British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Pathways from pilot to demonstration: How can research advance CO_2 geological storage deployment?

Energy and Marine Geosciences Programme

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Pathways from pilot to demonstration: How can research advance CO_2 geological storage deployment?

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Foreword

This report is a summary of the discussions held at an international workshop hosted by the British Geological Survey's CO_2 Storage Team at their office in March 2016. The CO_2 Storage Team would particularly like to thank BGS support staff who ensured the workshop ran as smoothly as it did, most notably Mrs Christina Edwards and Mrs Linda Hetherington.

Acknowledgements

In addition to the BGS staff acknowledged in the Foreword, the workshop was financially supported by the UK Foreign and Commonwealth Office (FCO) under their CCS Global Knowledge Sharing Programme. This support via Mr Aatif Baskanderi at FCO's Alberta office, Canada, was very gratefully received and was primarily used to support the attendance of a number of delegates.

Contents

1 Introduction

An international workshop was hosted by the British Geological Survey (BGS), supported by the United Kingdom's Foreign and Commonwealth Office (FCO), from the 1st to the 3rd of March 2016 at the BGS offices in Keyworth, Nottingham, United Kingdom.

The workshop objectives were to:

- Examine how pilot, field laboratory and laboratory projects can inform and advance large-scale CO_2 storage and low-carbon geo-energy resources.
- Reinforce the importance of advancing CCS through practical experience at varied relevant scales: pilots/field labs (testing concepts) and demonstrations (deploy technologies and identify new technical questions for pilots to examine)
- Strengthening international links between field lab, pilot, demonstration and large scale project operators to make it easier to share lessons learned
- Exchange research learning between CCS and other geo-energy disciplines

The workshop outcomes were intended to identify of opportunities for collaboration and development of outline proposals to advance CCS and geo-energy research through practical experience and demonstrations.

Workshop invitees included policy makers, demonstration project representatives, academics and pilot project operators. A total of 75 delegates attended, who represented 46 organisations including research institutions, industry (national, multinational and suppliers), global and national CCS networks and trade associations (see attached delegate list – Appendix 1), and a government representative from UK DECC. Delegates were from 13 countries worldwide.

The agenda (Appendix 2) provided an opportunity for delegates to gain a full overview of key storage pilot and field laboratory programmes globally, representing most of those of which we are aware. No further pilot projects were identified during the meeting which could have been invited, though we did not include larger demonstration projects or pilot experiments that were completed over two years ago that had been very well published and discussed at previous meetings.

2 Sharing practical experiences to inform deployment of CO_2 storage

The context for the workshop was provided with an introduction from Professor Mike Stephenson, BGS Chief Scientist, which recognised that coal-fired power generation will continue globally for many decades and that the targets set through the international agreements at CoP21 in Paris will require negative emissions technologies such as bioenergy CCS. Mike outlined the vision for the UK Energy Security & Innovation Observing System for the Subsurface (ESIOS) which will allow independent, rigorous and replicable observations of subsurface processes and enable use of the subsurface for the benefit of society and the economy. It is hoped that data obtained from monitoring at ESIOS sites will be published openly in real time.

Session 1 provided a an opportunity to hear perspectives on research drivers from a number of industrial project developers and large 'commercial-scale' demonstrations, including a summary of Norwegian perspectives on research drivers by Philip Ringrose of Statoil; a keynote presentation from Andreas Busch from Shell on their CCS activities and views on research needs for large scale deployment; and a review by Kyle Worth, Petroleum Technology Research Centre, of the Canadian Aquistore project. Pilot-scale projects for offshore monitoring in the North Sea by the STEMM-CCS project and in South Korea were presented by Jerry Blackford (PML) and Sang Hoon Lee (KIOST), respectively. An update was given by Tony Surridge, South African Centre for Carbon Capture and Storage, on their plans for a storage pilot in South Africa. Finally the coordination of European CCS research facilities that comprise ECCSEL were summarised by Sverre Quale of the Norwegian University of Science and Technology. Bob Gatliff, BGS, Science Director of Energy and Marine Geoscience presented aspects of research in the hydrocarbons sector relevant to CO_2 storage.

Key research themes that emerged were related to both injection processes such as mitigation strategies and understanding behaviour of CO_2 in wells and post-injection (and post-abandonment) phases such as long-term wellbore monitoring. Efficient and cost-effective monitoring was seen as requiring some further development, both in the wellbore and to provide intelligent baseline information especially offshore.

Discussions were centred around three themes of monitoring, experience from demonstration projects and the issue of micro-seismicity. Firstly, the value of rapid publication of "raw" data to the public was discussed; experiences from operations such as Snøhvit and Weyburn indicated that the public could benefit more from publication of an interpreted dataset to help them understand the context and processes that could be observed in the data. The challenges of providing quality data and managing very large amounts of data were identified.

Secondly, research and development of monitoring technologies at demonstration projects was typically motivated by a number of simple questions that can be summarised as the need to quantify processes; what are the measurable detection limits, how frequently should measurements be taken and what are the measurement requirements? It was recognised that monitoring requires integration of different sensors and disciplines. Pilot projects can play a role in providing facilities to develop new or improved cost-effective monitoring technologies which could then be deployed and tested at larger demonstration sites. Whilst many pilot projects focus on demonstration of successful storage it was felt that there remained a need to also evaluate mitigation and remediation options in failure scenarios. It was recognised that getting funding for this can be challenging.

Thirdly, induced micro-seismicity was recognised as an issue of particular interest amongst communities living close to a number of subsurface operations (for example CO_2 storage, hydrocarbon production, mining and quarrying). A range of opinions were expressed over the use of routine pressure monitoring. Whilst reservoir pressure data was generally agreed to be very valuable information the capabilities to routinely monitor bottom-hole pressures for example were not fully accepted by all during the discussion. Some pilot projects had BHP datasets that the delegates felt would be very worthwhile sharing amongst the community. Whilst above-reservoir pressure measurements are now routinely taken in some countries, there remained a gap in smarter interpretation of extrapolated reservoir pressures. Furthermore there was also a need to monitor regional pressure responses, especially in pressure-connected stores, where scale-up of pressure management may be needed.

3 Active test sites and pilot projects – opportunities for collaboration.

The Geoenergy Test Bed in the UK (Ceri Vincent, BGS) is in the early stages of development. The two target sandstones are at about 25 and 220 m depth with the lower analogous to the Bunter Sandstone offshore, a potential CO_2 storage reservoir. The site aims to improve understanding of gas migration in the shallow subsurface and environmental impacts of geo-energy activities, develop monitoring technologies and develop and validate modelling software.

The Sulcis project in Sardinia (Alberto Plaisant, Sotacarbo) plans to inject CO_2 into Eocene Limestones, including the investigation of fluid migration in a fault at depths ranging from shallow to potentially more than 1 km. Site characterisation is well advanced. The facility is open to international collaboration especially to develop low cost drilling, downhole monitoring tools and to manage leakage risks to protect groundwater and the environment.

