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What Have We Learnt from Operational CCS Demonstrations – *Phase 1b*

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Executive Summary

In 2009, the IEA Greenhouse Gas R&D Programme (IEAGHG) carried out an assessment of learning that is being provided by operational, large-scale, pilot, demonstration and commercial CCS projects around the world. This was undertaken by questionnaires and analysis of the responses and a report was published, presenting the results. Phase 1b was intended to be an addendum to the original report, gaining further information from projects on more specific topics within the subjects of well injectivity, regulation and public communication. In Phase 1b, twelve projects responded out of the twenty nine that were contacted. IEAGHG received 7 responses on well injectivity, 10 on regulation and 8 on public communication.

The well injectivity document asked for information on topics including injection conditions, predicting injectivity, injectivity in practice and improving injectivity. The projects were also questioned on features of injectivity, such as reservoir parameters and operating parameters. The projects questioned covered a wide range of injection depths, reservoir thicknesses and brine salinities. Many of the projects reported that it is difficult to predict injectivity solely on the basis of reservoir models and properties – therefore injection tests are invaluable for calibration. There was some evidence that injecting CO_2 could enhance injectivity over time. Collectively the projects had tried a range of techniques to improve or maintain inflows.

The results from the regulation questionnaire showed that many projects had no specific aspects of interaction with regulations or regulators that caused them concern during the project. There were, however some minor issues at a couple of the projects with permitting and applying for certificates, but these were easily overcome and interaction with regulations was generally positive. Most of the projects found that regulations and standards were adequate for the pilots and regulators were often flexible. There were no gaps identified in the regulatory framework, but a couple of projects found that there were several overlaps between different jurisdictions, which may lead to new legislations being more self-contained.

Regarding public communication, the projects were questioned on the general approach taken, methods employed, any novel communication methods that may have been used, lessons learned and any suggestions for public communication strategies for future projects. Many projects emphasised the effectiveness of an informal approach and the importance of listening to concerns of various stakeholders. Careful planning of public outreach strategies was considered essential by all of the successful projects. A key lesson discovered in Phase 1b of the What Have We Learnt study is that objections to a CCS project are unlikely if there are identifiable local benefits.

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1. Introduction

An assessment of the learning that is being provided by operational, large-scale CCS (carbon dioxide capture and storage) projects around the world was undertaken by the IEA Greenhouse Gas R&D Programme (IEAGHG, 2009). This second consultation round (phase 1b) intends to add additional information to the original report on:

- Well injectivity
- Regulation and permitting
- Public communication.

By compiling and assessing this information we hope to continue to increase awareness of current projects and associated learning, along with assisting 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.

We contacted the 29 projects that were recognised in the initial phase (1a) of the What Have We Learnt study, of which 12 projects (see table 1) came back with responses. The following indicative criteria were chosen in the original study 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.

As mentioned above, the three topics chosen for further investigation were Well Injectivity, Regulation, and Public Communication. Questionnaires were drawn up by IEAGHG and additional expert advice was sought on the questions – on the well injectivity section in particular. The questionnaires were then sent to applicable projects (for example some received all three sections/questionnaires; others just received one or two where appropriate). The majority of the responses referred to in table 1 responded by completing and returning the questionnaires, while others were telephoned where possible.

Capture Projects	Storage Projects
Chemical Co. 'A' CO2 Recovery Plant	CO2SINK (Ketzin Project)
IFFCO CO_2 Recovery Plant – Aonla	Nagaoka
IFFCO CO_2 Recovery Plant – Phulpur	Otway Basin Project
Petronas Fertiliser Plant	Pembina Cardium Project
	Schwarze Pumpe
	SECARB – Tuscaloosa Cranfield II
	MRCSP Phase II
	Zama EOR Project

Table 1 – Projects which responded in Phase 1b of the 'What Have We Learnt' study

2. Well injectivity

Additional information about well injectivity was obtained from a total of 7 injection projects.

