WHAT HAVE WE LEARNED FROM CCS DEMONSTRATIONS?

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Executive Summary

The IEA Greenhouse Gas R&D Programme (IEA GHG) has undertaken an assessment of the learning that is being provided by operational, large-scale, pilot, demonstration and commercial CCS projects around the world. This was undertaken by questionnaire and analysis of the responses.

From the analysis of the responses, key themes, learning points and areas for beneficial collaboration are identified. The extent of coverage of projects is summarised in terms of geological properties and monitoring techniques.

From this initial analysis, a number of key learning areas have been identified that also warrant further investigation. These include:

- Effectiveness of various monitoring techniques
- Injectivity – prediction, restoration and enhancement
- Design to avoid hydrate formation
- Performance of materials in CO_2 environments
- Scaling up capture train size
- Wells – designing, placing, and monitoring cementation

It is clear that whilst complete large scale CCS systems on power plant still to be demonstrated, there is already significant operation of closely integrated parts of CCS systems. The survey returns are also encouraging in that they show some specific areas where more information sharing is likely to be of benefit to future projects. In particular this can help in defining those areas which need further development and testing.

1. Introduction

The IEA Greenhouse Gas R&D Programme (IEA GHG) has undertaken an assessment of the learning that is being provided by operational, large-scale, pilot, demonstration and commercial CCS projects around the world. This activity was approved by IEA GHG contracting parties and sponsors at the meeting of the Executive Committee held in April 2008 in Berlin.

By compiling and assessing this information we hope to increase awareness of current projects and associated learning, to assist wider CCS development and deployment. We also hope to use the information to identify gaps within the global CCS portfolio to help direct future funding, research and ultimately further projects.

The following indicative criteria were chosen to define operational large-scale CCS projects:

- Operational by the end of 2008, and satisfying one of the following criteria:
- Capturing over 10,000 tCO_2 per year from a flue gas;
- Injecting over 10,000 tCO_2 per year with the purpose of geological storage with monitoring;
- Capturing over 100,000 tCO_2 per year from any source;
- Coal-bed storage of over 10,000 tCO_2 per year;
- Commercial CO2-EOR is excluded unless there is an associated monitoring programme.

Whilst acknowledging relevant learning gained from smaller projects and research; the purpose of this exercise was to focus only on these larger projects.

Information was collected during the second half of 2008. Twenty-six projects which meet the criteria were initially identified, contacted and sent a questionnaire designed to elicit key information. The questionnaire was in five parts, parts 1-4 requesting basic information on the project, and part 5 focusing on the key learning aspects. It was envisaged that the questionnaire would form the first phase of an iterative process to compile a global dataset on active projects; we see the updating of this information as an ongoing activity every 2-4 years, and in conjunction with other activities, leading to a global network of learning from large scale CCS projects.

2. Questionnaire Responses

Of the initial 26 projects that were thought to meet the criteria, we have received 17 completed questionnaires and in addition, information was provided by telephone interview for 3 further projects. It is noted that questionnaire responses were not received for the Sleipner and Snøhvit projects, so detailed learning information has not been obtained from them or included here. However their basic geological data, being public domain, has been included in the coverage assessment to ensure the most relevant project activities are included. In addition, we were informed that the Teapot Dome Test Centre does not meet the criteria as the start of injection was delayed into 2009.

We have however received notification and completed questionnaires from three additional projects that do meet our criteria. These projects were;

1. IFFCO Commercial CO_2 Recovery Plant (Phulpur unit) in India
2. IFFCO Commercial CO_2 Recovery Plant (Aonla Unit) in India
3. Chemical Company "A" Commercial CO_2 Recovery Plant in Japan

Therefore with three projects added and one removed, the total list of eligible projects now stands at 28 (Table 1 and Figure 1) with a total of 20 questionnaires returned and information provided verbally from 3 other projects.