Injection at the Hontomín pilot, Spain (Carlos de Dios, Ciuden) is into a deep fractured carbonate saline aquifer at 1600 m depth with capacity to upscale from 1 kt to 2-4 Mt of CO_2 storage. The project has investigated injection strategies and studied the effect of impurities on injection. Gaps exist in geophysical monitoring (plume tracking), deep monitoring tools, dynamic modelling combining fluid dynamics and geochemical effects and well abandonment techniques.

In South Korea (Eungyu Park, K-COSEM) the Environmental Impact Test facility is developing environmental monitoring and risk assessment technologies through controlled CO_2 release in the unsaturated zone at 2m depth and the saturated zone below 15 m depth. An initial shallow injection into Quaternary alluvium has been completed. The adjacent deeper injection will be into weathered granite. A trend estimation method has been developed for risk assessment that is robust even given large measurement errors and non-Gaussian data distribution.

The Pohang Basin project, South Korea (Insun Song, KIGAM) is a small scale test bed for monitoring technologies intended for upscaling to commercial projects. Sandstone reservoirs are being targeted at depths between 295 and 426 m. The Janggi Basin pilot plans injection of 10 kt of CO_2 into a conglomerate at c. 550-1000 m depth and will focus on deeper subsurface monitoring methods, especially downhole.

Guandong offshore CCUS project (Liang Xi, UK-China Guandong CCUS Centre) will shortly start Front End Engineering Design for a 0.5 Mt integrated project with potential storage through CO_2 EOR and in a saline aquifer in the Pearl River Mouth Basin. Three hydrocarbon fields have been shortlisted as possible storage sites.

Possible onshore CCUS opportunities in China (Xiaochun Li, Institute of Rock and Soil Mechanics) have been identified in at least 5 basins. A number of integrated CCUS pilots are underway or planned with annual injection rates of up to 1.0 Mt.

At Nagaoka, Japan (Ryozo Tanaka, RITE) 10.4 kt of CO_2 were injected onshore at 1100 m depth from 2003-5. Monitoring has concentrated on downhole or cross-hole techniques in 3 observation wells. All four trapping mechanisms were observed in the first 7 years of post-injection monitoring. Knowledge gaps include incorporating heterogeneity into models, interpreting mineralisation indicated and building geochemical reaction into history matching.

The Tomakomai project also in Japan (Jun Kita, RITE) plans to inject 100 kt of CO_2 from onshore wells into offshore sandstone and volcanic reservoirs at 1100-1200 and 2400-3000 m depth from 2016-18. Leakage simulations have considered migration up sub-seismic faults and dispersion in sea water. Thresholds for ecological impact have been estimated, baseline surveys completed and monitoring plans drawn up.

In Canada the Field Research Station (Don Lawton, Containment and Monitoring Institute) intends to inject at about 300 and 500 m depth, the lower reservoir having a better seal than the upper. A range of geophysical and geochemical monitoring is planned with baseline data already collected. Collaborations have been established with LBNL, UKCCSRC and University of Guelph.

The Ginninderra controlled release site, Australia (Andrew Feitz, Geoscience Australia) is nearing the end of its life. There have been 3 sub-surface CO_2 releases (at 2 m depth) and one methane surface release experiment, which were used to test a variety of monitoring and environmental impact methods. The leakage patterns and rates were affected by prevailing weather and soil conditions. A recent surface release tested detection and quantification techniques with most methods within 20% of the actual release rate.

A shallow injection (30 m depth) is also planned at Otway, Australia (Charles Jenkins and Andrew Feitz, CO_2CRC) into a faulted limestone aquifer. The main injection is into a saline formation at about 1400 m depth; 10 kt have been injected so far. The objectives are to ascertain detection limits for CO_2 in the subsurface, observe plume development and verify stabilisation. An announcement of opportunity has been made for collaboration, with specific areas where reinforcement would be welcome defined. Submissions may help to firm up Stage 3 of the project, which is at a conceptual phase.

3.1 KEY MESSAGES

In this session there were talks on active test sites and pilot projects from 8 countries, which provided examples of a wide range of such facilities. They covered test sites with very shallow injections (2 m depth) and surface releases (e.g. Ginninderra, Australia and South Korea), releases at shallow to moderate depth (maximum a few hundred metres), such as the GeoEnergy Test Bed, UK; Sulcis, Italy; Pohang Basin, South Korea; Field Research Station, Canada and Otway, Australia and deeper pilots at operational CCS depths (below 800 m) including Hontomin, Spain; Chinese sites and Nagaoka and Tomakomai in Japan and Otway.

Sites are at different stages of development with a few nearing the end of their life. However, the majority of sites described are under active site characterisation and development with some having already started injection.

All of the sites described welcome external collaboration, either national or international. Many already have collaborators. Such external links need to strengthen existing areas of work or fill gaps, which are site specific.

Attempts have already been made to foster collaboration between groups of similar sites. This is particularly true of the shallow test sites (0 to a few hundred metres injection depth). For example UK and Italian sites will work together under the EU ENOS (ENabling Onshore Storage) project due to start in autumn 2016. An unsuccessful bid was made to link sites in Australia, South Korea and the UK. At the very least it should be possible for informal networks of similar types of site to share information, arrange meetings etc. so that experiences in different environments can be compared (e.g. between carbonate and clastic reservoirs, different aquifer chemistry, soil types and climatic conditions).

3.2 OVERARCHING AND COMMON THEMES

In general sites share many objectives and characteristics in common e.g.:

- Developing monitoring techniques and protocols
- Improving simulations/models
- Understanding processes
- Evaluating possible environmental impacts
- Improving operations and reducing costs e.g. drilling, injection

These vary between sites but with significant areas of overlap. Inevitably there are differences of emphasis between deeper pilot sites, where there is a focus, for example, on improvements in plume tracking and modelling/history matching, and test sites focussed on shallow processes, such as fluid leakage and effects on aquifers and near surface ecosystems. A number of the shallow test sites have aspirations to examine fluid movement in faults/fractures.

All sites welcome collaboration. Some have formal mechanisms in place for this. In most cases collaborators would need to find their own funding from outside the test or pilot project.

4 Opportunities for mutually beneficial collaboration

The workshop participants were assigned to one of three breakout topics according to their known research interest and pilot/demonstrator project expertise and experience. Participants were offered the opportunity to 'swap' with another contributor if they wished. Each breakout topic was by two groups to allow each group to be small enough to encourage individual conversation and contribution by everyone. A chairman and a rapporteur, with known relevant international expertise and experience in leading and recording discussions, respectively, had been asked to lead and capture the discussion. Each session had been tasked to identify research areas they would wish to add to their own site, wider 'gaps' in research knowledge and how that that might be met by collaboration between projects and sites and align with research on other geo-energy resources. Summaries of the discussions in each breakout session were prepared by the chairman and rapporteur and presented to the workshop by the rapporteurs. Themes for collaborative research that were identified in common by the breakout groups were highlighted and

The three breakout topics, chairmen and rapporteurs were:

1. **Deep monitoring and injection optimisation and other geo-energy resources**
   Session 1A - chairman Charles Jenkins (CO_2CRC), rapporteur Jim White (BGS)
   Session 1B – chairman Ceri Vincent (BGS) and rapporteur Ton Wildenborg (TNO)
2. **Shallow migration/leakage monitoring & remediation and other geo-energy resources <u>onshore</u>**
   Session 2A – chairman Dave Jones (BGS)and rapporteur Matt Hall (GERC)
   Session 2B – chairman Kyle Worth (PTRC) and Andrew Feitz (Geoscience Australia)
3. **Shallow migration/leakage monitoring & remediation and other geo-energy resources <u>offshore</u>**
   Session 3A - chairman Jerry Blackford (PML) and rapporteur Karen Kirk (BGS)
   Session 3B - chairman Andy Chadwick (BGS) and rapporteur Sue Horvorka (TBEM)

Summaries of the discussions in each breakout session were prepared by the chairman and rapporteur and presented to the workshop by the rapporteurs. After the presentations themes for collaborative research and steps in a process to that were identified in common by the breakout groups were highlighted.