Injection conditions
The projects cover a wide range of injection depths and reservoir thicknesses as shown in Figure 1. Injection pressures, as expected, vary with depth and are very much in line with the hydrostatic gradient. (Figure 2). Where reported (3 returns) the fracture pressure gradient was similar at 16.8 – 20.1 kPa/m and all projects reported a substantial margin of fracture pressures over initial downhole injection pressures ranging from 65-90%. The projects covered a wide range of brine salinities as shown in Figure 3, an important concept when it comes to injection, due to the effects that the viscosity contrast between brine and CO_2 has on mobility.

Predicting injectivity
Five of the projects included an injection test in their development programme and two relied on previous experience with the formation. The injection tests were generally preceded by estimations of injectivity derived from core flood tests and well logs. Several projects reported that it is difficult to predict injectivity solely on the basis of reservoir models and properties and as such injection tests are invaluable for calibration.

Injectivity in practice
Three of the projects experienced somewhat higher injection rates than predicted – one project expected an average of 38 tonnes per day for vertical injection wells and achieved an average of over 100 tonnes per day and a second project predicted 20 ton/day and experienced 40 ton/day. For some, injectivity was not a limitation because the formation had a very high permeability. One mentioned a problem well which even after acid treatment had difficulty maintaining planned rates. Another had problems of well blockage caused by sulphate reducing bacteria (SRB) but was able to back flush this and restore sufficient injectivity.

There was some evidence that injecting CO_2 might tend to enhance injectivity over time but this is difficult to distinguish from other effects particularly changes in reservoir pressure which influence inflow rates.

The average injection rates achieved by the various projects as well as the reported normal minimum and maximum rates are shown in Figure 4.

Actions to improve injectivity
Despite the generally favourable injectivity found in practice compared to design predictions, operators had collectively tried a range of techniques to improve or maintain inflows. These have included acid injection (employed by two projects in Japan and Canada), re-perforation, horizontal drilling (which was employed successfully at the Pembina Cardium site, increasing well productivity) as well as pre-injection fracking and pre-injection back flushing (both employed at projects in Canada).

Conclusions

CO_2 injection has now been demonstrated successfully in a wide range of settings. The methods used to predict and enhance injectivity are based on commonly used industry techniques and are reliable.