Table 1: 28 Large-scale Operational Projects

Bellingham Co-Generation Facility	**IFFCO CO_2 Recovery Plant – Aonla**
CASTOR Project	**Prosint Methanol Plant**
Great Plains Synfuel Plant	**Rangely CO_2 Project**
IMC Global Soda Plant	**Schwarze Pumpe**
In Salah	**SECARB – Cranfield II**
K12-B	**Shady Point Power Plant**
Ketzin Project	**Sleipner**
MRCSP – Michigan Basin	**Snøhvit LNG Plant**
Nagaoka	**Sumitomo Chemicals Plant**
Otway Basin Project	**SRCSP – Aneth EOR-Paradox Basin**
Pembina Cardium Project	**SRCSP – San Juan Basin**
Petronas Fertiliser Plant	**Warrior Run Power Plant**
IFFCO CO_2 Recovery Plant – Phulpur	**Weyburn-Midale**
Chemical Co. "A" CO_2 Recovery Plant	**Zama EOR Project**

Figure 1: Location of Large-scale Operational Projects

The analysis was separated into two parts; the first part looked at the total portfolio to see how well they cover the spread of project types, technologies, etc needed to fully demonstrate CCS. The second part of the analysis looks at key learning from the projects to help identify gaps, overlaps and potential areas of collaboration.

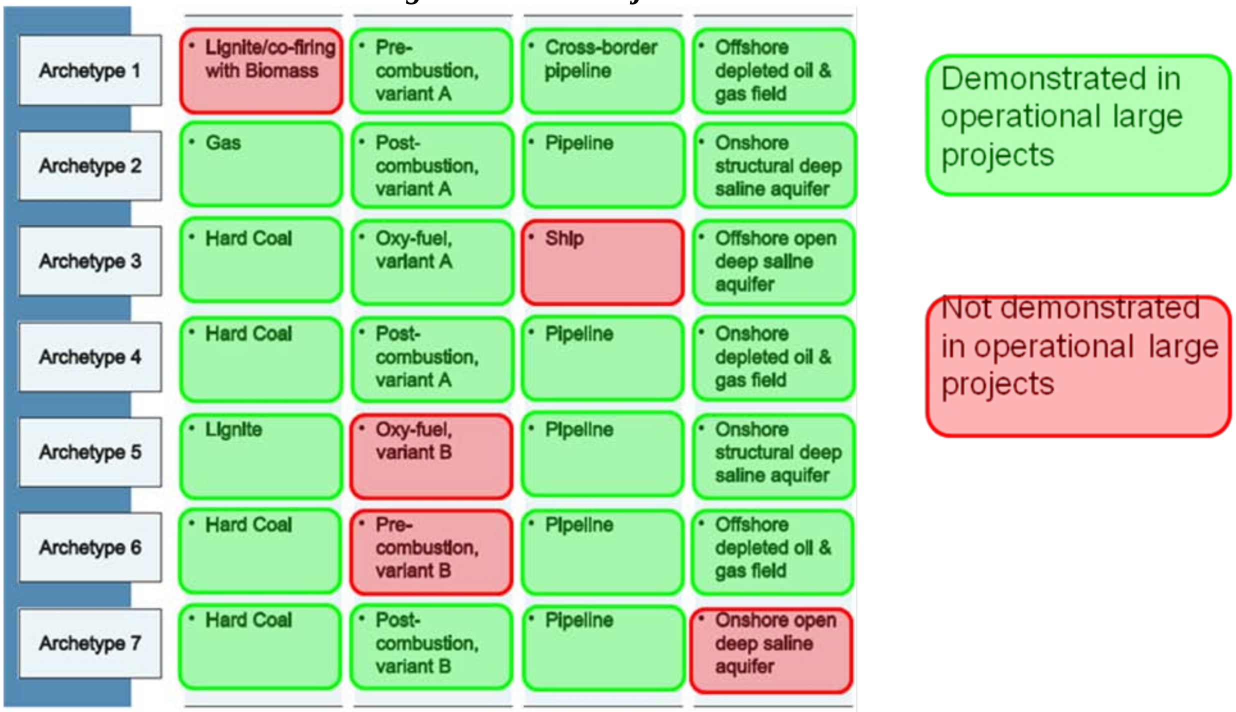
3. Extent of Coverage of the CCS Demonstrations