The presentations prepared by the breakout groups (Appendix 3) were used to compile this summary of key messages, steps in a process to enable collaboration between sites and common themes in collaborative research topics summarised in the following text sections.

4.1 KEY MESSAGES

Key messages taken from the presentations given by the breakout group rapporteurs and discussion with

1. A primary benefit of international collaboration between projects is to build confidence in CO_2 storage and give a social licence to operate for CCS.
2. Comparisons between different technologies that have been applied at different sites with different geological conditions will increase confidence in the operation and wider deployment of CCS.
3. Pilot projects provide opportunities for capacity building to take CCS forward and the transfer of skills and expertise, as much as knowledge, would be a primary benefit of collaboration between projects to truly achieve best practice.
4. Transfer of knowledge and application of techniques which have been developed at onshore pilots to offshore sites, where experimental development is less accessible and more costly, should be encouraged.
5. Exchange of data across projects is essential for collaboration on developing cost-effective monitoring.
6. Potential synergies with other geo-resources were identified**:**

- Re-inject CO_2 with recirculated fluids from geothermal energy production;
- Provide pressure support for hydrocarbon operations from CO_2 injection and storage;
- Producing heat from brine produced for pressure management of a CO_2 storage site;
- Use of the ^{14}C signature of the injected anthropogenic CO_2 source as a tracer for environmental assessment;
- Low-cost drilling techniques developed for CO_2 storage applied to other subsurface activities and vice versa;
- Application of techniques developed as CO_2 storage site corrective measures to environmental remediation, and vice versa;
- CO_2 migration characterisation and prediction modelling by 'fault laboratories' applied to radioactive waste repositories, hydrocarbon migration pathway assessment.

4.2 STEPS IN A PROCESS TO CREATE OPPORTUNITIES FOR RESEARCH COLLABORATION

- Broaden the applicability of 'best practice' by combining and integrating findings at two (or many) pilot sites
- Identify and integrate existing 'best practice' reporting and recording
- Consider publication of learning gained by comparison of sites, including the processes inferred and recognised at pilot sites, e.g. compare findings at onshore sites with QICS offshore pilot release site
- Give access and provide information to allow opportunities for collaboration between pilots with large-scale projects to be identified via:
  - A portal or web site to share metadata on datasets collected or being acquired at pilot sites
  - An archive of data agreed for sharing
  - Funding to present metadata/data to a standard suitable for collaboration and sharing
- Identify a portfolio of sites that would be willing to consider collaboration, that would be described in a common format
- Present a process for sites to offer and implement opportunities for mutually beneficial collaboration by sharing:
  - Schedules of planned pilot site experiments and research, with a diary of deadlines to consider 'volunteer' complementary research activities
  - Alignment with national and international funding sources and objectives to leverage additional resources
- Invest in 'overseas' research to gain benefit for the implementation of CO_2 storage in one's own country, e.g. collaboration by Japanese and UK research consortia at the QICS pilot site
- Agree and offer datasets for concerted multi-organisation interpretation, e.g. modelling of multiple realisations of pilot site datasets
- Identify organisations that would facilitate collaboration between pilot sites and large projects

4.3 COMMON THEMES IN COLLABORATIVE RESEARCH TOPICS

A number of common themes were identified from the discussions that offer potential for further development.

4.3.1.1 Role and effect of faulting on fluid migration in CO_2 storage

- Property attribution in the fault structures or volumes including generic characterisation of fault zones to inform monitoring techniques
- Quantification of the volume of fluid migration in damage zones around faults and the rate of migration
- Stimulation of fault reactivation by increased pressure of injection
- Investigation of the role of fine-scale faulting, unresolved on seismic data, in fluid migration
- Combining many pilot-scale fault laboratories into a global-scale experiment

4.3.1.2 Increasing monitoring efficiency, reducing and minimising cost of monitoring

- Investigation and testing new monitoring technologies, e.g. remote data access and download, smaller, lighter and more robust monitoring hardware and ‘real time’ monitoring
- Establish a minimum portfolio of monitoring techniques to be deployed by collaboration at pilot sites, such as monitoring of adequate well completion.
- Identification of monitoring techniques relevant to different scales of monitoring
- Development of new monitoring sensors and assessment by deployment in a hostile environment, e.g. onshore development and offshore deployment
- Monitoring of geochemical tracers to reassure secure containment
- Reduce cost of monitoring by minimising the area to be monitored and use of mobile, rather than static, surface monitoring techniques
- ‘Permanent’ installation of monitoring sensors and arrays for monitoring at depth
- Optimisation of data gathered and ‘sifting’ of data acquired during monitoring
- Qualitative and quantitative comparison of monitoring data between pilot sites
- Mass balance and quantification of injected CO_2 to instil confidence in the efficacy of storage

4.3.1.3 Up-scaling from pilot to large scale

- Scaling of pilot projects to ensure the results will be suitable to inform large-scale projects
- Consider the implications to certainty of prediction when extrapolating from small areas of high data density to large project areas
- Examine what inferences can be drawn about deep monitoring from shallow measurements
- Prediction of pressure and temperature changes in the wellbore to inform scaling up
- Offshore implementation of monitoring technology developed and tested at onshore sites
- Increased monitoring resolution of stored CO_2 to increase confidence in capacity and reduce cost
- Optimum characterisation of a well to inform upscaling to assess future injectivity and storage efficiency

4.3.1.4 Post-closure monitoring, overburden and remediation studies

- Long-term, minimal-input monitoring to demonstrate conformance, assurance of post-closure site behaviour and satisfy regulatory requirements
- Study of the overburden to storage sites by investigation of strata at depths greater than surface site investigations and less than hydrocarbon exploration.
- Analysis of terrain and bathymetric surface datasets to infer overburden characteristics e.g. fault mapping

- Completed pilot project sites to be made available as test beds for remediation technologies and methods or corrective measures e.g. plume steering by microbes or biofilms

4.3.1.5 Public perceptions

- Instil public confidence in the security and integrity of CO_2 storage by ensuring good project management, public awareness activities and careful choice of terminology used
- Share and publish the methods followed to manage perception of project risk and achieve a 'social licence to operate'

5 The broader perspective: experience of international CCS collaboration and industry view of research needs

5.1 LESSONS LEARNED FROM THE EXPERIENCE OF INTERNATIONAL RESEARCH COLLABORATION

The broader perspective on international collaboration to share research and the lessons learned from the experience of IEAGHG was presented by James Craig. He highlighted journal publications, conference presentations, workshop and network meetings, research secondments and knowledge exchange visits as mechanisms for collaboration and illustrated projects demonstrating the value of international collaborative research. Examples were given of international collaborative projects that demonstrated the breadth and worldwide extent of research on the overburden to storage sites, experimental controlled releases of CO_2 and development of monitoring and modelling technologies.