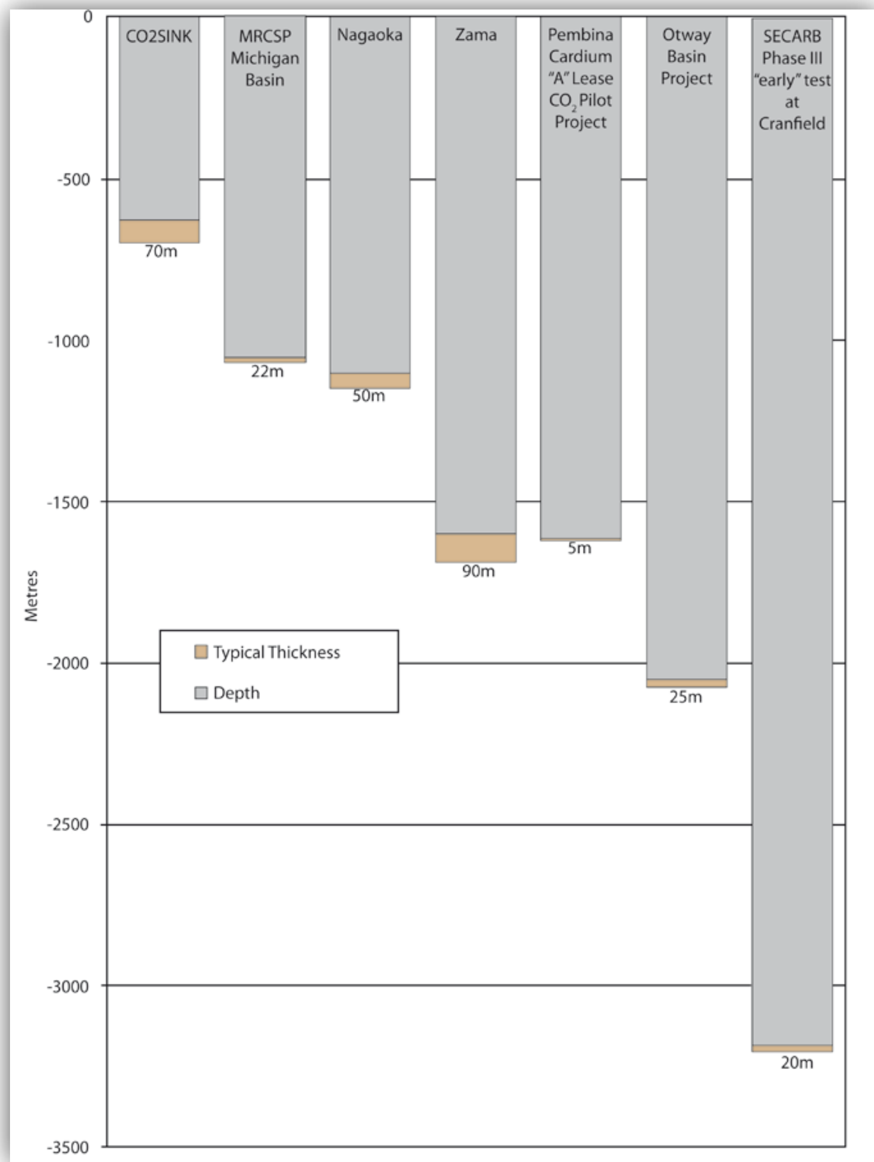

Figure 1 – Depth and thickness of the CO_2 storage reservoirs

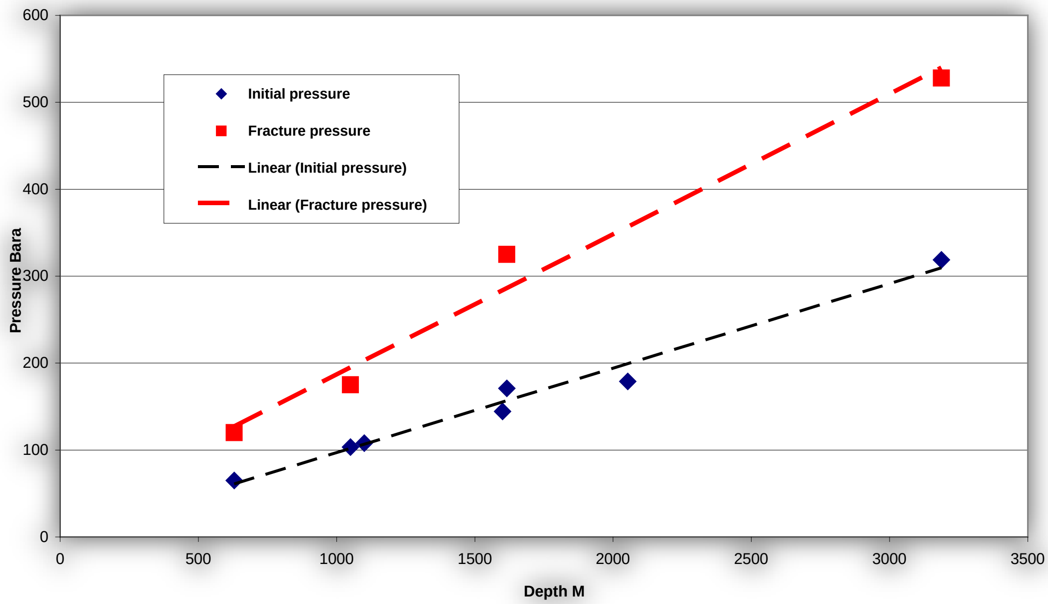

Figure 2 – Pressure-depth relationships

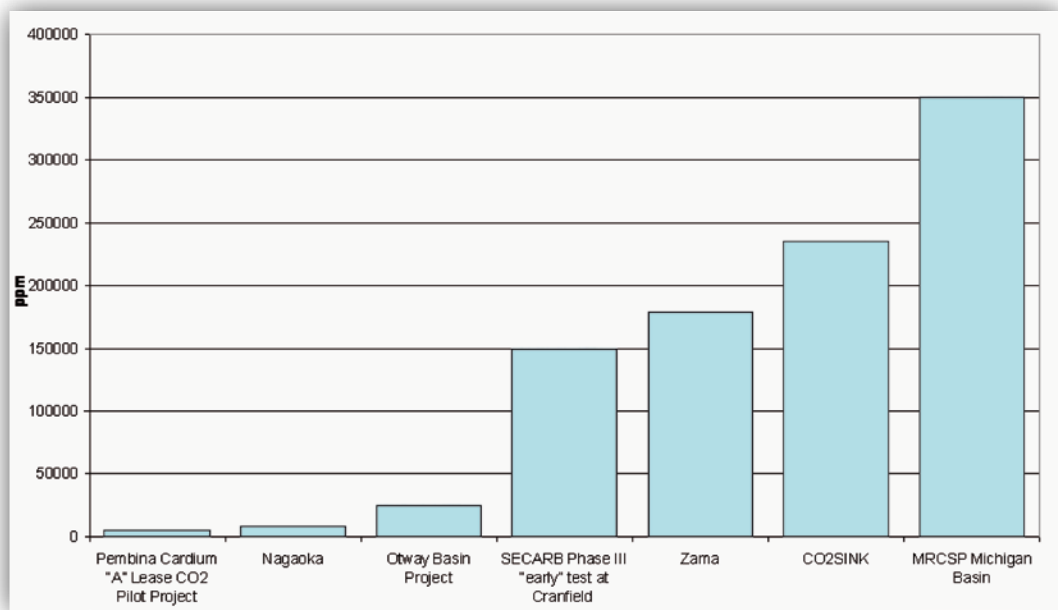

Figure 3 – Formation water salinity

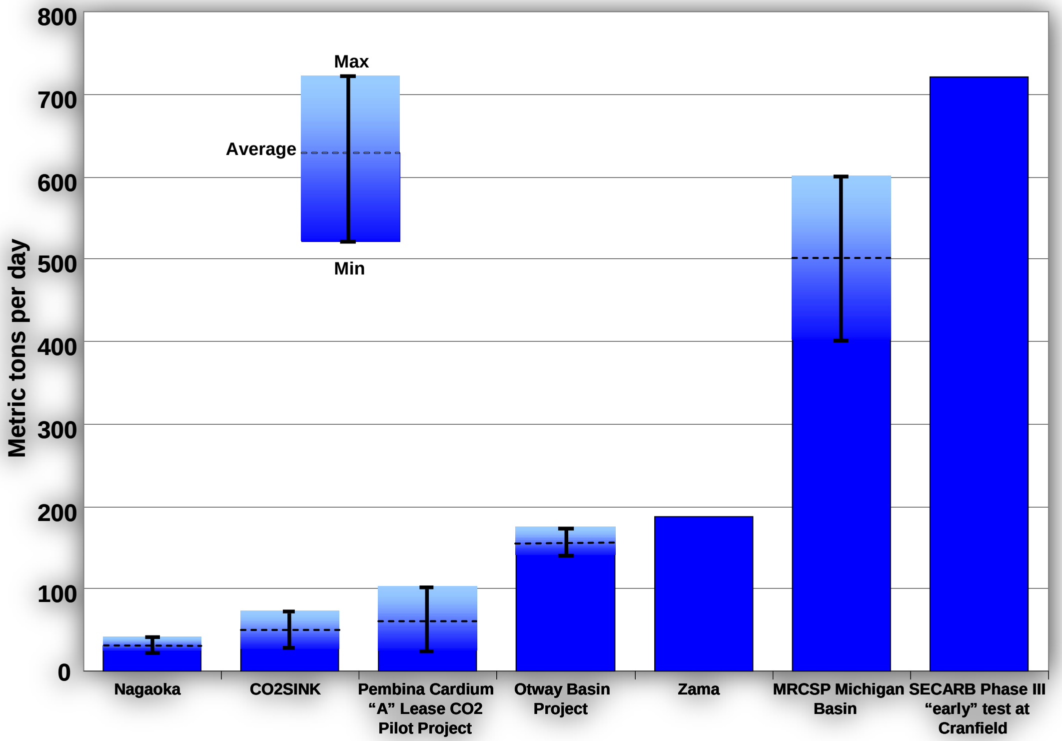

Figure 4- Injection rates

3. Regulation

Information from ten CO_2 injection projects on regulation was received in phase 1b of the What Have We Learnt Study. The information gained demonstrated the differing aspects of regulatory issues in each individual project.