As the CCS industry looks to move from demonstration phase to full scale deployment, it is useful to assess which technologies have been demonstrated and which are yet to be demonstrated. There are a number of lists and matrices that attempt to identify the key technology steps that will be required. One such matrix was produced by the European Union Zero Emissions Technology Platform (EU ZEP).

The EU ZEP initiative analysed in some detail the range of CCS technologies which need to be demonstrated. As a result of this analysis, they recommended the building of 10-12 large scale projects as a practical way to cover the full range of CCS technologies and applications which need to be demonstrated, with a minimum of 7 archetypal projects which would just be sufficient to give the required coverage as shown below. The reason for 10-12 projects is to ensure all criteria can be realised in practice.

The projects covered in this study cover a significant part of this matrix (Figure 2) although not always at the scale which is ultimately required.

Figure 2: ZEP Project Matrix



Questionnaire responses indicate that there are only a small number of capture processes from flue gas and these are predominantly from natural gas combustion. Detailed information for coal and lignite capture demonstrations have been received from: the Schwarze Pumpe oxy-combustion project which uses lignite; the Dakota gasification plant which is also processing lignite; and the CASTOR project which involves capture from hard coal. In addition, Bellingham Cogeneration facility and Warrior Run power plant also capture CO_2 from coal combustion.

Apart from the capture project at the Dakota Gas project, there are no further pre-combustion demonstrations represented. Nevertheless there have been a number of demonstrations and commercial scale plants employing the key gasification step. This is perhaps an area where there is already significant technology demonstration and to which more attention should be given.

Trunk CO_2 pipeline transport information has only been provided by the Weyburn project, although several other projects use the established CO_2 trunk line system in the USA for their supply but have not provided relevant information. Ship transport is not represented by the projects.

Several projects are using onshore structural traps in deep saline aquifers but not yet open reservoirs. Interestingly the EU matrix above has no category for offshore structural deep saline aquifers perhaps, because the long experience at Sleipner is already considered adequate.

4. Learning from Storage Projects

A brief analysis of the key attributes of target storage formations was made to assess: the purpose and annual rates of injection, reservoir lithology, and ranges of depth, permeability and porosity.

The projects are a mix of CO2-EOR and dedicated CO_2 storage as shown in Figure 3; annual quantities stored vary considerably with net storage rates ranging from 10,000 up to nearly 3,000,000 tons per year (Figure 4). Just over half of the projects identified the storage formation type; there is an approximate even balance between carbonate and sandstone reservoirs (Figure 5). The target formations generally range in depth from 1000-2000 meters (Figure 6) and have permeability and porosity typically within the ranges 10-100mD and 10-25%, respectively (Figures 7 and 8). Note these are typical values provided to us by the project operator and may not fully represent the complexity of the storage formations.