Lessons learned from the review are that international collaborative CCS research projects are:

- Valuable to exchange research, development and design experience worldwide
- Excellent opportunities for comparative approaches for project development
- Platforms for technical innovation
- Enable comparison of approaches to regulation and outreach
- Inform strategies for risk assessment and mitigation

Research knowledge gaps were identified by the IEAGHG review were the capability to discriminate between the effects of changes in pressure and saturation from seismic data, and improved monitoring technologies hardware, better data processing and analysis, improved shallow subsurface imaging and more robust communications for permanent real-time monitoring. Quantification of geologically stored CO_2 and the detection and quantification of leakage also remain as a technical challenge.

5.2 INDUSTRY PERSPECTIVE OF CCS RESEARCH KNOWLEDGE GAPS

Industry participants, who had also participated in the breakout sessions, gave their perspective of knowledge gaps that should be addressed by CCS research.

Mervyn Wright, Wright Energy Solutions Ltd., emphasised the needs to advance CCS are reducing costs, by economy of scale and reducing the risk premium, and increasing confidence. Confidence should be increased for all stakeholder groups: regulators and other storage formation users in secure containment; policy makers in the affordability of CCS; investors in the performance of CCS chain. He advised to apply what was already available and to take a positive approach to illustrate that 'CCS works', give examples of success, and by drawing comparison with existing data and subsurface activities. A minimal approach to storage site monitoring and education of the regulators at the highest level, e.g. European Commission, was also recommended.

Tony Esbie, BP, advised that research is needed to transform CCS from a feasible technology to a business by reduction of cost, also to increase storage capacity and confidence in operation and so reduce cost. Overall, the objective should be to change the perception of CCS to a view that 'CO_2 storage is cheap'. Technologies for monitoring should be simple and straightforward, such as 2D and 3D seismic datasets, but cheaper technologies should be sought and development of fibre sensors was suggested for deployment both onshore and offshore. Telemetry systems are needed to transmit down-hole monitoring records. A system is needed to transmit monitoring data from pressure sensors deployed in wells fitted with packers and cement plugs. Mitigation of leaks fr

Theo Mitchell, Carbon Capture and Storage Association, summarised the industry perspective that practical implementation of CCS and at large scale would bridge knowledge gaps. He summarised the research and development priorities perceived by industry which are available at: www.ccsassociation.org/index.php/download_file/view/990/496/. Cost reduction, with rapid reduction in cost over the next 5 years, and increased confidence and certainty of cost are needed for CCS. Research should reduce the cross-chain risk to impart confidence in the CO_2 transport infrastructure, offshore storage and capture.

Andreas Busch, Shell, also affirmed the need to reduce costs and singled out monitoring as the largest cost for CO_2 storage. Cheaper methodologies and smarter technologies should be developed, also research to minimise baseline monitoring by reducing the areal extent and number of surveys. Research on migration processes, including the hydrodynamic properties of faults, is needed to inform computer flow modelling and tested at laboratory and pilot-scale projects. Funding support for data exchange, negotiating intellectual property issues and embargo periods, would allow co-ordination not competition between storage formation operations. Overall, CCS research and development should aim to make CCS more cost effective and instil confidence in people who are not experts in CCS.

Rolando di Primo, Lundin, supported the research needs identified by the preceding industry speakers and additionally highlighted CO_2 not as a cost but as a solvent for Enhanced Oil Recovery (EOR). Research should consider how the cost of CO_2 storage could be reduced by CO_2 EOR, especially below the oil-water contact. He felt that zero-emissions hydrocarbon production, mandated by legislation, should be anticipated, with research to investigate the cost reduction associated with shared infrastructure for CO_2 storage and hydrocarbon production and delayed demobilisation of offshore infrastructure.

Alan James, Pale Blue Dot (Caledonian Clean Energy), noted that the greatest savings in cost can be made in those areas of largest spend. Knowledge sharing of costs would enable the areas of greatest spend to be identified. He felt that the biggest cost for transport and storage is infrastructure and research into increased storage efficiency would give greater return on the investment in costly CO_2 storage infrastructure. Other research areas identified were the monitoring and steering of the injected CO_2 plume and the geomechanical stability of depleted gas fields with re-pressurisation by CO_2 storage. Intermittency of CO_2 supply and increased cost associated with intermittent flow should also be investigated. Similarly, the consequence of abandoned wells and how to reduce the associated risk and cost of their presence within the extent of a storage site

6 Summary and conclusions

A number of ideas were proposed that delegates considered would help enable collaboration and support further CCS deployment. These activities are as follows:

1. *Co-operate during project planning and progress to enable comparison of datasets.* Discussions between project teams both during the planning of pilot-scale projects and during their operation could significantly improve opportunities for the development of datasets that could be more easily compared.
2. *Agree acquisition of appropriate datasets.*
   By acquiring data in similar formats would enable easier comparisons between datasets at different pilot sites. This could also include use of accepted feature descriptions rather than geological ages or stratigraphic names. To allow comparisons, petrophysical descriptions of geological units are more important than their stratigraphic descriptions.
3. *Identify common issues, processes and technologies*
   Research groups should identify common hypotheses, processes and technologies that can be addressed by comparison and interrogation of data from two or more sites.
4. *Agree a process between projects to extend project objectives.*
   It would be very beneficial to develop a process, possibly facilitated by an international organisation, whereby the project objectives can be extended through additional collaborative research opportunities.
5. *Access funding to collaborate*
   Funding should be sought through international collaborative mechnisms to enable knowledge exchange between projects and to support collaboration with other projects and sites
6. Seek funding to present ‘clean’ data sufficient to enable comparison between sites
7. Pilot projects to ‘piggy-back’ on large projects to address additional research questions and extend the knowledge generated on expenditure of research resources.

BGS undertook to discuss some of these ideas with relevant organisations and report back to the attendees.

