Evaluating technology options to mitigate greenhouse gas emissions

summary report of the 2nd ieaghg joint network meeting

IEA GREENHOUSE GAS R&D PROGRAMME

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

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Front & back cover images: Saint Francis Cathedral, Santa Fe / Santa Fe Sunset / Tim Dixon examining the erosion in the volcanic tuff in Frijoles Canyon / Canyon Road, Santa Fe / Elizabeth Keating explaining the geology at Chimayo Natural Release Site

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Delegates in Meeting Room / Santa Fe Skyline

Introduction

The Joint Network Meeting co-ordinates all four of the geological storage networks: Risk Assessment; Monitoring; Modelling; and Wellbore Integrity; and the Environmental Impacts of CO_2 Storage Workshop Series. The 2nd IEAGHG Joint Storage Network meeting was held from the 19th to the 21st of June 2012 in Santa Fe, New Mexico, USA. It was hosted by Los Alamos National Laboratory and sponsored by Sandia National Laboratories, Los Alamos National Laboratory and Schlumberger Carbon Services. Sixty-eight delegates attended, representing 11 different countries.

The aims of the meeting were to:

- Ensure the Networks are working in the most efficient way without duplication or gaps,
- Identify cross-cutting issues and their consequences; requiring input from more than one network,
- Set the framework for the future direction of the networks.

The 3 day event consisted of 2 main sessions. Session 1 considered how far we have come, and included reviews from the IEAGHG CO_2 storage networks on developments in their own areas, and lessons learnt from CO_2 storage projects on cross-network issues previously identified, followed by breakout discussion sessions to consider lessons learnt. Session 2 was highly discussion based and considered where we should go next for all the networks. This included sessions to identify R & D knowledge gaps and reviewing the current networks to see how they can be used to meet the needs of the R & D and wider CCS community. The third day consisted of a meeting held by NRAP in the morning and a field trip based around the local geology and Chimayo natural CO_2 release site in the afternoon.

Session 1: How Far Have We Come?

IEAGHG Network Development

Network Progress since 2008, Tim Dixon, IEAGHG

Some recommendations from the previous Joint Network Meeting have been followed through, including the creation of the modelling network and commissioning of studies related to technical gaps identified. Expertise from the networks has been able to be drawn upon for peer reviews including the Otway peer review in 2009 and the US EPA VEF in 2008. They have been useful for regulatory developments including the UNFCCC, where three of the networks addressed the issues for CCS in CDM and some network members played a significant role in the 2011 Technical Workshop in Abu Dhabi, which went on to influence negotiations of CCS in the CDM towards their successful result.

The Risk Assessment Network, Charles Jenkins, CSIRO and Hubert Fabriol, BRGM

Over the past Risk Assessment meetings some of the main topics addressed include: risk communication, which requires a common language and the importance of building trust; regulatory development, where it is important to take an active role in addressing new and emerging regulations, including provision of information for regulators; risk assessment methodologies; risk profiles, for which knowledge is improved as more information is available from demonstration projects; impacts, for which further understanding is needed and is an active area of research; risk and incident management and monitoring. There is further work needed regarding corrective measures.

It was highlighted that it is important to know who the audience is when talking about risk assessment and particularly for quantitative risk assessment. The network has also taken a role in the identification of 'emerging risks' that are thought to be increasingly important, such as the potential effect on groundwater and induced seismicity.

The Monitoring Network, Kevin Dodds, BP AE and Sue Hovorka, University of Texas

The Monitoring Network meetings have covered a wide range of technologies as well as how different techniques can be used together to see the full picture. Much learning has been taken from demonstration projects, particularly regarding history matching, which needs to be carried out throughout the project allowing accuracy of prediction over time. Emerging and evolving regulations have been taken account of during the meetings and it is important to maintain communication with the regulators.

An issue highlighted is that monitoring needs to be able to cover the different goals of showing climate change mitigation, show that resources are protected and to account for carbon credits. It was also noted that the detection threshold can be site specific and determining quantification is an active research area.

The Modelling Network, Neil Wildgust, PTRC and Jeremy Rohmer, BRGM

The Modelling Network has had 3 successful meetings since its conception at the last Joint Network Meeting. The meetings have highlighted knowledge gaps and complex issues needing to be dealt with by modellers, including modelling the complexity of the subsurface which includes complex hydrofacies architecture, fracture networks and information from core flooding. There are also issues related to history matching and the impact of model uncertainty. This is of particular importance as it is part of the iterative process as more monitoring results are available and can affect what is required regarding regulations.

The Modelling Network web pages have also been used to host Statoil's Sleipner benchmark model, which is available to all members of the Network.