Figure 3: Purpose of CO_2 Injection

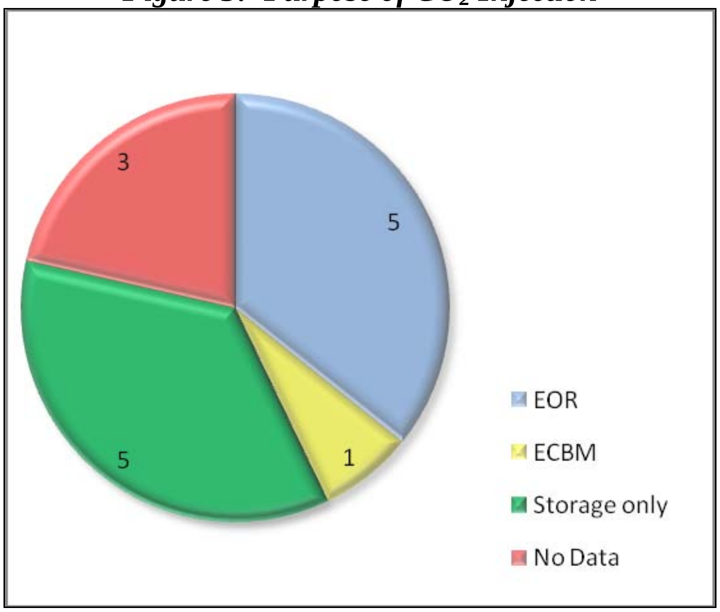


Figure 4: Net Annual Storage

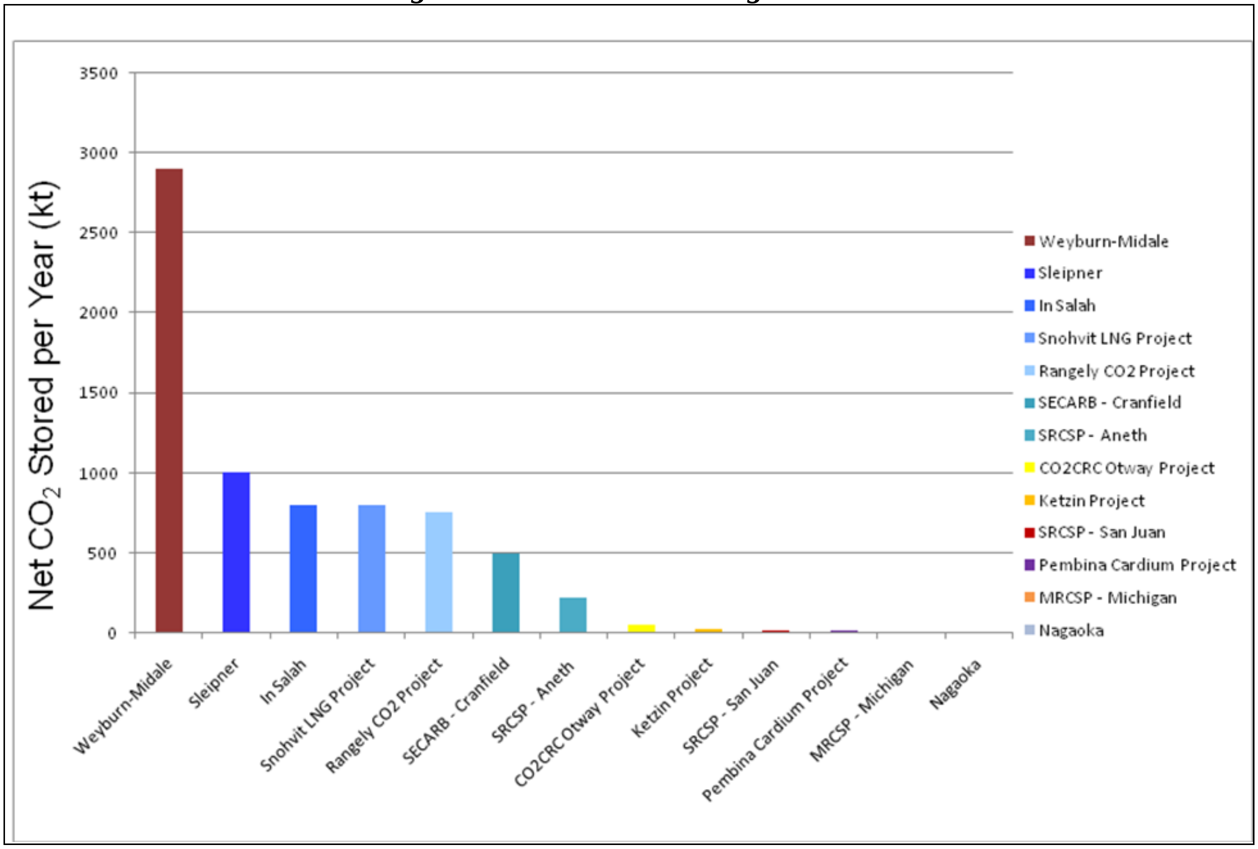