Appendix 1 List of delegates

	Name	Organisation	Country
1	Jonathan Pearce	British Geological Survey	UK
2	Ceri Vincent	British Geological Survey	UK
3	Maxine Akhurst	British Geological Survey	UK
4	Dave Jones	British Geological Survey	UK
5	Andy Chadwick	British Geological Survey	UK
6	Mike Stephenson	British Geological Survey	UK
7	Chris Rochelle	British Geological Survey	UK
8	Gemma Purser	British Geological Survey	UK
9	Karen Kirk	British Geological Survey	UK
10	Jim White	British Geological Survey	UK
11	Keith Bateman	British Geological Survey	UK
12	Jo Booth	British Geological Survey	UK
13	Michelle Bentham	British Geological Survey	UK
14	Don Lawton	Carbon Management Canada	Canada
15	Kyle Worth	Petroleum Technology Research Centre	Canada
16	Andrew Feitz	Geoscience Australia	Australia
17	Charles Jenkins	Commonwealth Scientific and Industrial Research Organisation and CO_2CRC	Australia
18	Max Watson	CO_2CRC	Australia
19	Tony Ripley	Department of Energy and Climate Change	UK
20	Jerry Blackford	Plymouth Marine Laboratory	UK
21	Matt Hall	University of Nottingham	UK
22	Paul Nathanail	University of Nottingham	UK
23	Max Bardwell	University of Nottingham	UK
24	Den (Dennis) Gammer	Energy Technologies Institute	UK
25	Carlos de Dios	CIUDEN (Fundación Ciudad de la Energía)	Spain
26	Alberto Pettinau	Sulcis	Italy
27	Enrico Maggio	Sotacarbo	Italy
28	Alberto Plaisant	Sotacarbo	Italy
29	Michela Vellico	OGS (Instituto Nazionale di Oceanografia e di Geofisica Sperimentale)	Italy
30	Sabina Bigi	University of Rome Sapienza	Italy
31	Susan Hovorka	Bureau of Economic Geology, Texas	USA
32	Lee Spangler	University of Montana	USA
33	Seong-Tak Yun	Korea University and K-COSEM	Korea
34	Eungyu Park	Kyoungbuk National Univ and K-COSEM	Korea
35	Soon-Oh Kim	Gyeongsang National Univ and K-COSEM	Korea
36	Jina Jeong	Gyeongsang National Univ and K-COSEM	Korea
37	Insun Song	KIGAM (Korea Institute of Geoscience and Mineral Resources)	Korea

38	Seong-Gil Kang	KRISO (Korea Research Institute of Ships and Ocean Engineering)	Korea
39	Sang Hoon Lee	KIOST (Korea Institute of Ocean Science and Technology)	Korea
40	Jun Kita	RITE (Research Institute of Innovative Technology for the Earth)	Japan
41	Ryozo Tanaka	RITE (Research Institute of Innovative Technology for the Earth)	Japan
42	Xiaochun Li	IGGRSM Chinese Academy of Sciences	China
43	Jiang Xu	Chongqing University	China
44	Shoujian Peng	Chongqing University	China
45	Qian Zhang	Hubei NGU Human Resources Services Co, Ltd	China
46	Zhenxing Fan	CPI Yuanda Environmental Protection Engineering Co Ltd	China
47	Liang Xi	Guangdong CCUS Centre	China
48	Thinus Cloete	Council for Geoscience	South Africa
49	Tony Surridge	SANEDI (South African National Energy Development Institute)	South Africa
50	Thulani Maupa	SANEDI (South African National Energy Development Institute)	South Africa
51	Ton Wildenborg	TNO (Netherlands Geological Survey)	Netherlands
52	Mervyn Wright	Wright Energy Solutions Ltd	UK
53	Theo Mitchell	Carbon Capture and Storage Association	UK
54	Geraint West	Sonardyne	UK
55	Tony Espie	BP	UK
56	Philip Ringrose	Statoil	Norway
57	Gareth Johnson	University of Edinburgh	UK
58	Geoff Baxter	British Geological Survey	UK
59	Bob Gatliff	British Geological Survey	UK
60	Sverre Quale	Norwegian University of Science and Technology (NTNU)	Norway
61	Benjamin Court	Global CCS Institute	Belgium
62	Tom Parker	Silixa	UK
63	Rolando di Primio	Lundin	Norway
64	Harald Brunstad	Lundin	Norway
65	Alan James	Pale Blue Dot	UK
66	James Craig	International Energy Association Greenhouse Gas programme	UK
67	Andreas Busch	CO_2 Storage Research, Shell	Netherlands
68	Zoe Kapetaki	Global CCS Institute	Belgium
69	Ciara O'Connor	UK CCS Research Centre	Edinburgh
70	Alv-Arne Grimstad	SINTEF Petroleum AS, Norway	Norway
71	Maria Barrio	SINTEF Petroleum AS, Norway	Norway
72	Rachel Kilgallon	University of Edinburgh	UK
73	Linda Hetherington	British Geological Survey	UK
74	Christina Edwards	British Geological Survey	UK

75	Zhu Chen	British Consulate General, Chongqing	China

Appendix 2 Final Agenda

BRITISH GEOLOGICAL SURVEY AND UK FOREIGN AND COMMONWEALTH OFFICE CO_2 STORAGE WORKSHOP

Pathways from pilot to demonstration: How can research advance CO_2 geological storage deployment?

1 – 3 March 2016, British Geological Survey (BGS) Keyworth, near Nottingham, NG12 5GD, UK

Workshop objectives:

- Examine how pilot, field lab and lab projects can inform and advance large-scale storage
- Reinforce importance of advancing CCS through practical experience at varied relevant scales: pilots/field labs (testing concepts) and demonstrations (deploy technologies and identify new technical questions for pilots to examine)
- Strengthening international links between field lab, pilot, demo and large scale project operators to make it easier to share lessons learned
- Exchange research learning between CCS and other geo-energy disciplines

Workshop outcomes: Identification of opportunities for collaboration and development of outline proposals to advance CCS and geo-energy research through practical experience and demonstrations.

Workshop programme
Starting with lunch on 1 March and finishing after lunch on 3 March 2016

Day 1: Tuesday 1 March 2016

11:30 Free coach transport departs Jurys Inn hotel, Nottingham for BGS Keyworth

12:00 Registration and lunch at BGS Keyworth

Session 1: Sharing practical experiences of the role of research and international learning to inform deployment of CO_2 storage

Advancing CCS through practical experience at varied relevant scales, i.e. test sites and pilot projects (testing concepts) and demonstrations (deploy technologies and identify technical questions for pilot projects to examine).

Each speaker 15 minutes maximum plus five minutes for questions

Chair: Andy Chadwick, BGS

12:50	Welcome	Jonathan Pearce, BGS, Team Leader CO_2 Storage
13:00	Introduction and aims of the	Mike Stephenson, BGS, Director

	workshop	of Science and Technology
13:10	Research drivers for large-scale deployment of CO_2 storage: Norway perspective	Phillip Ringrose, Statoil
13:30	The Aquistore project and its relevance to large scale storage in Canada	Kyle Worth, PTRC
13:50	Keynote: CCS activities in Shell and research needs for large-scale implementation	Andreas Busch, Shell
14:20	STEMM-CCS monitoring of an offshore CO_2 release	Jerry Blackford, PML
14:40	Offshore CO_2 storage in South Korea: R&D progress and future plans	Sang Hoon Lee, KIOST
15.00	Carbon capture and storage in South Africa: mandate and progress	Tony Surridge, SACCCS
15:20	ECCSEL: European Carbon Dioxide Capture and Storage Laboratory Infrastructure	Sverre Quale, ECCSEL
15:40	Refreshments and workshop photograph	

Session 2: Exchange of learning between CCS and other geo-energy sectors. Each speaker 20 minutes including five minutes for questions.