The Wellbore Integrity Network, Bill Carey, LANL and Stefan Bachu, AITF

The Wellbore Integrity (WBI) Network has also had 3 meetings since the last joint meeting and 4 meetings prior to that. The main considerations have changed over time, with the starting point looking at whether materials survive CO_2 injection, changing to frequency of well leakage, defects and geomechanical impacts and more recently the focus has been on EOR.

Wellbore integrity is also related to the risk profile, potentially causing a risk increase in the long term, due to the breakdown of materials. Some other issues considered are cement stability in CO_2, steel corrosion, design of CO_2-resistant cement, best practices in well completions, well abandonment practices, detailed modelling of fluid-wellbore interactions, field-scale modelling of wellbore performance and remediation technologies. The largest uncertainty and risk are old abandoned wells in the area of review as the state of completion may not be known.

Environmental Assessment workshop series, Lee Spangler, MSU and Franz May, BRGM

This workshop series, started as an ad hoc workshop in 2008, Defining R&D Needs to Assess Environmental Impacts of Potential Leaks from CO_2 Storage, which was then followed by another workshop in 2010, Natural Releases of CO_2: Building Knowledge for CO_2 Storage Environmental Impact Assessments. The next workshop and the first since approval of the workshop series will have a focus on controlled release experiments.

Much work has been carried out in this field and the network has helped to highlight knowledge gaps and areas where research and experimentation is needed. Research areas include how flux rates in natural settings relate to potential leaks, impacts under different situations – some of which is being considered in controlled release experiments and monitoring methods.

Lessons Learnt from CO_2 Storage Projects

Review of Large Scale Projects, Angeline Kneppers, GCCSI

The Global CCS Institute continually tracks the status of large scale integrated CCS projects (LSIPs) worldwide. The Institute identified 73 LSIPs around the world, including 15 currently in operation or in construction. In terms of recent progress, since 2009 the strongest early movers are still in progress and those in the early operational or construction stage are projects mainly in North America (mostly EOR), Europe (mostly saline aquifers) and China (enhanced coal bed methane, or ECBM).

The general needs to accelerate the deployment of CCS fall into three categories – stoppers, delayers and enablers. Stoppers may include long-term investment environment, financial security (i.e. CO_2 price, subsidies etc.), liability and public perception. Delayers include factors like the speed of funding allocation, technical gaps in approval/acceptance processes, infrastructure planning and slow/reluctant supportive policies, legislation and frameworks. Enablers for the deployment of CCS include the reuse of infrastructure, use of CO_2 for EOR or EGR, efficient use of existing knowledge and international collaboration on all of these issues.

Key lessons learned include knowing that there are no technical barriers to the storage of CO_2 (with sufficient knowledge/experience). More data is needed from operational projects and the data required for site assessment should not be underestimated (5 to 10 years lead times from screening to injection). CO_2 disposal requires the same attitude, approach and capability to that of a major petroleum development. It is key to note that it is most likely that significant financial investment may be required prior to project sanction.

Ancient cliff dwellings exploiting geological erosion at Bandelier National Monument

Migration from the Primary Store: A Cross network challenge, Max Prins, Shell

An important question for any CCS project is how to detect migration from the primary store. This work was carried out at the Longannet to Goldeneye project– and had a problem statement of 'how do we determine if we can detect migration from the primary store?', looking at where it is likely to occur, where it can occur, at what rates and what volumes can be detected. In terms of risk assessment, a full bow-tie analysis was carried out and safeguards identified. The bow tie results lead to identification of threats and potential migration paths – particularly important is the timing of migration. For most scenarios the system will stay hydrostatic (for approximately 1000 years) as the CO_2 cannot be driven out. For the volume at risk you take each well then calculate the mobile CO_2. To look at the rates of migration, significant modelling is required. For leak detection it is key to have an integrated approach – through networks including wells, risk assessment, monitoring, modelling and environmental.

Cross cutting issues research – Carbon Capture Project Phase 3, Kevin Dodds, BP AE

The CO_2 Capture Project (CCP) has been in place since 2001 and the 3rd phase is due to be completed in 2013. CCP3 is looking at areas including assurance R & D (wellbore integrity, subsurface processes, monitoring and verification (M & V), optimisation), field trialling and stakeholder issues. In wellbore integrity, a key study is the field acquisition of cement in wells. Key findings were that the cement was carbonated, the interface erodes (where the cement does not) and there was evidence of calcite precipitation. In subsurface processes, capillary entry pressure and impurities were looked at (physical and chemical effects like rock alteration), along with the impacts of these processes on storage and injection. In storage optimisation, all site data was looked at with the process of coming to a conclusion as to the viability of the project. This was applied to a number of sites (including In Salah) and this will be developed further into optimisation and economics, whilst addressing a range of CO_2 assurance issues. A retrospective assessment of M & V was carried out, assessing the suitability of monitoring for sites and addressing issues related to the sensitivity of monitoring (site-specific). Modular borehole monitoring (MBM) was looked at in detail, with a final idea to look at all options and create a guidance document for general reference. CCP3 trialled MBM deployment at the Citronelle site (USA), carried out through casing resistivity tests at the Otway project (Australia) and completed trials on borehole gravity at the EOR and storage site at Denbury Cranfield (USA). Stakeholder issues are being looked at in a contingency study to inform the relative effectiveness of monitoring technology to detect and characterise types/modes of leaks – more work is planned on this in workshops to be held in 2012 and 2013.