Figure 5: Storage Formation Types

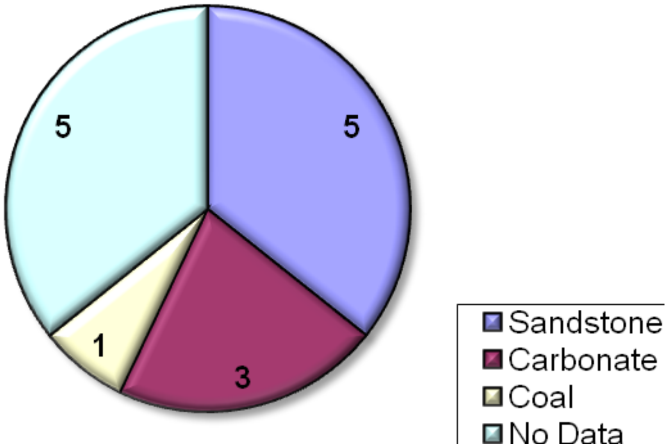


Figure 6: Depth of Storage Formations

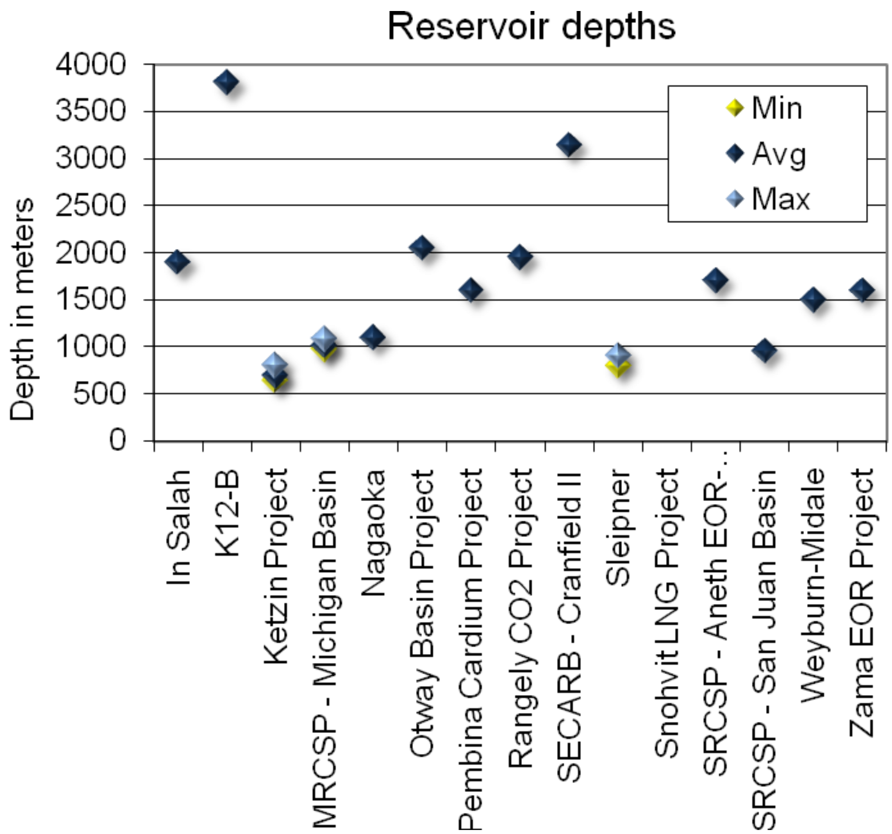


