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Technical and Commercial Progress Towards Viable CO2 Storage

The report from The Catalyst Group Resources considers the technical and commercial feasibility of CCS from three critical perspectives - regulatory, transportation and storage - and provides a timely synopsis of the major enabling factors that need to be progressed for CCS to move forward.

The challenge

To meet the goals of the Paris Agreement, CCS storage projects will need to scale at an unprecedented rate. The current developmental pace for policy, legal and regulatory drivers of CCS storage is inconsistent with this need, however there are enablers that can significantly advance knowledge and scale CCS.

If the global community continues to develop and adopt international, national, and sub-national policies to mitigate global climate change, CCS will likely play a critical role. To enable this role, substantial and rapid development in CO2 pipelines will also be needed.

A scenario was put forward by J.P. Morgan to transport and store 5 gigatons (Gt) of CO2 equivalent to 15% of the current 33 Gt of CO2 emitted annually and around a third of the necessary 13-14 Gt reduction required in IPCC models. Such a reduction results in a requirement whereby the CCS infrastructure would be larger than the global oil ecosystem developed over the best part of a century.

Achieving this level of CO2 reduction through CCS is not an impossible goal, but it is a daunting one. A concerted global effort is needed to develop the technology, infrastructure, and enabling policy, legal and regulatory regimes for CCS to scale in the coming decades.

Outlook for CO2 storage to be commercially viable

The main challenges to be overcome comprise:

- Reduction of uncertainties, e.g. related to storage capacity estimates and costs
- Gaining political and societal support
- Introduction of efficient carbon taxing
- Adoption of commercial-scale full-chain CCS projects
- Introduction of comprehensive regulation
- Public perception and outreach

Reducing uncertainties that are mainly related to the geological heterogeneity of the deep subsurface are key to reducing the overall costs. Sound economical project planning with reduced uncertainties will make CO2 storage projects become an attractive business model.

This can be promoted by broad political support of CO2 storage technology. For example, when an efficient carbon taxing > 40US$/tCO2 emitted can be introduced, it is very likely that substantial investments into CO2 storage become justifiable as potential long-term revenues will be provided.

These substantial investments are necessary to promote the implementation of commercial-scale full-chain CCS projects. Only at this complex project level can CCS technology contribute significantly to solving the carbon problem. Commercial-scale CO2 storage projects also necessitate regional approaches, e.g. for estimating storage capacities and monitoring. This in turn calls for the introduction of comprehensive regulation and CCS-specific laws. These would have to address the management of environmental risks as well as regulate the long-term requirements for monitoring, stewardship and liability.

Last but not least, in order to make commercial-scale CO2 storage projects viable, unbiased information has to be provided to the public. Local stakeholders and communities have to be included in the engagement process, this also includes clear communication of the risks and benefits of CO2 storage. Without public support, further implementation of CO2 storage technology at the commercial scale will not be viable.

Regulatory drivers for storage

Supporting tax incentives, such as the U.S. 45Q program, can substantially impact the commercial viability of both CCS-EOR projects and pure geologic storage projects, however there is still ample room for policy innovation. Tax-exempt bonds, master limited partnerships, expanded CO2 storage tax credits are all options that could, if enacted, work to address the economic and financial challenges currently facing CCS storage projects.

While most recent efforts to develop and adopt policies to govern and incentivize CCS storage have only been modest adjustments to the extant legal systems and incremental developments in terms of new policies, the 2018 U.S. expansion of CCS tax credits (45Q) is a notable and important exception to this trend. In 2019, California also authorized tax credits for that can be applied to CCS projects. Importantly, these credits can be stacked with the 45Q credits, thereby substantially improving the financial profile of potential CCS projects.

Important developments are also underway as the EU ETS concludes Phase 3 (2013-2020) and moves toward Phase 4. Running through 2030, Phase 4 will increase the Linear Reduction Factor (LRF) to 2.2 percent and double the intake rate for the Market Stability Reserve (MSR) for the first five years (2019-2023) of operation from 12 percent to 24 percent if the threshold of 833 million allowances is exceeded.

However, the current pace of CCS development is modest and largely limited to projects that leverage EOR opportunities and is not sufficient to meet Paris Agreement targets. Absent is an expansion of economy-wide CO2 reduction targets, an increase in the adoption of CCS-specific legal and regulatory regimes that address the full life cycle of CCS projects, and the introduction of tax and other financial incentives. Overall CCS development will likely continue to move forward at an incremental pace.