Recent research developments from the IEAGHG Weyburn-Midale Project, Neil Wildgust, PTRC

The Weyburn-Midale research project has two key deliverables – a technical best practice manual (BPM) and an issue of the IJGGC journal. The BPM will cover characterisation, performance predictions, geochemical monitoring, geophysical monitoring, performance validation, well integrity, risk assessment and community outreach.

The study area here has a huge amount of pre-existing information – meaning data management is an issue. The migration scenarios assumed certain wellbores leaked at a certain rate and a natural analogue study was also carried out – results showed that despite the CO_2, there is limited evidence of any major reactions of porosity etc. and as the use of the 3D seismic information was successful, they are able to show that it is an effective tool at this site for mapping the CO_2 in the reservoir. However, it is more problematic to look at the CO_2 saturation – so it is important to have a model to constrain the interpretation. Seal integrity and fracture mapping is an important issue, where they found a reasonable match for core samples. In passive seismic modelling there was a lot of useful information on geomechanics. The leakage allegations in 2011 generated a lot of bad press, but soil gas monitoring results disproved these allegations. The wellbore integrity field testing programme is a key research issue and permeability testing of the cement sheath confirmed the effectiveness of the cement. When looking at risk assessment and geological storage, the geosphere and biosphere risk was focussed on. The containment risk profile showed that well cement and leakage through the wellbore is a key risk scenario, but such risks actually demonstrate acceptability.

Key Messages from operational storage sites – Findings from the CO_2ReMoVe Project, Henk Pagnier, TNO

The main objectives of the CO_2ReMoVe project are to develop/test technology for predicting, monitoring and verifying geological CO_2 storage, to test procedures and technologies at a unique set of large scale and pilot sites, to demonstrate

that CO_2 can be stored in a safe and effective way, and to develop best practice guidelines for M & V. the project is involved with a unique set of injection sites, for example Sleipner, In Salah, Snøhvit, K12-B, CO_2SINK and RECOPOL.

The project aims to address several questions, the first being whether CO_2 can be stored in a safe manner. Evidence suggests that it can be stored safely and effectively with no leakage to the biosphere. Monitoring of site performance can deviate from single predictions – so you must establish acceptable deviations or demonstrate convergence between the model and measurement and the acquirement of robust baseline data is essential for effective performance verification. The second question focusses on whether storage is practical and affordable. A limited portfolio of monitoring tools is needed to provide assurance at a given site and a much wider range of monitoring techniques was investigated than a commercial project is likely to use – allowing a higher degree of flexibility. Another question considers if some procedures/ requirements can be standardised – CO_2 storage standards should not be technology prescriptive; there is no 'one-size-fits-all' monitoring programme. In conclusion, CO_2ReMoVe has unprecedented access to several industrial and pilot scale sites, has developed, deployed and tested multiple tools and integrated monitoring strategies to address regulations.

The Illinois Basin – Decatur Project: Updates and Recent Experiences, Randy Locke, ISGS

This project is a demonstration of carbon storage in a saline reservoir at the Decatur site in Illinois, USA, where 1 million tonnes of anthropogenic CO_2 will be injected over 3 years – alongside a comprehensive 7 year monitoring framework (with the verification well completed in May 2011). The focus of the project is the Mount Simon Sandstone, with CO_2 injection in the base of the section and as of the 16th June 2012, 184,000 tonnes had been injected.

For early implementation stages of projects, it is important to integrate new field data into models and communicate changes in model predictions (i.e. rates of CO_2 migration) quickly so that necessary adaptations can be made. The Decatur project has a comprehensive monitoring programme involving 20 different technologies and methods. Successful efforts in the project include site characterisation, permitting, drilling, reservoir modelling, engineering, risk assessment, public outreach and baseline monitoring.

The Lessons Learned about cross-network issues from MRSCP and Mountaineer Projects, Neeraj Gupta, Battelle

Battelle Carbon Management is involved with many CCS efforts and other projects, where the focus has recently been shifting to EOR and commercial oil and gas. FutureGen is a commercial scale oxycombustion project with pipeline transport and storage in the Mt Simon Sandstone. The AEP Mountaineer project has injection wells in 2 formations (approximately 37,000 tonnes injected so far), with an extensive monitoring programme. The Michigan Basin II injection test is leveraging the existing EOR infrastructure and overall testing indicates rates of 600 metric t/day (or higher) could be obtained here in the formation.