Figure 7: Permeability of Storage Formations

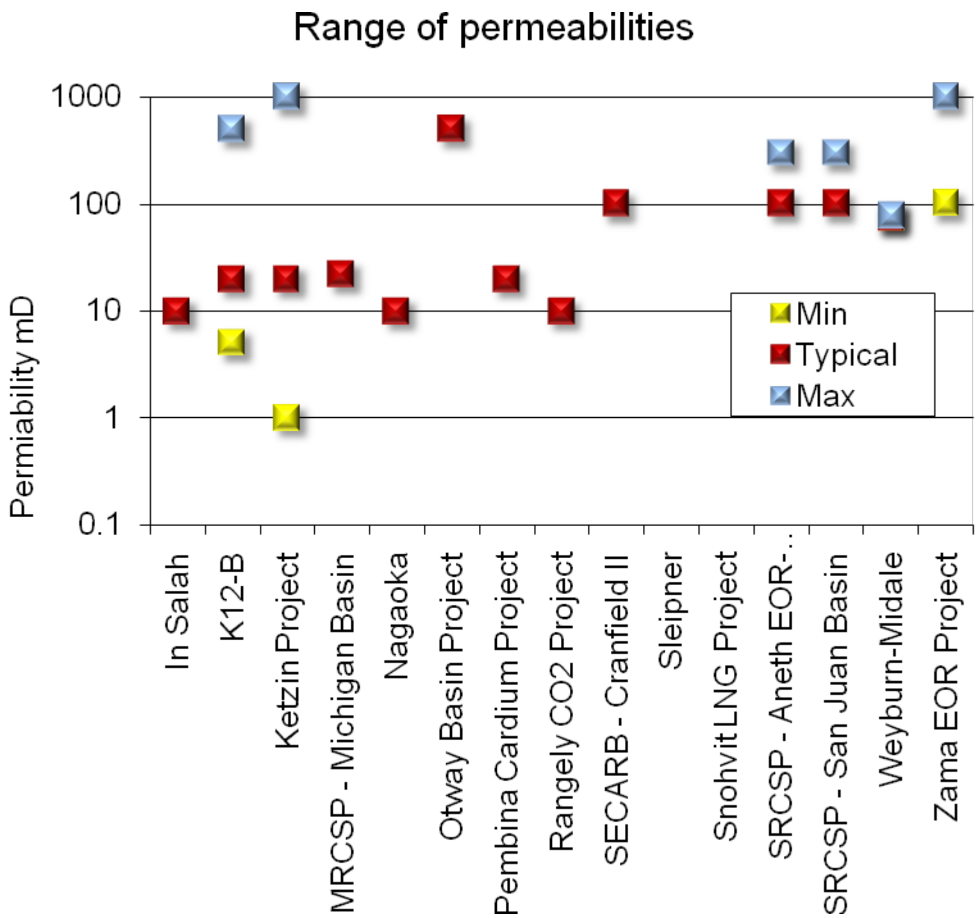
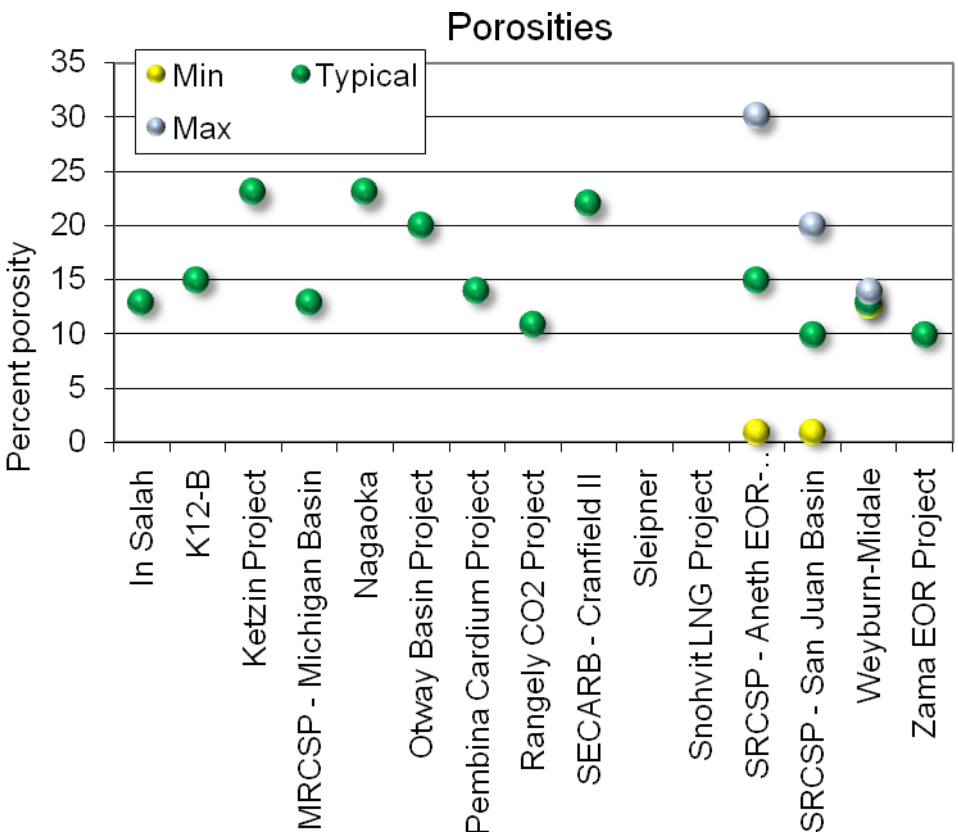