Interaction with regulations and regulators

Many of the projects had no specific aspects of interaction with the regulations or regulators that caused them concern during the project. There were some issues with the Mining Safety Laws and Regulations when projects were located in an active hydrocarbon field. Some difficulty was encountered at one project when trying to apply for various authorisation certificates. Some issues arose on how to permit the observation wells for a particular project – these issues were overcome by permitting them as producer wells. Interaction with regulations was generally positive, although there was some difficulty with projects in areas where there were no regulations for CCS in place (and it was not allowed under the existing regulations – so a site-specific regime was created).

Many projects found that regulations and standards in conjunction with pro-active community policies have resulted in a satisfactory relationship with the community.

Areas where assurance was important but regulations were poorly placed?
Most of the projects found that the regulations and standards were adequate for the pilots and regulators were often flexible to allow a dynamic monitoring regime. Issues occasionally arose with the regulations that were in place when looking into potential failures of the CO_2 pipeline and with caprock integrity (for example the Nagaoka project (Japan) found issues with regulations dealing with CO_2 leakage, seepage to groundwater etc.).

Some projects found it challenging where governments had not yet ratified various guidelines or directives on implementing CCS legislation. It has caused some concern and created risks in some work at the Schwarze Pumpe site in Germany (although not direct problems), as the project then does not know all the demands on them (for example when it comes to what information is needed, etc.).

Gaps in the regulatory framework
Most projects had no specific issues when it came to possible gaps in the framework. A couple of projects found that there were several overlaps between different jurisdictions which sometimes proved problematic – but they are hopeful that the new legislation will be more self contained.

Underground CO_2 inventory
In terms of learning from the management of the underground CO_2 inventory (in the context of emissions accounting), one project measured the tonnage of CO_2 injected along with all emitted out of the reservoir (including all flare) but has not tried to test the accuracy by applying for credits. Most of the projects have not attempted to register any CO_2 credits at this stage. A key learning was the better understanding of the range of characterisation activities and supporting MVA (Monitoring, Verification and Accounting) documentation that may be required in the presence of a carbon credit market – knowledge that will be applied to ongoing efforts to inject large tonnage of CO_2 into the subsurface in an effort to mitigate the current practice of venting to the atmosphere.

One project in particular gained valuable experience in making subsurface measurements, in precision and estimates of uncertainty. It is difficult to predict mixing in a reservoir where natural gas is already contained – the density decrease affects the flow pattern. The temperature changes are presumably due to equilibration with the rock and/or in situ fluids, but perhaps also related to the heat content of the introduced CO_2 – also affecting flow patterns. Above-zone pressure monitoring was used to document the inventory – where the monitoring is carried out in the zone above the storage formation, which can indicate any anomalies (i.e. leakages) from below. It is important that the injection reservoir is completely isolated from the intervals above where pressure is being monitored.

Conclusions
For the most part, there was little concern caused when it came to interaction with regulations and regulators – the minority did come up against some issues in certain situations. It was found that regulations and standards, coupled with proactive community policies led to a positive relationship with the community. Most projects found that regulations and standards were adequate, with regulators displaying flexibility in most cases. We found that all projects which responded to the regulation questionnaire have not yet attempted to register CO_2 credits.

We have seen that the first demonstration projects are too small to come across many significant issues in terms of regulations – and any problems have been relatively easy to address. At best, some authorities have been alerted to the fact that at full scale there may be some potential issues.

4. Public communication

Additional information about public outreach and information dissemination was received from 8 CO_2 injection projects – all of which have been successful. All projects had recognised that public acceptance was important and had deployed considerable efforts in this direction. The lessons learned are perhaps rather obvious but are nevertheless worth describing.