Breakout Session 1: Lessons Learnt

Risk Assessment Network

Risk assessment is the central part of a project – it defines how work is done. Risk communication was not one of the original Network objectives, but throughout all meetings it was a common theme that communication is key – it is important to talk to more people, both inside and out of the usual parties. A lot of useful work has been done in this Network but is perhaps not getting out there enough – the question is how to facilitate this. The need is there to converge toward a common language. It has been observed that NGOs are often neutral on the technical aspects but participate more to the regulation discussions – consequently their position can, and does, change. Where we are at the moment, we are at the stage where we have new regulations, new projects almost permitted etc. – so soon shall see if risk assessment has satisfied the regulators, which will then tell us about where we need to go.

Monitoring Network

The regulatory environment is currently maturing and in this process it has become clear that there are still things to be done. A lot more progress needs to be made in quantification and the role of risk processes in monitoring integration has

been recognised and strengthened. A key achievement is the contribution of multiphysics and recognition of the value of this; where different types have been brought together (i.e. Weyburn). A baseline terminology used expertise to interpret changes that occurred and the importance of public perception has been frequently addressed.

Explaining the geology of the region on the field trip

Wellbore Integrity (WBI) Network

This Network has covered a range of topics including the mechanisms, magnitude, frequency and impact of CO_2 leakage, self-healing of wells, modelling of well leakage, risk assessment, monitoring of well integrity, remediation of wells, best practices and regulatory agency interactions. Slow, low-rate leakage is the main problem for CCS and it is not likely to be the injection wells that are a problem, but the existing wells. The risk profile for projects should reflect the potential for long-term deterioration of wells and the movement of plumes to encounter leaking wells. Cement is key to reducing wellbore integrity issues – if the cementing is good (in terms of the role of centralisers and in design, quality and placement), the well is most likely to perform as expected. Certain cements have the ability to self-heal (in some circumstances). The Network also identified key risk factors potentially leading to well failure.

Environmental Impacts

This workshop series is now starting to 'define more refined', specific questions. Much work has been done in looking at the response of systems (soil, plants, microbial etc.) to the high CO_2 environment, for example in indicator species. We know that there are some systems available to study – but how analogous are these to CO_2 storage? The knowledge of pathways is essential for impact assessment – the relation of CO_2 discharge points to groundwater flow systems and tectonics. Major rock constituents can impact groundwater chemistry and it is important to acknowledge that impacts are not only caused by CO_2 but also from associated brine and formation fluids. It is key to engage other communities, but we have learnt that they don't often understand the environment they are communicating in – and it is critical to take care when trying to communicate environmental impacts.

Modelling Network

Modelling has made a lot of progress in the last 4 years, and specific improvements that have been made in the Network include the greater emphasis on 3D now rather than 1D and 2D. A lot of work has been done on improving core flooding in lab experiments and matching that to modelling floods (with increasing success in extrapolating the small scale up to basin scale). More detailed models have emphasised the importance of heterogeneity and there is now a better understanding of processes, along with achievements made in coupling processes. More complex problems have also been addressed and accounted for – i.e. impurities and well leakage – and there is now a larger number of available tools and higher standards of technology. Experimental data leads to improvements in models, but it is important that there isn't an expectation to provide fully integrated models (simplified can also be very useful). More models are now available but there is a danger in this – poor parameter input will demonstrate inaccurate results. In calibration and prediction, there has been good history matching in several cases and the new data has provided an opportunity to evolve and improve the models. It is important to meet the expectations of the regulator when it comes to matching – what is a good match?

Session 2: Where do we go next?

Part 1 – Identifying R & D Knowledge Gaps

This session was introduced by Franz May who talked about the 6 discussion topics selected by delegates out of a possible 10 derived by the Steering Committee. These were then discussed in breakout sessions, where the instructions were to discuss knowledge gaps and identify needs of the R & D and wider CCS community, discuss how networks can assist in meeting needs of the R & D and wider CCS community, identify areas requiring input from more than one network and discuss if there is a need for networks or ad-hoc workshops in other key areas.

Breakout Group 1: Uncertainty in simulations forming parts the permits (e.g. risk assessment, reactive transport in storage reservoirs). Model updating (history match) consequences for validity of operation license?