Chair: Lee Spangler, Montana State University

16:00	Research in the hydrocarbons sector relevant to CO_2 storage	Bob Gatliff, BGS, Science Director of Energy and Marine Geoscience
16:20	Integrating research for geo-energy and CCS by ESIOS (Energy Security & Innovation Observing System for the Subsurface UK)	Mike Stephenson, BGS, Director of Science and Technology
16:40	Discussion	
17:40	Close	

17:40 Informal networking drinks reception at BGS
(includes 15 minute briefing of breakout group chairmen and rapporteurs)

18.40 Free coach transport departs BGS to Jurys Inn hotel, Nottingham
Selection of suggested restaurants for informal dining in Nottingham.

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Day 2: Wednesday 2 March 2016

08:00 Free coach transport departs Jurys Inn hotel for BGS Keyworth

Session 3: Active test sites and pilot projects – opportunities for collaboration. Each active site or project 15 minutes maximum plus five minutes for questions.

Chair: Dave Jones, BGS

08:45	Welcome, introduction and aims	Jonathan Pearce
08:50	Geoenergy Test Bed, UK field lab site – a fluid flow field laboratory, Nottingham, UK	Ceri Vincent, BGS
09:10	The Sulcis CCS project, Italy: the characterization phase	Alberto Plaisant, Sotacarbo
09:30	Hontomín Pilot Site (Spain). CO_2 injection in a carbonated deep saline aquifer	Carlos de Dios, CIUDEN
09:50	Potential of robust trend analysis methods for long-term CO_2 leakage predictions: A case study based on a controlled shallow CO_2 leakage site in Korea	Eungyu Park, K-COSEM Research Center and Kyungpook National University
10:10	Pilot sites in the Pohang Basin, Janggi Basin and Youngil Bay, South Korea	Insun Song, KIGAM
10.30	Refreshments	

Chair: Jonathan Pearce, BGS

11:00	Guangdong CCUS project, China	Liang Xi, UK-China (Guangdong) CCUS Centre
11:20	Pilot project(s) in China	Xiaochun Li, IRSMCAS
11:40	Nagaoka Project, Japan and its collaboration opportunities	Ryozo Tanaka, RITE
12:00	Tomakomai pilot project, Japan, and its collaboration opportunities	Jun Kita, RITE
12:20	CaMI.FRS: a field research station monitoring test site, Alberta, Canada	Don Lawton, Containment and Monitoring Institute
12:40	Lunch	

12:40 Lunch at BGS Keyworth

Session 3 continued

13:30	Ginninderra controlled release facility, Australia	Andrew Feitz, Geoscience Australia
13:50	Developments and opportunities at the CO2CRC Otway project, Australia	Charles Jenkins, CO_2CRC

Session 4: Breakout sessions Discussion groups to identify research topics with benefit across projects and disciplines and prospective upcoming funding calls in respective areas and nations.

14:10	Introduction to breakout group sessions	Jonathan Pearce
14:20	**Group 1:** Collaboration between projects and across disciplines on **Deep monitoring and injection optimisation and other geo-energy resources**	**1A,** Chairman – Charles Jenkins Rapporteur – Jim White, BGS
		1B, Chairman – Ceri Vincent Rapporteur – Ton Wildenborg, TNO
	Group 2: Collaboration between projects and across disciplines on **Shallow migration/ leakage monitoring, environmental impacts & remediation and other geo-energy resources <u>onshore</u>**	**2A,** Chairman – Dave Jones, BGS Rapporteur – Matt Hall, GERC/BGS
		2B, Chairman – Kyle Worth Rapporteur – Andrew Feitz
	Group 3: Collaboration between projects and across disciplines on S**hallow migration/ leakage monitoring, environmental impacts & remediation and other geo-energy resources <u>offshore</u>**	**3A,** Chairman – Jerry Blackford, PML Rapporteur – Karen Kirk, BGS
		3B, Chairman – Andy Chadwick, BGS Rapporteur – Sue Hovorka
15:20	Refreshments	

Session 5: Plenary on outcomes from breakouts – identified topics and opportunities for mutually beneficial collaboration

15:50	Introduction	Jonathan Pearce
16:00	Feedback from Group 1A	Jim White
16:10	Feedback from Group 1B	Ton Wildenborg

16:20	Feedback from Group 2A	Matt Hall
16:30	Feedback from Group 2B	Andrew Feitz
16:40	Feedback from Group 3A	Karen Kirk
16:50	Feedback from Group 3B	Sue Hovorka
17:00	Summary of outcomes from breakout groups – group discussion	Maxine Akhurst, BGS
17:40	End of day 2	

17:45 Free coach transport departs BGS to Jurys Inn hotel, Nottingham

19:30 Free coach transport departs Jurys Inn hotel, Nottingham to Trent Bridge Cricket Club for dinner

22:30 Free coach transport departs from Trent Bridge to Jurys Inn hotel

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Day 3: Thursday 3 March 2016

09:00 Free coach transport departs Jurys Inn hotel, Nottingham, for BGS Keyworth

Session 6: Next research steps from demonstration along the path to deployment

Chair: Bob Gatliff, BGS, Science Director of Energy and Marine Geoscience

09:30	Review of outcomes from breakout groups	Jonathan Pearce
09:40	Perspective on collaboration to share research learning – lessons learned from international experience	James Craig, IEAGHG
10:00	Feedback from storage project developers and operators on breakout group outcomes, ensuring relevance to demonstration and deployment	Industry panel – BP, CCSA, Guangdong CCUS project, Lundin, Pale Blue Dot (Caledonian Clean Energy), Shell, Wright Energy Solutions Ltd,
11:00	Refreshments	
11:30	Discussion - Identification of concrete opportunities for collaboration between test sites, pilot projects and deployment - Outline concepts for proposals to implement the research	Maxine Akhurst, BGS

	collaboration opportunities	
12:30	Summary of next steps	Jonathan Pearce
12:45	Meeting close	

12:45 Lunch at BGS Keyworth

13:30 Free coach transport departs from BGS Keyworth to Jurys Inn hotel, Nottingham

Tours of the BGS geological walk, 3D visualisation suite and core store, approximately 20 minutes duration, can be arranged after lunch for those who wish. Delegates are welcome to remain on the BGS campus to undertake the short tours which will be arranged as requested.

Appendix 3 Output from collaboration breakout discussion sessions

Deep monitoring and injection optimisation and other geo-energy resources

Potential topics for collaborative site-specific research

Breakout group 1A - Charles Jenkins and Jim White

Workshop participants assigned to breakout group 1A: Geoff Baxter; Harald Brunstad ; Carlos de Dios; Rachel Kilgallon; Alberto Pettinau; Shoujian Peng; Gemma Purser; Nino Ripepi; Tony Surridge; Mervyn Wright.

Key lessons

- Our discussion revealed a limited scope for collaboration on deep monitoring between the pilot projects unless data is made available across projects.
- It was felt that the transfer of skills, as much as knowledge, would be the primary benefit.
- Pilots provide capacity building to take CCS forward.

Where is CCS?

