2010. The network can record events as low as -3. In 2010 very low magnitude (-1.1 to -0.2) very near seismic events were detected below/in the reservoir, possibly due to injection or production. Since April 2011, very low magnitude micro-seismic events have been located from 100m to 600m from injection identified (3.1 to -1.4). As part of the risk management process there are varying levels of alarm e.g. if there is an event of magnitude more than 5 then need to cease injection and check operations. Events have been much lower than that. The project highlights a logical progression from risk analysis to implementation and definition of alarm thresholds.

Induced seismicity is a recognised risk in any Earth-engineering endeavour that changes the stress state or pore pressure of a rock mass, including oil and gas production, mining, enhanced geothermal system (EGS) development. Drawing on his past experience, Nicholas Deichmann of ETH-Zurich **discussed lessons learnt from induced seismicity connected with the exploitation of deep geothermal energy**; highlighting non-EGS cases and those of deep geothermal systems, explaining the difference between 'induced' and 'triggered' seismicity. The Basel EGS project developed a traffic light system of how operators would react to seismicity dependent on magnitude of events. In 2006/2007 there were 11000 detectable seismic events and 3000 locatable events, with the largest magnitude of 3.4. The 3.4 event 6 days into stimulation caused non-structural damage leading to mistrust, primarily due to poor communication. Risks of induced seismicity were considered beforehand but information had not reached the authorities or the public and subsequently the authorities stopped the project. Several technologies have learned to cope with induced seismicity, requiring high sensitivity seismic monitoring to distinguish between natural and induced, hence seismic monitoring is a must even where seismicity is not expected. Seismic risk communication is key and monitoring in co-operation with independent institution can aid credibility.

Further discussion highlighted the importance of a strong seismic array to enable distinction between the reservoir and caprock, and questioned the use of a baseline dataset to assist in the separation of natural and induced events reiterating the importance of a dense network to be able to identify the location accurately to pinpoint whether it is associated with operations.

Session 6: Monitoring Performance

Chaired by Ken Hnottavange-Telleen, Schlumberger Carbon Services.

To share key outcomes from the **2011 IEAGHG Monitoring Network workshop**; held in Potsdam, Germany; Charles Jenkins of CSIRO/CO2CRC presented details of the programme based on EU CCS Directive requirements. Recommendations included: a monitoring and verification plan has to be risk based and should contain 'detection' and 'quantification'; the route to interpretation of 'detection' should be clear in advance and negotiated with regulators and, accuracy levels of techniques have to

be understood. Additional points included: the need for cheap surveillance techniques with known sensitivity and risk analyses should guide where to target monitoring.

Ton Wildenborg of TNO presented the results of the EU FR6 **CO2ReMoVe project**, which aimed to develop and test technology for predicting, monitoring and verifying geological CO_2 storage; testing procedures and technologies on real projects; demonstrate CO_2 can be stored in a safe and effective way and, develop best practice and guidelines for monitoring and verification. The project has conducted site-specific prediction and verification in the regulatory perspective at Sleipner, Ketzin and In-Salah. CO2ReMoVe has also investigated Snohvit, K12-B, Kaniow and Weyburn. Geochemical models are integral to assessment, particularly for In-Salah which experienced surface uplift, and 3D-reservoir pressure and geomechanical changes have been modelled, history matching behaviour. Semi analytical modelling combining pore pressurisation and fault pressurisation has also been conducted to investigate the impact of a non-sealing fault on CO_2 plume development around injection well KB-502 by Imperial College, London, but local observations remain a challenge. The project has demonstrated and provided comparison of performance prediction and monitoring.

Anna Korre of Imperial College presented the preliminary results of the **IEAGHG study Quantification Techniques for CO_2 Leakage**: to identify and review potential methods for quantifying CO_2 leakage from a storage site from the ground or seabed surface as required by the EU ETS and for GHG inventory purposes. Examples of potential methods such as groundwater hydrochemistry and long open path sensing were provided. To quantify CO_2 flux no one technology has been identified and the development of a monitoring portfolio will depend on the specific environment. The study stresses the importance of deep subsurface monitoring to identify potential pathways, locating surface monitoring according to the risk-based monitoring plan and, highlights the importance of detection techniques before the implementation of quantification techniques.

The **QUEST project**; a joint venture of Shell, Chevron and Marathon to improve the GHG performance of oil sands operations in Canada; uses an iterative design process to reduce risks: risk-based, site specific, and adaptive to respond to observed performance with contingency plans in place. Stephen Bourne of Shell presented the fully integrated Saline Aquifer CCS Project. The storage site is within basal Cambrian sandstone with 20% porosity, 50mD permeability and a thickness of 20-40m, with multiple seals: first regionally extensive beyond project boundaries in the middle Cambrian, second a salt complex and the ultimate upper seal is the Lotsberg salt. Monitoring, Mitigation and Verification (MMV) is developing in parallel with regulations. A bow-tie approach has been used to identify risks and safeguards, using a systematic and evidence based evaluation of safeguards and monitoring technologies through collective expert judgement. A suite of monitoring techniques is needed as a diverse program eliminates dependence on a single technology, selected on cost-benefit ranking. MMV contributes to risk acceptance. Implementation of active safeguards e.g. monitoring and corrective measures rapidly decreases the risk metric for broadly acceptance of risk.

Discussion highlighted the importance of evidence of absence for communication, for example in the case of verification of no notable change (within a level of uncertainty) on seal pressure gauges; the sharing of information and coordination of best practice between the QUEST project and Goldeneye depleted gas field project offshore Scotland and, on-going public/community engagement process by the QUEST project to allow concerns to be raised and the flexibility to respond.

Session 7: Outcomes and Recommendations

Chaired by Charles Jenkins, CSIRO/CO2CRC and Ameena Camps, IEAGHG

The recurring lessons were identified as:

- A participatory process in pivotal in Risk Assessment, particularly for community assets, and benefits and impacts should be discussed not just numbers.
- The objective of the Risk Assessment method is more important than the method itself, though it is important to note the process use for traceability.
- Monitoring should be risk-based.

- Baseline data is crucial.
- Risk Assessment should be systematic and evidence based using collective judgement.

Drawing from all the sessions, research areas which would benefit from further exploration in future meetings and studies were identified by the members of the RAN. These areas include: further detailed assessment of induced seismicity; further understanding of hydrogeological and geochemical variability and heterogeneity; assessment of remediation/mitigation techniques; further investigation of microbiological catalysis of geochemical reactions in modelling; a dedicated collation of experiences and knowledge of incident management; a comparative analysis of risk assessment methodological outputs and, a dedicated translation of RAN outputs for laymen/policy makers.

The participants from the 6th meeting of the IEAGHG RAN recommend:

- Methodologies need to be consistent with ISO standard
- There is a need for benchmarking outputs of methodologies
- There is a need for translation of Risk Assessment outputs to common language
- It is important to include community asset value in Risk Assessment
- Further work is required on the evolution of risk through time.