2019-IP12: CSLF Pore Space Utilisation Report

In 2015, a task force was formed by the Carbon Sequestration Leadership Forum (CSLF) to 'investigate the current status of techniques that have the potential to improve how well the capacity of reservoirs for CO_2 storage are utilised'. This is a key issue as pore space in a CO_2 storage system is the all-important resource for a site operator; it is therefore crucial to utilise this pore space efficiently. Presently, the efficiency of the storage resource is quite low (representing between 1 and 4 % of the bulk volume) and to increase this would improve the economics of CCS projects.

In April 2019, a summary report of this task force's investigation was published and this Information Paper summarises that report.

Currently there are a number of large-scale CO_2 storage projects across the world; some operational, some under construction, and others in various stages of development. Together these facilities are storing nearly 40 Mt of CO_2 per year. Despite this successful storage rate, these projects storing CO_2 in saline formations do not come close to the limit of the formations technical storage capacity (according to the US Department of Energy, 'utilised storage capacity is typically about two orders of magnitude lower than the pore space resource'), nor is there any obligation to increase the rate of storage. There are technical solutions to maximise storage in some CO_2-EOR operations, but it lacks a strong economic case to do so.

There are a number of reasons as to why the pore space of a CO_2 storage system is poorly utilised. Usually, the injected CO_2 will rapidly migrate to the top of the saline formation (CO_2 reservoir) due to buoyancy and then migrate laterally; therefore the bulk of the reservoir rock's pore space is missed due to this quick rise. The large extent then of the CO_2 plume (large areal extent but thin) could increase the probability of leaks along faults in the area, legacy wells or other permeable zones in the caprock. There have been many publications looking into methodologies for the estimation of storage resource in saline aquifers, hydrocarbon reservoirs and coal seams, leading to improved global storage estimates and noting that investment-ready storage resources are small relate to the target storage rate of 2,400 Mt of CO_2 by 2035 (meaning more effort is required here). The past work has also noted that utilisation (storage efficiency) into the existing resources must be optimal.

This CSLF task force reviewed several existing technologies and areas to see how they could help better utilise pore space within the realms of the geological storage of CO_2:

- Non-technical issues related to improved pore space utilisation
- Improved sweep efficiency
- Pressure management
- Microbubble CO_2 injection
- CO_2 saturated water injection and geothermal energy production
- Swing injection

Non-technical issues

The CSLF task force report looked into non-technical issues related to improving the utilisation of pore space and based their assessment here on two IEAGHG reports; 'Comparing Different Approached to Managing CO_2 Storage Resources in Mature CCS Futures' (2014; report number 2014-01) and 'Interaction of CO_2 Storage with Subsurface Resources' (2013; report number 2013-08). They highlighted that current regulations in CCS mean that the licensing of storage sites is usually done on a first-come first-served (FCFS) basis and that storage sites will be chosen when it is the most economically advantageous. Sedimentary basins have a number of potential uses, raising the possibility of projects conflicting with other uses in the area. Increased pore fluid pressure in a reservoir may reduce storage capacity, increasing costs in adjacent sites and possibly reducing the efficient use of the resource. Therefore, it is key to have a more strategic approach to ensure optimisation of a basin include the cost, risk minimisation, access to a range of uses and the value of the resource. All these factors would need to be considered with the framework of energy policies and it's important for stakeholders (i.e. operators and regulators) to understand any potential consequences of a pressure increase over an area larger than the extent of the CO_2 plume. The report looks into three case studies related to storage capacity, regulations, conflicts, permitting and management of the pore space. The case studies cover UK regulations and the Southern North Sea, underground permitting in the Netherlands and managing the pore space in Alberta (Canada).