- CCS often follows a similar path to oil and gas. Where is our opportunity to take things forward in a mature industry.
- Well leakage and very long term monitoring. Zone from reservoir to surface.
- Deep monitoring will be there to satisfy regulatory systems - Containment and conformance.
- Key is to identify how it can lead to commercial CCS, and mitigate against CO_2 emissions.

Use of pilots – capacity building

- Gain experiences to ensure transition of technology to commercial deployment. Efficiency and safety.
- So are pilots simply a training tool to help scientists/policy makers move to full-scale deployment?
- Evaluation method to assess the monitoring tools in hostile environment. Confidence builder? But same as oil and gas. But these can be shared.
- Period of monitoring is longer than anything previously
- Increasing confidence of people in other parts of the chain.

Collaboration on technology

- Transfer of novel techniques (e.g. pressure tomography, novel/quantum gravity sensors, DAS, fibre VSP, perm source) between sites.
- All pilots have similar kits. BUT DIFFERENT BEHAVIOUR. What lessons can be learnt. What can be shared to make conclusions applicable to the community
- What should be measured, and how does this satisfy regulatory requirements?

- What do shallow measurements tell us about deep ones? Can we join the gap? How are they linked to reservoir?
- Biofilms as a mitigation strategy.

Collaborative themes

- Lessons learned demonstrating conformance to pre-injection plan.
- Detectability thresholds for leakage. Collaborations between sites.
- How to quantify leakage – small and catastrophic volumes?

Key points

- Sharing data – more data allows us to better understand
- Development of best practice approach.

Breakout group 1B – Ceri Vincent and Ton Wildenborg

Workshop participants assigned to breakout group 1B: Keith Bateman; Michelle Bentham; Thinus Cloete; Alv-Arne Grimstad; Alan James; Philip Ringrose; Tom Parker; Rolando di Primio; Max Watson; Jiang Xu.

Injection optimisation and cost reduction

- Plume monitoring and steering (sweep-efficiency management) with polymers and brine production
    - Brine production which requires monitoring water quality (chemical content, temperature)
    - Relationship between required injection volume and the architecture of the reservoir
- Near-well issues like salt precipitation, hydrate formation
- Operational instability caused by frequent starting up and shutting down due to varying CO_2 stream
- Use other compositions of the injected CO_2 stream with chemical and thermodynamic effects in the well and the reservoir
- Optimum characterisation of a well for upscaling in terms of future injectivity and storage efficiency
- Lack of data on CO_2-brine relative-permeabilities which are scale dependent
- Optimised injection has great potential for cost saving though increased storage efficiency and reduced number of wells required

Monitoring

- Fibre optics with a variety of sensors including VSP, leak detection, inflow into formation, heat pulse measurements making continuous injection (production) possible and has a cost reduction potential
- Chemical sensors, e.g. pH tracers, redox and salinity
- Make wells available for monitoring tool development and use of alternative cement materials
- Long-term monitoring techniques downhole (e.g. pH) and surface techniques for deep investigation, (e.g. gravity)

- Weighing up value/risk of more wells for monitoring

Upscaling from pilot to demo

- Appropriate scale of test at pilot scale should be meaningful for large injection volumes and large storage capacity
- Predicting pressure and temperature change in wellbore is very useful for larger-scale projects
- Instrumenting wells to be abandoned and available in other projects for future relocation and integrity test

Corrective measures

- Using polymers resistant to CO_2 in sealing off fracture zones
- Plume steering requires sufficiently deep well and pressure gradients to be effective
- Use of $Ca(OH)_2$ becoming reactive in the presence of wet CO_2
- Use of microbes for creating flow barriers (e.g. biofilms, siderite)
- Test bed for remediation methods or plume steering methods
- Also applicable to other industries, e.g. environmental remediation for chemical spills

Synergies with other georesources

- Re-inject CO_2 with recirculated fluids from geothermal energy production and provide pressure support
- Producing heat from brine production
- ^{14}C source as a tracer
- Low-cost drilling
- See corrective measures

Shallow migration/leakage monitoring &remediation and other geo-energy resources <u>onshore</u>
Breakout group 2A – Dave Jones and Matt Hall

Shallow release – onshore

Workshop participants assigned to breakout group 2A: Sabina Bigi; Gareth Johnson; Soon-Oh Kim; Don Lawton; Alberto Plaisant; Insun Song; Lee Spangler; Michela Vellico; Seong-Tak Yun; Qian Zhang.

- Primary benefit is to build confidence and social licence to operate
- Not the site specifically, but comparing different technologies into different places, difference geological conditions.
- Mass balance/quantification question to instil confidence
- Portfolio of techniques for different scales

Comparability

- The need to report evidence in similar way
- Comparison between different facilities
- Resources and collaboration to publish more comparisons between projects in papers
- Sharing of project meta data on a website
- Archival, curation of data

Wider audience

- Sharing how you deal with risk management, social licence to operate
- Make sure leakage experiments are well managed, risks considered, public perceptions, wider impact on the geological storage community
- Rather than talking about risks, talk about safety cases
- Conceptual geological model – using similar terminology, describe features (e.g. coal, halite, fractured limestone) rather than using ages or stratigraphy (different members, formation names)

Fault experiments

- Potential sites for fault experiments
  - CO2CRC
  - Bongwana, SA
  - Sulcis, Italy
- More in-depth studies, understanding processes at natural or injection experiment sites
- Fault that looks like this, expect this type of behaviour
- All sites open for collaboration
- Multiple models using the same data

Questions faults experiments

- Can experiment answer these questions:
  - How much migration in the damage zone
  - Natural attenuation in thief (high perm) zones?
  - Rate of migration?
  - How to you monitor migration?
  - Predicting fault behaviour?
  - Or have these already been answered?
- Could be applied in other geoenergy industries, mining
- Generic characterisation of fault zones to inform monitoring techniques

Funding

- High level agreements
  - UK and US (DoE, NSF)
- Early warning of tests to get funding in place
- A controlled releases calendar
- Support from different groups can help get funding
- Global experimental program of geological storage
- Combing lots of little projects into a larger global program
- Where can we invest in research overseas to get benefit to our country
- Minimum portfolio of techniques that would be deployed at a leaking site
- Who oversees the global experiment, e.g. IEA

Breakout group 2B – Kyle Worth and Andrew Feitz

Workshop participants assigned to breakout group 2B: Maria Barrio; Zhenxing Fan; Jina Jeong; E Xiaochun Li; Enrico Maggio; Thulani Maupa; Paul Nathanail; Eungyu Park; Jonathan Pearce; Chris Rochelle.