Knowledge gaps identified were issues specific to CCS as this is a wider issue and relevant to other industries, from where lessons can be learnt, such as the oil, gas and nuclear industries. Specific CCS knowledge gaps identified were wide spatial scales (e.g. pressure-impact zones), time dependency: e.g. temporal evolution of risk profile and public perception. A second knowledge gap identified was model uncertainty; it is not only a matter of knowledge gathering, but also how to adjust/re-do model concepts in the light of new knowledge, which is an iterative process. There needs to be a balance between sophistication, number of parameters, increase of number of uncertainty sources and the question to be asked is: what is enough? And how to integrate model uncertainty in the permitting process? The third knowledge gap identified was related to communicating uncertainty on the results/knowledge to the public and regulators; communication approaches may differ depending on the background of each audience.

Needs identified were for a need for systematic / robust approaches for an iterative link between statistical-based procedure, risk assessment, monitoring, verification, possibly in the form of a best practice guide with in-built flexibility for reservoir specific issues. There needs to be systematic sensitivity approaches: from the model, identify key parameters and form an iterative process with the characterisation phase. When dealing with uncertainty, the potential consequences should be considered in the mitigation plans. Uncertainty treatment approaches exist, but there is a need for validation through application. There is also the need to better understand the needs of the public and regulators.

This topic would require input from the risk assessment and monitoring networks, and potential future workshops identified are 'Communication with wider stakeholder (public/regulators) group on handling Uncertainty' and 'Lessons learnt from the application of different approaches' (e.g. In-Salah).

Breakout Group 2: Completeness of observation and quantification of leakage, especially in shallow and surface monitoring

Several knowledge gaps were identified, including what the definition of a leakage should be; does it include brine and hydrocarbons and should it be redefined in terms of potential impact, which by definition can already be measured though receptors must be defined – it is noted that this does not address the issue of carbon credits. Leakage could be qualified as 'detectable' or 'significant' and current regulation requirements will change with technology. The 99% sequestration criteria in the US is fundamentally impossible to meet as it is not possible to "prove" that the CO_2 is in the reservoir.
Attribution (interpretation of monitoring data) may not be adequately understood; integration of diverse data sets may be necessary as is determining the source of the leakage, such as through wells, fractures, caprock, spills and migration. Determining when the baseline is adequately characterised is an issue.

Monitoring issues include uncertainty of off-shore monitoring methods and approaches. Monitoring at depth, while expensive, may allow remediation before impacts occur in the shallow subsurface.

Needs identified are work on attribution, involving determination of the origin of potential leakage in complex and realistic situations from CO_2, brine and mobilised hydrocarbons, which could involve testing on analogue sites. New theoretical and analytical methods of attributing leakage need developing as does determination of the most effective monitoring methods for each site – learnings from controlled release sites are essential. Other identified needs include determining the variability of aquifer response to CO_2 – passage of fronts, buffering capacity, metals and understanding how a laboratory characterisation of drinking water aquifer (core samples) relates to likely impact of CO_2; understanding differences between confined and unconfined aquifers, development of methods that can monitor large areas effectively. Collaboration was suggested with new work on methane leakage attribution and work on off-shore gas detection.

Networks that could provide input to this topic are Environmental Impacts, Monitoring and Wellbore Integrity.

Breakout Group 3: Corrective measures plan/remediation plan

When looking at corrective measures on deep reservoirs, the first stage is recognising the problem, then characterising it (through monitoring), then thirdly to set up the specific actions.

Knowledge gaps identified were distinguishing between deep reservoir and shallow aquifers; in the reservoir the plume may not where as predicted (it is necessary to take into account the real reservoir complexity), resulting in pressure increasing above the allowed limit, well failure and leakage from unknown flow pathways (e.g. bubbles coming out at the reservoir).

There are various solutions, including pressure management and changing the flow direction and relative permeabilities (using chemical treatments, biofilms etc.), but a major issue is related to cost with respect to the impact. There are also knowledge gaps related to caprocks, where there may be a fracture or linear structure (e.g. sand channel), it may be possible to inject a gas cap over the CO_2 with a different wettability – more research is needed into this.

Further research is needed into breakthrough technologies, it is important to know the effects of injecting exotic species in the reservoir.