The report emphasised that the FCFS basis will likely be sustainable in the short- to medium-term, but there will be competition for the pore space in all regions, meaning that a strategic managed approach to a large area may be optimal. Regional storage characterisation is recommended to understand the potential consequences of multiple storage sites in one area, and a detailed techno-economic evaluation of storage clusters would be needed). It may be that rather than clusters, fewer (more geographically dispersed) storage sites would be able to meet future requirements. CO_2-EOR is a technology that could potentially ensure net CO_2 emission reductions, but there are some uncertainties and it is key that more CO_2 is permanently stored than the emissions from operation and oil production. There is uncertainty with CO_2-EOR due to the economic viability, regulatory environment and public acceptance; much legal and regulatory management would be needed.

Sweep efficiency

Improving sweep efficiency technologies has been looked at in the hydrocarbon sector for a number of years and the task force undertook a literature review of methods that have been considered from the oil and gas area to be applied to the storage of CO_2. The main improvement agents for increasing sweep efficiencies have been polymers, surfactants, foams and infill drilling. There are four methodologies to improve the sweep efficiency of the injection of $CO_{2:}$ increased CO_2 viscosity and foams; modifying the capillary factor; sequential fluid injection; and bio-clogging.

The review highlighted that mobility and conformance control for CO_2-EOR (with foams, thickeners, gels etc.) can be technically and economically achievable in some fields, suggesting that these methodologies could also be used in CO_2 storage. Although this research has been EOR-related, most of these techniques can be applied to the geological storage of CO_2.

Pressure management

An increase in the pore pressure around the wellbore occurs as a result of CO_2 injection and the displacement of native fluids in the reservoir. This condition could put the secure containment of CO_2 at risk. Pressure management technologies such as the removal of brine from a CO_2 reservoir is a mechanism to reduce the risk caused by such increases in pore pressure and can help optimise the storage efficiency of a reservoir. The Gorgon project was given as an example, where the possibility of brine extraction through four water production wells is being implemented to control pressure.

Microbubble CO_2 injection

In comparison with normal size bubbles, microbubbles are smaller, with low buoyancy and high solubility. The microbubble concept involves CO_2 injection into a reservoir with water. CO_2 is thought to enter a smaller pore space, mostly shrink and dissolve rapidly into the formation water, and along with the lower buoyancy of the bubbles, can be a method of optimising the CO_2 storage resource in open structure reservoirs, fractured rocks and tight reservoirs. This would therefore make source-sink matching and storage for small-scale emissions easier and could also be applied to CO_2-EOR to improve sweep efficiency. Studies have shown that microbubble CO_2 injection could provide a 3 to >10% higher oil recovery rate than normal CO_2 bubbles.

CO_2 saturated water injection and geothermal energy production

The task force provided a summary of another literature review for this area, looking into the CO_2-DISSOLVED concept targets small-scale emitters, combining CCS and the production of geothermal energy, using dissolved CO_2 rather than supercritical. The advantages of using this method include no pressure build-up effects, no initial displacement of brine and low leakage risk. However there is a physical limitation; the solubility of CO_2 in brine and therefore this concept is suited more for small to medium industrial emitters. The literature review noted that the applicability of this technology has been mapped to potentially comparable sites and looked briefly into examples in France, Germany and the USA. This, along with an economic feasibility study, shows that CO_2-DISSOLVED can act as a 'complementary technology to traditional CCS approaches and enlarges the potential of CCS for small or medium industrial emitters', whilst enriching the portfolio of technologies such as bio-CCS (BECCS).

Swing injection

The concept behind swing injection is 'active plume management'; actively controlling the behaviour of the CO_2 plume. There are three different technologies that can be used; compositional, temperature and pressure swing injection to manage the plume by stabilising the front of the CO_2 injection. More pore space is utilised for the storage of CO_2 and in CO_2-EOR a better sweep efficiency is achieved. The changing of the temperature, pressure or composition of the injected CO_2 means the thermodynamic equilibrium can be manipulated so to obtain the desired plume behaviour. Well design also plays a key part in maximising the capacity in the reservoir, with the task force recognising that standard vertical injection wells cannot guarantee the injectivity or pore space capacity. A horizontal well design was shown to be a better option to enhance injectivity, avoid early pressure build up and utilising more pore space.