- Build confidence
- Not the site specifically, but comparing different technologies into different places, difference geological conditions.
- Mass balance/quantification question to instil confidence

- Quantify
- Broad-scale detection and flexibility
- Portfolio of techniques for different scales
- Social licence to operate, build public acceptance
- The need to report evidence in similar way
- Resources and collaboration to publish more comparisons between projects in papers
- Sharing of project meta data on a website
- Archival, curation of data
- Sharing how you deal with risk management, social licence to operate
- Make sure leakage experiments are well managed, risks considered, public perceptions, wider impact on the geological storage community
- Rather than talking about risks, talk about safety cases
- Better collaboration and coordination
- Potential sites for fault experiments
  - CO2CRC
  - Bongwana, SA
  - Sulcis, Italy
- More in depth studies, understanding processes at sites
- All sites open for collaboration
- Multiple models using the same data
- How experiment answer these questions:
  - How much migration in the damage zone
  - Natural attenuation in thief (high perm) zones?
  - Rate of migration?
  - How to you monitor migration?
  - Predicting fault behaviour?
- Could be applied in other geo-energy industries, other mining
- Characterisation of fault zones, inform monitoring techniques
- High level agreements
  - UK and US (DoE, NSF)
- Comparison between different facilities
- Fault that looks like this, expect this type of behaviour
- Conceptual geological model – using similar terminology, describe features (e.g. coal, halite, fractured limestone) rather than using ages or stratigraphy (different members, formation names)
- Early warning of tests to get funding in place
- A controlled releases calendar
- Support from different groups can help get funding

- Global experimental program of geological storage
- Combing lots of little projects into a larger global program
- Where can we invest in research overseas to get benefit to our country
- Minimum portfolio of techniques that would be deployed at a leaking site
- Who oversees the global experiment, e.g. IEA

Shallow migration/leakage monitoring &remediation and other geo-energy resources offshore

Breakout group 3A

Chairman: Jerry Blackford – PML

Rapporteur: Karen Kirk – BGS

Workshop participants assigned to breakout group 3A: Maxine Akhurst; Max Bardwell; Bob Gatliff; Seong-Gil Kang; Zoe Kapetaki; Sverre Quale; Tony Ripley; Ryozo Tanaka; Liang Xi; Geraint West.

Research topics

- Marine environment
  - Adequate baseline summary on a budget
  - Assess risk and impact
  - Most efficient way to detect a leak
  - Quantification of that leak
- Geological
  - Shallow characterisation
  - Knowledge transfer onshore to offshore

Baselines

- Qualitative and quantitative comparison of different sites
  - Carbonate Chemistry, pH, DIC etc.
  - Stoichiometric relationship analysis – potentially more challenging in the marine environment than onshore - can we sufficiently define this? (need high frequency, local occurrences of high resolution data – which are very rare)
- Get together with data from existing projects to carry out a comparison of observations
- Initial activity – to compare observation programmes to maximise potential inter-comparison.

Who?

- STEMM – North Sea
- Tomakomai - Japan
- Ulleung - Korea
- Texas University – Gulf of Mexico
- CSIRO – Australia
- Guangdong - China

Monitoring

- How to monitor efficiently and effectively:
    - AUV/RoV only if quiet;
    - issues - battery life, amount of data being collected –
- NB need to sift and extract the meaningful data (acoustics, pH measurements etc.)
- Relevant data is set by regulatory requirements
- Algorithms required to sift through data for the relevant data to make most efficient use of these units
    - Algorithms are site specific
    - Detectability may be better at times of year with low natural variability, but we need to consider operational issues such as not deploying in bad weather. There could be a trade-off.

How to monitor effectively, efficiently and cheaply – key challenge is to reduce the spatial extent of the survey

- Knowledge from offshore projects can inform array layout for shallow monitoring – would need to be mobile not static as don't know where it will occur
- ability to carry out mobile monitoring has local constraints e.g.
    - for example would be effected fishing in Japan, red crabs in Korea and oil and gas in North Sea
- Start with a synthesis of onshore and offshore in a paper – shallow geophysical flow pathways
    - Several onshore sites that could be used to compare to QICS and similar offshore projects, possibly volcanic analogue sites

How small a leak do we need to quantify?

- Quantification of leak
    - Only pick up fraction of leak as gas bubbles, can't easily detect dissolved phase
    - Look at sediment and look at how much is likely to be retained and how much released as gas (%)
    - Can pick bubbles up easily by sonar
    - Sediment baseline
    - How small would we measure?
    - Could use a % of the amount stored to set the threshold

Targeted workshop

- If the collaborations suggested are successful we propose a targeted workshop in approx. 2-years-time to facilitate knowledge exchange.

Breakout group 3B

Chairman: Andy Chadwick

Rapporteur: Sue Horvorka

Workshop participants assigned to breakout group 3B: Jo Booth; Andreas Busch; Benjamin Court; James Craig; Tony Espie; Den Gammer; Jun Kita; Sanghoon Lee; Theo Mitchell; Ciara O'Connor.

Goals

- Monitoring cheaply real time
- Impacts of release
- Remediation
- Attenuation during transport- how much of a leak would arrive at surface?
- Allegations/unknown un-attributed changes
- Long term post closure
- Intermediate zone – cap rocks and secondary reservoirs between reservoir and surface

Monitoring cheaply real time

- What could be done at experimental sites?
    - ETI AUV in development
    - Water sampling
    - Bubbles
    - Ecosystem
    - Need for telemetry
- Which sites have right facilities?
    - QICS (borehole, shallow water, public acceptance)
    - Tomakomai
    - STEMM-CCS (deeper water, injection tube)
- When could research be done?
    - 0-5 years
- By whom?

Impacts of release

- What could be done at experimental sites?
    - Ecosystem response to injection related things
    - Analogues (?)
- Which sites have right facilities?
    - QICS
    - STEMM-CCS
- When could research be done?
    - Waiting for calls, Korea Japan China?
- By Whom?

Remediation

- What could be done at experimental sites?
    - Most needed remediation will be done in well at depth
    - Which sites have right facilities
    - Few
    - Mont Terri (CCP) mitigation of damage
- When could research be done?

- By whom?

Attenuation during transport- how much of a leak would arrive at surface?

- What could be done at experimental sites?
    - Mass balance – injected (to simulate leakage from depth) vs escape to water column
        - Could use onshore sites as process is similar
- Which sites have right facilities?
    - QICS
    - Onshore- Atmosphere: CMC, Otway, GERC
    - ZERT, Ginninderra too shallow?
- When could research be done?
    - Next Horizon 2020 call; current NERC
- By whom?
    - Site owners
    - Researchers

Allegations/unknown un-attributed changes

- What could be done at experimental sites?
    - Distinguish between ambient variability from changes created by leakage or other unwanted side effects of injection O_2/CO_2/N_2 ratios
- Which sites have right facilities?
    - QICS
    - Onshore- Atmosphere: CMC, Otway, GERC
    - ZERT, Ginninderra, too shallow?
    - North Sea reference sites STEMM CCS
- When could research be done
- By whom?

Long term post closure

- What could be done at experimental sites?
    - Post closure monitoring – do it?
- Which sites have right facilities?
    - Nagaoka
    - Ketzin
    - Old EOR fields
    - Natural analogues hydrocarbon and CO_2 fields
- When could research be done?
- By whom?

Intermediate zone – cap rocks and secondary reservoirs between reservoir and surface

- What could be done at experimental sites?
    - Measurement and modelling
    - Stimulation of faults via pressure
    - Geochemical methods including tracers
- Which sites have right facilities?
    - Rad waste sites fault and fracture network leakage (e.g. Mont Terri)
    - Petroleum system as analogues
- When could research be done?
- By whom?