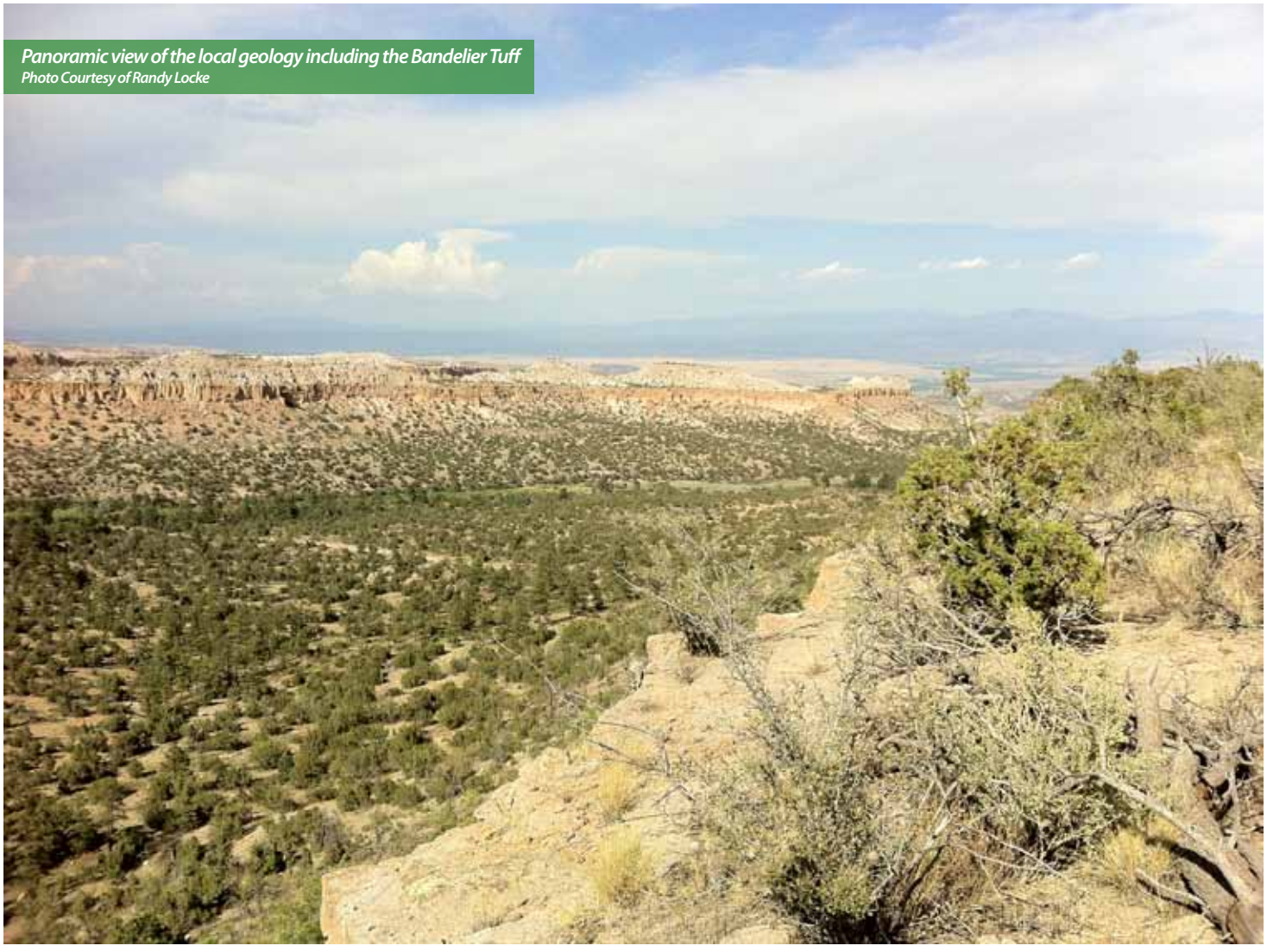
It was suggested that regulators need to have the same level of expertise as the operators to understand what they are told about, which is a role that the networks can help in.

A workshop based on this topic was thought to be useful, though there is a current IEAGHG study looking at mitigation of unwanted CO_2 in the subsurface, so a well-timed workshop could be when this is due to be published. Any workshop should attempt to attract people from industries with the appropriate experience. Networks that would provide input to this are the risk assessment, monitoring, wellbore integrity and modelling and environmental impacts networks.

Breakout Group 4: Monitoring Plan – site specific and based on risk assessment and potential migration pathways

Knowledge gaps identified were the relationship of geophysical data to actual CO_2 and geological parameters; site specific calibration will be needed in each case. Detection vs quantification is an issue and how accurate it is possible to be; there may also be non-quantitative key indicators showing escape. Better understanding is needed of physical and chemical transport processes (e.g. if secondary pooling is common, seismic could be effective for leakage monitoring).

There is no general recipe and it would be useful to see how existing projects have needed to adjust monitoring plans.



Panoramic view of the local geology including the Bandelier Tuff
Photo Courtesy of Randy Locke

Another knowledge gap is how much monitoring is needed due to a mismatch of the generally accepted risk profile and knowledge profile. Integration of various monitoring purposes represents a challenge and the regulatory environment is part of site specificity.

Needs identified were what monitoring is needed to improve the initial model and what model outputs are needed to define risk assessment, as well as what environmental consequences are of greatest concern.
It was concluded that a workshop drawing from all networks on this subject might be useful.