Figure 8: Porosity of Storage Formations



Monitoring Techniques

Project operators have indicated a wide range of monitoring techniques in use (Table 2). The extent of seismic surveying varies, with 3D and occasional 4D sets being common. Several projects have used vertical and/or crosswell seismic techniques, whilst a smaller number are starting to use electrical conductivity methods. Several projects have employed tracers but downhole fluid sampling is uncommon. Several projects have attempted to utilise microseismic monitoring.

Apart from the measurement of downhole pressure and temperature, which is standard practice for a majority of injection projects, surface seismic surveying was the second most widespread method and is regarded as the principal technique for imaging of storage reservoirs and CO_2 plume migration – and also represents the best technique for in-situ quantification of volumes stored. Whilst some negative comments on the applicability of surface seismic were made by 3 project operators, it is very important to stress that these were made in a site-specific context, i.e. where localized factors limited the suitability for surface seismic. Whilst 3D surface seismic is relatively expensive and not applicable to all geological scenarios, the technique will remain the mainstay of monitoring suites for many storage sites.

Table 2: Range of Monitoring Techniques Employed

Technique	Number of Projects	Positive comments	Negative comments
DH temp/pressure	10		
Surface seismic	8	2	3
Geochemical	8		
Soil gas	7		
Microseismic	6		1
VSP	4		1
Crosswell seismic	2	1	
Electrical Conductivity	2		
Satellite	2	1	
Gravity	2		1

Soil gas sampling is the most common surface monitoring technique, but eddy covariance methods have also been employed. Satellite imaging and tiltmeters to detect ground movement have also been tested, the former revealing impressive results from In-Salah.

Vertical and/or crosswell seismic techniques have also been employed, but require suitable monitoring wells. Electrical conductivity measurements are seen as promising additions to the monitoring suite although their value beyond experimental projects has yet to be demonstrated. Monitoring of layers above the target reservoir is regarded as a potentially convincing way of showing storage integrity to non-technical stakeholders. Better and more extensive sampling of downhole fluids under reservoir conditions is considered worthwhile and does not seem to be practised by many projects. Injectivity is a critical issue for all projects, a positive aspect of the survey has been a common theme that any practical problems encountered have been overcome.