General approach and setting

Several projects emphasised the effectiveness of an informal approach, whereby staff directly engaged at the grass roots level in the development are given an opportunity to discuss the project and their part in it with local residents and other local stakeholders. A key subject seems to be the establishment of situations where conversations can be held as equals. In one project much of the dialogue was left to "landmen" working on the ground to establish and sign up residents to mineral right and land access leases. Many of the landmen were in fact local residents and presumably such negotiations help to establish a dialogue between parties on an equal footing. Others had smallish gatherings to impart information or mark key milestones in the project at which there were good opportunities for staff involved with the project to mingle and explain the technology.

Several projects mentioned that underground operations formed a part of the local economy so that local residents to some extent already understood and were interested in the type of underground operations being proposed.

Communication methods employed

Most projects had at some stages encouraged visitors to the site of operations. Most had organised meetings generally of an informal kind to which local residents and interested parties were invited. Turnout does not seem to have been large, typically a few tens of persons might come. All projects set up websites with information. The information provided was both about CCS in general and also the project plans in particular. Different projects placed different amounts of emphasis on the two aspects but most at some stage appear to have concentrated on the project plans.

One project emphasised the importance of listening to the concerns of the various stakeholders. No mention was made of the extent to which concerns were acted upon, only that there appeared to be no particular adverse reactions to carrying out the projects. The only major concerns raised were related to the correct use of government funding and out of region expertise rather than impacts of the project.

Novel communication methods

The projects were asked about any particularly effective ways of communicating about CCS. One project described a hands-on display involving porous and non- porous rock samples. Simply using a water spray, visitors could observe the difference in sample properties. A more sophisticated display involved submerged core samples with a hole drilled in connected by tubing to a bicycle pump. Visitors could experience firsthand how effective non-porous rocks were as only porous rocks allowed air to bubble through. Another project had constructed a device to show, in a high pressure steel chamber with a sight glass on either side, how CO_2 transitions from the gas/liquid phase to the dense phase and back.

Lessons learned
As expected, careful planning of public outreach was considered essential by all of the successful projects. Creating conditions for informal discussions between interested stakeholders and those working on the project at an early stage should be a key aim. Why such an informal approach seems to be effective is not revealed but may be due to the fact that this creates a good setting for listening to any concerns.
The existence of identifiable benefits of some sort, either direct in the form of royalties or indirect through enhanced employment opportunities seems to have been present at most of the sites. Some of the individual responses would suggest that a perception of some sort of benefit is important and that risks are not considered to be a significant reason for objection. Many of the sites have a history of successful and safe underground operations and it is possible that this underlies this apparent lack of concern.

The key lesson is thus that objections to a CCS project are unlikely if there are identifiable local benefits. For sites where there is no previous history or experience with underground operations, safety and risk may be seen as reasons for objection and if coupled with a lack of benefits, serious objections might be expected. Future projects will have to adapt to positively address these issues.

Suggestions for future projects
Large projects will require proportionately larger efforts and organisation to interface effectively with all of the stakeholders. Projects should aim to be the first to provide information on all of the key project activities. More work needs to be done to establish clearly identifiable benefits for local communities in the vicinity of possible storage sites. This could be particularly important in jurisdictions where land rights are not vested in the local community.

5. Conclusions

This additional consultation round provided IEAGHG with further information on some of the 29 originally identified operational large-scale projects.

The depths of the storage reservoirs at these particular sites vary from 600 to 3300 metres, with the reservoir thicknesses ranging from 5 to 90 metres. Most projects experienced higher injection rates than anticipated, with the average rate ranging from approximately 30 to 500 metric tonnes per day. Injection pressures vary with depth and hydrostatic gradient (as expected) and all agreed that injection test were invaluable for model calibration. Injection of CO_2 has been successfully demonstrated at all projects.

Regulations and standards were found to be adequate, although many agreed that most demonstration projects are too small to come up against many significant issues with regulators. In order to maintain a good relationship with the community, regulations and standards should be coupled with practical community policies.

The careful planning of public outreach policies is crucial and the effectiveness of an informal approach with the public was emphasised. It was found that objections (from the local community) to a CCS project were unlikely if there are identifiable local benefits. Projects should aim to be the first to provide information to the community on all key project activities and establish clearly identifiable benefits to the local community early on.

6. References

IEAGHG, “What Have We Learned from CCS Demonstrations?” 2009-TR6, November 2009