Breakout Group 5: Groundwater Protection

Knowledge gaps identified were addressing the site specific nature of groundwater protection as there is no one prescriptive answer for each site; how to integrate and apply knowledge from various research techniques to predicting impacts; how to assess the outcome of exogenous fluids entering a shallow aquifer; with the need for complete hydrogeochemical characterization, how is effort managed with respect to reward; how are natural impacts or those from other industries separated from those induced by CCS activities; what is the nature and extent of migration of fluids (brine and CO_2); to what extent will a release enter and impact an aquifer (intermediate interceptors, buffering) and how is this monitored; and how are the contaminants of concern determined.

A workshop on this subject based on one particular site was suggested.

Breakout Group 6: Link between monitoring results and (mandatory) operational consequences (e.g. thresholds, conditions for site abandonment)

A trigger was defined as something that merits attention, but is not necessarily an event that needs to be dealt with; it is a deviation from the model and needs to be continuously reassessed (iterative assessment of trigger and range).

Challenges/knowledge gaps identified were risk and their analysis and how this can be quantified; how monitoring is defined to address perceived risks (e.g. uncertainty, resolution, quantification); how monitoring is tied to the operation (safety protocols of normal operations vs. what can be addressed through monitoring); what is an acceptable deviation from the model; and process/systematic way of going through uncertainties as you move forward.

Needs identified were categories of monitoring to set trigger boundaries; triggers of the operation need to be defined, as well as how significant it needs to be; there should be continued improvement of existing monitoring technologies and development of new tecnologies; and risk driven research (still requires definition of the risks and the process).
A workshop focusing on how more mature industries deal with this issue was suggested.

Ad hoc session on Induced Seismicity

In addition, a session was included at short notice in order to discuss the Zoback paper in PNAS on induced seismicity, published that week. Many of the attendees had read the paper but some had not. The discussion was considered useful, and in addition the group agreed to produce the following statement:

> *The topic of induced seismicity and the Zoback paper was discussed by the international gathering of experts at the IEAGHG Joint Network Meeting, and the majority agreed: "Induced seismicity is important to consider for CO_2 geological storage and has already been the subject of extensive research and risk assessment for current CCS projects. There is not sufficient information available to justify the conclusions drawn in the last sentence of the abstract of the paper by Zoback".*

Breakout Session 3: IEAGHG Storage Networks: Future focus and direction

In the light of the previous information and discussions, breakout groups met to agree details for future issues, topics, and activities for each of the Networks. The following summarises their recommendations.

Environmental Impacts, Lee Spangler

Discussions formulated new ideas and directions for the network. Important areas recognised include the understanding of processes, fluxes and the relation to impacts, the issue of near surface expressions, a greater focus on brine and mobilised substances is needed and more information should be drawn from industrial analogues. This information has to be suitable, however, and it is key to put this into the correct context. Issues come up against include communication (it was suggested that a good route would be through those who write about science for the public), the correct naming of the workshop (as it is treated as a Network) and as meetings are only every 18 months, this can prove challenging. For the future, this group should look at network needs and continue to generate joint proposals (i.e. the first workshop initiated the RISCS project).

Wellbore Integrity Network, Bill Carey

This Network has a huge relevance to CCS – it is the link between the reservoir and surface, it drives risk and monitoring, is a rich modelling subject and is a source of environmental impacts. New topics that could potentially be looked at include existing oil and gas practices (i.e. design of cement/casing), leakage potential, monitoring of abandoned wells, security of long-term well abandonment and the impacts of fracking and seismicity. Network interaction with other IEAGHG groups is difficult (all meetings in disparate locations) – perhaps a way to deal with this is to have a concurrent session meeting of all networks, with an end plenary session. Expertise (and membership) of the WBI Network is localised so holding meetings on a geographical basis is hard – filling the agendas has been somewhat challenging, utilisation focus in the US and Canada is increasing the importance of this topic, but progress has been somewhat slow with a difficulty in involving industry. Potential alternatives to the existing Network could be to hold meetings every 2 years, to have joint meetings with the other Networks, to distribute WBI tasks between the other Networks, or to consolidate meetings into ones based around topics/themes. If the WBI Network was to be halted, we would lose industry participation in a key area. There is an important connection between EOR and CCS that is kept strong by this Network and some research areas and operational focus areas would be lost.

Modelling Network, Neil Wildgust

Key issues within the Network include the challenge of calibration of models with monitoring data, EOR and depleted gas fields are important (i.e. residual oil zone etc.), as are impurities and the concept of scale. The current format for this works well in providing an outlet to share technical information, but perhaps there could be more online material and the workflow for model updating should be validated (perhaps by holding a joint meeting between the modelling and monitoring groups). The Modelling Network is rather focussed on reservoir modelling, but keeping the title of the group is important as it is allows for broader talk topics if required. It is valuable to rotate the Steering Committee each year and would be useful to collaborate more with the other Networks. It would be useful to get more expertise from those involved in EOR modelling and to look at the storage aspects of EOR.