Potential for more Collaboration

Selection of the best suite of monitoring techniques, and the best methods of proving storage integrity to stakeholders, are key potential areas of collaboration. The construction of a monitoring programme will always have to be a site specific process given the variation in site characteristics and the different capabilities of monitoring techniques.

Hydrate formation is mentioned in a minority of questionnaires as a practical, surface problem experienced in relation to transport and injection. This is an area that may require further examination both through research and at existing projects.

Injection performance is a common issue with a couple of examples of impairment; however respondents appeared to be reasonably confident that they can predict and manage injectivity. One issue which has been revealed is the difficulty which under-pressured reservoirs cause when perforating because there is not the normal capability to flow the well to clean it up. Injection of CO_2 into de-pressured formations can be expected to increase and collaboration and dissemination on this subject would be valuable.

Several operators mentioned successful management of materials selection/corrosion and sharing of this experience will be helpful in reducing costs.

5. Learning from Capture Projects

Capture from pressurized gas is represented several times at scales upwards of one million tons per year, with Great Plains and Rangely having capacities of 2.5 and 4.43 million tons per year respectively, a range of commercial processes is covered. Capture from flue gases is at a lesser scale. Only two main processes are in use, Fluor's "Econoamine" and Mitsubishi's KM-CDR for the most part capturing from gas fired facilities on a scale up to 100,000 tons per year. Oxy-combustion capture is represented by Schwarze Pumpe but it is too early for information from this project. Basic information on capture from pre-combustion at Dakota gasification has been returned.

It is evident that large scale capture projects are limited in number and therefore much learning is yet to occur. The only capture processes which have significant presence in the market place are two proprietary processes for flue gas. In addition there are a number of proprietary gasification processes which will form the heart of any pre-combustion capture and this technology at present is (apart from Dakota Gasification) outside the scope of the survey. The gasification industry is served by specialized conferences and forums and is also commercially competitive, making collaboration difficult. Thought needs to be given to how best if at all to get better coverage of the demonstration of this technology.

6. Conclusions

It is evident that whilst complete large scale CCS systems as envisaged by the EU ZEP matrix have still to be demonstrated, there is already significant operation of closely integrated parts of CCS systems. The expertise needed to set up and operate a large scale CCS system is in existence around the world but drawing it together for the major projects will be a challenge. The questionnaire returns are based on a very significant amount of engineering and scientific work, much of which is relatively routine to the operators concerned. The survey returns are also encouraging in that they highlight some specific areas where more information sharing is likely to be of benefit to future projects. In particular this can help in defining those areas which need further development and testing

From the initial analysis that has been performed a number of key learning points have been identified that warrant further examination. These are points that will be kept in consideration during further analysis and could be explored further through additional questionnaires or correspondence with the project operators. These include:

- Effectiveness of various monitoring techniques
- Injectivity – prediction, restoration and enhancement
- Design to avoid hydrate formation
- Performance of materials in CO_2 environments
- Scaling up capture train size
- Wells – designing, placing, and monitoring cementation

As the CCS industry develops there will be an increasing trend towards deployment of proprietary technologies in increasingly commercial projects. This will make collection and dissemination of information more difficult for organizations such as IEA GHG. On the other hand developers and vendors of CCS technologies will gain by publicizing their products. One way in which this might be done would be to encourage some form of independent sharing/learning/benchmarking process.

7. Recommendations

There are a number of potential next steps to progress further with the analysis of what we have learnt from demonstration projects. Certain topics can be investigated in more detail, and means of sharing the learning will be explored.

As the analysis progresses it is expected that further gaps, overlaps and areas for collaboration will emerge. IEA GHG will continue correspondence with project operators to investigate and share results, which will also be used to update the IEA GHG R,D&D Project database. This study process is intended to be repeated every 2 years to track the learning and knowledge development from CCS demonstration projects as we progress towards full scale commercial deployment. Future activity here by IEA GHG is expected to be in collaboration with the Global Institute for Carbon Capture and Storage (GCCSI).