Analysis of techniques

The task force summarised the report by ranking the effectiveness of the techniques looked at in terms of their Technology Readiness Level (TRL) (see tables 1 and 2, below).

Microbubble CO_2 injection has a very high potential for better pore space utilisation, as does swing injection and increasing the pressure of the CO_2 injection. Active pressure management has been tested at commercial scale in hydrocarbon operations, but not yet with CO_2 storage. It will be important to look into this with projects such as the Gorgon storage operation and gain learning for future CO_2-specific operations.

CO_2 saturated water injection and the production of geothermal energy would help enable the ramp-up of CCS due to its 'complementary technology nature', but it is more of a niche technology and is site-specific, requiring further research.

Table 3: Technology Readiness Levels (TRLs) in the Project Lifecycle", Ministry of Defence website www.aof.

Technology Readiness Level	Description
TRL 1	Basic principles observed and reported.
TRL 2	Technology concept and/or application formulated.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Technology basic validation in a laboratory environment
TRL 5	Technology basic validation in a relevant environment
TRL 6	Technology model or prototype demonstration in a relevant environment
TRL 7	Technology prototype demonstration in an operational environment
TRL 8	Actual Technology completed and qualified through test and demonstration
TRL 9	Actual Technology qualified through successful mission operations

Figure 1, table from the report showing TRLs as mentioned in the above summary.

Table 4: Comparison table of pore space utilisation technologies. Technologies are ranked in order of priority (column 'P') for continued technology maturation. Green indicates high perspectivity for the technology, light green less urgency, while orange indicates lower technology prospectively broadly, yet strong niche opportunity.

P	Technology Type	Prior R&D and application	Technology Readiness Level (TRL)[#]	Technology Prospectively	Core Recommended Action
1	Microbubble CO_2 Injection	Laboratory and Modelled, prototype	TRL 4	High potential	Trial at in field research facility
2	Swing Injection	Laboratory and Modelled	TRL 3	High potential	Validate technology at lab scale
3	Increased Injection Pressure	Laboratory and Modelled	TRL 3	High potential	Validate technology at lab scale to assess sweep effectiveness in heterogeneous reservoirs
4	Active Pressure Relief (increase sweep & reduce lateral spread)	EOR, planned for Gorgon CO_2 injection project	TRL 6	High potential	Pressure relief - Key lessons drawn from active commercial project using pressure relief wells as a risk mitigation technique
5	Foams (block high permeability pathways)	EOR	TRL 6	Reasonably well understood	Modelling of application effectiveness prior to Demonstration at commercial scale
6	Passive Pressure Relief	Modelled	TRL 4	Limited effectiveness	Trial at field research facility. Consideration around long-term fluid management
7	Polymers (increase formation water viscosity)	EOR	TRL 7	Reasonably well understood	Cost effectiveness investigations. Demonstration at commercial scale*
8	Surfactants (reduce residual saturation of formation water)	EOR	TRL 7	Reasonably well understood	
9	CO_2 saturated water injection & geothermal energy	Laboratory and Modelled	TRL 3	Site specific & lower volume	Seek opportunity to trial PI-CO_2 technology at lab scale

* minor modelling and laboratory investigations may be required prior to commercial scale application
[#] See technology readiness chart

Figure 2, table showing the raking of the effectiveness of technologies, as mentioned in the above summary.

IEAGHG's Tim Dixon and James Craig were members of the task force and contributors throughout.

The full report from the Task Force on Improved Pore Space Utilisation can be found at: https://www.cslforum.org/cslf/sites/default/files/documents/Task-Force-on-Improved-Pore-Space-Utilisation_Final-Report.pdf

The CSLF website can be found at: https://www.cslforum.org/cslf/

Samantha Neades
26th September 2019