Monitoring Network, Sue Hovorka

The role of the IEAGHG Networks are to have international updates, to be a small enough forum to have interaction within the group, to have frank technical discussions and to benchmark one project against another. It is important to encourage cross-network interactivity – but we need this interaction without sacrificing depth, which could be done by having back to back meetings, with overlapping sessions, to have a topic-driven workshop (performance assurance is a

cross-cutting theme that could be expanded upon as such), or by having ambassadors from one network to another. The priorities within this particular Network include field implementation, demonstrations and applications, to promote best practice (via examples/lessons learned) and encourage new people to the community.

Risk Assessment Network, Charles Jenkins

This is the 'umbrella' group of the Networks and is conscious that it should be influencing more, for example with NGOs and regulators – and provide a more explicit engagement policy. The Network needs to prioritise what should be achieved in the short and long term, to be involved in ISO TC 265 and to look at how uncertainties affect the outcome of risk assessment. It mustn't be forgotten that risk management includes monitoring and corrective measures, so a joint meeting with another Network would be valuable and a strong idea was to change the name of the Network to Risk Management. The Network is conscious that many in the group are not risk professionals. The previously published terminology report was useful and it was suggested that this could be updated and disseminated. A common theme in discussions was that the Network (and all others) should have more of an existence in between meetings – perhaps via webinars or another online medium.

Part 3 – Outcomes and Recommendations

Plenary Discussion: Outcomes and recommendations of the 2nd Joint Network Meeting

The aims of this second IEAGHG Joint Network Meeting were to ensure the Networks are working in the most efficient way (without duplication or gaps), to identify cross-cutting issues (and their consequences) and to set the framework for the future direction of the Networks. The common needs recognised throughout the workshop include systematic iterative links between risk assessment (including monitoring and WBI), monitoring, verification and best practices, dealing with uncertainty, consequences and mitigation plans, and defining criteria, thresholds and acceptable deviations from trends. Many suggestions were made during this plenary session, including the strong potential of holding smaller, more focussed, topic-based meetings in the future. The Monitoring Network proposed organising a special session in other international conferences (e.g. Pittsburgh, Trondheim, GHGT), although these meetings are extremely busy as it is and perhaps do not have the time or space for such a session. The Steering Committees could come up with a list of meetings for which associating with would be a useful exercise. The usefulness of combined meetings was discussed – CO2CRC have agreed to host the Monitoring and Environmental Impacts Networks in 2013 as a combined meeting – and since this Joint Network Meeting, Statoil have confirmed they will host the Modelling and Risk Assessment Networks next year.

The discussion looked at how interdisciplinary CCS is and that some publications are missed – it would be beneficial to have an information resource, an archive of papers to cover all disciplines. Issues such as journal copyright policy would have to be considered, but IEAGHG will look into the possibility of such an archive.

The future of the Wellbore Integrity Network was discussed in depth. Although interest and attendance has been reducing, and IEAGHG does not have the resources to continue as it is, its members were keen to keep this as a dedicated Network. IEAGHG will look into this issue further and discuss with Network members in order to make a decision on this Network.

Franz May examining the CO_2-rich well at Chimayo natural analogue site (CO_2 and brine leakage into an aquifer)

An increased operational focus was suggested involving more operators attending future events. This could include those working on demonstration projects. There also needs to be a standardisation; where tools/techniques have now been developed, there needs to be consensus on what to use globally (e.g. method for CCS capacity analysis) and then where applicable, deploy as a global standard via ISO. This can be discussed in future network meetings. It would also be useful to adopt a common terminology, in order to improve communication to the outside world.

The main recommendations from this meeting were to have more Network to Network collaboration, hold virtual meetings on 'hot topics', hold topic-based workshops (i.e. performance assessment, remediation), change the name of the Risk Assessment Network to Risk Management and to refresh more often the Steering Committee members.

No matter how the Networks move forward, it's essential that they keep their character. It would be valuable to ensure activity is maintained between meetings in all Networks – 'hot' topic-based or not – to keep momentum going and it could be valuable to hold additional small/focussed meetings linked to others (consulting via the Steering Committees to do so). All agreed that interaction of all Networks with the Social Research Network is important and recognised the value of holding combined meetings. A third Joint Network Meeting is a possibility for the future and a literature archive or alerting system will be looked into. IEAGHG will reflect on all of these recommendations from the meeting and look at how to act upon these in the best way for all.

An overall conclusion that can be drawn from the meeting is that, with a maturing regulatory environment, the technical knowledge and methods now exist in the area of storage so that there seem to be no significant technical barriers to projects meeting the requirements from the fairly stringent regulations in place in many regions. The IEAGHG Research Networks have contributed to this move from research to application. And finally, the Research Networks are highly appreciated by their members who wish them all to continue.

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