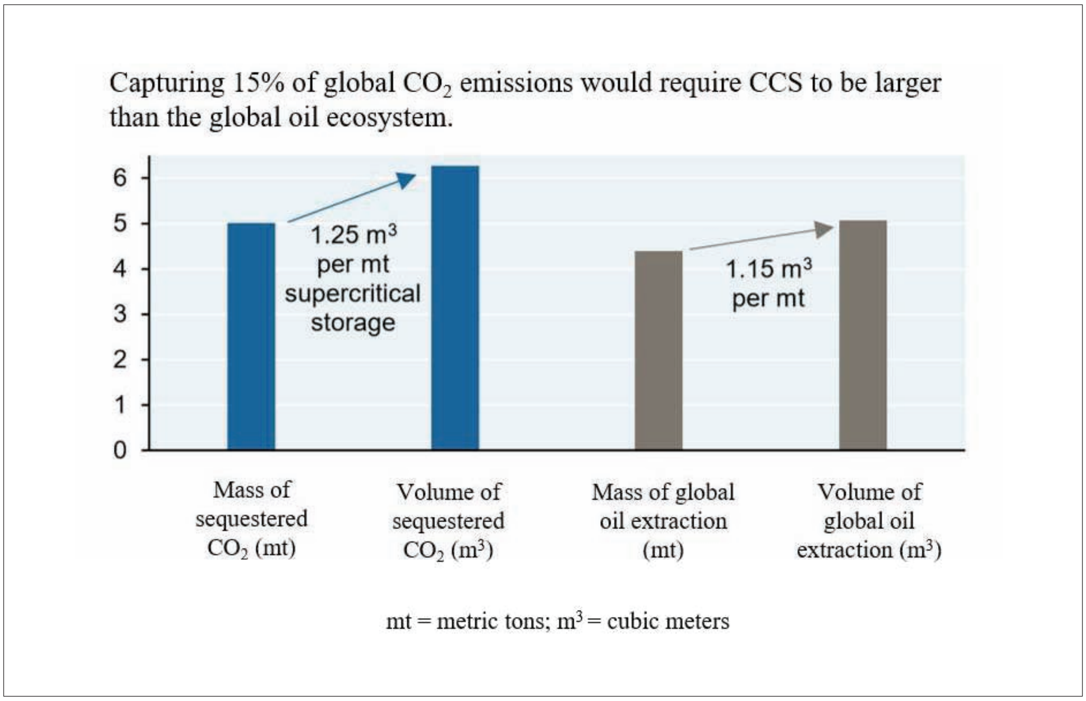

Figure 1 - Comparison of CCS Volume for 15% Global CO2 Emission to Oil Ecosystem (adapted from Cembalest, 2019)

Regulatory drivers for transport

Substantial and rapid development in CO2 pipelines will be needed to enable CO2 storage requirements. As CCS operations are deployed at greater operational and geographic scales, the current lack of policies to govern transborder transport of CO2 will become an increasing impediment to CCS development. Regional planning and coordination bodies both between and within countries will need to evolve to facilitate CO2 pipeline siting, regulation and oversight.

While jurisdictions with substantial CO2-EOR operations such as the U.S. and Canada have developed robust legislative frameworks and regulations to govern CO2 pipelines, outside of these jurisdictions there is a distinct lack of policies to govern the permitting and operation of CO2 transport systems.

CO2 pipeline projects require substantial capital investments and this factor presents a significant economic barrier to the development of CO2 pipeline networks particularly in an era of historically low oil prices. Tax policies such as 45Q that provide economic incentives for CCS projects are needed to improve project economics.

CO2 transport options

At present there is a combined total of over 8,000 km of CO2 pipelines around the world, predominantly in the U.S. Over 100,000 km of pipeline would be required to transport the 5 Gt scenario described above, this means that only 6.5% of the pipeline requirements have been realized. A more aggressive goal of 10 Gt would need 200,000 km by 2050 if the carbon neutral goals of the Paris Agreement are to be taken seriously.

The initial cost of pipeline is off-putting with the cost currently estimated at around US$10/ ton of CO2 per 100 km; the need for a booster station is required to transport CO2 in a supercritical state and this adds 16% to the unit cost of transport. Considering that a large project could be transporting CO2 over 1,000 km, the cost is currently far in excess of any carbon price. Reducing the cost to US$1-2/ ton CO2 per 100 km would likely be a more realistic level for project economics.

The choice between transportation modes, when both are feasible, should be based on the results and conclusions of an exhaustive comparative analysis. This analysis should address several parameters, including costs, environmental consequences, existent regulatory framework, public acceptance and so on.

Currently there is a lack of data in this field for CCS projects, due to its embryonic deployment, and very few studies and reports have been made to date focusing specifically on the cost of CO2 transport in the context of CCS. Furthermore, even if ship transport is an obvious complement or alternative to pipelines, few studies include this possibility.

Pipelines today operate as a mature market technology for transporting large volumes of gases and fuels and are the most common method for transporting CO2. The difference for CCS is that CO2 will be transported in a dense phase or supercritical phase at high pressures and through urban areas which changes the requirements considerably. More experience is required to text the feasibility of CO2 transport via pipeline.

CO2 also can be transported as a liquid in ships, road or rail tankers that carry CO2 in insulated tanks at a temperature well below ambient, and at much lower pressures. In some situations or locations, transport of CO2 by ship may be economically more attractive, particularly when the CO2 has to be moved over large distances or overseas.

Shipment of CO2 already takes place on a small scale in Europe, where ships transport food-quality CO2 (around 1,000 tons) from point sources to coastal distribution terminals. Larger-scale shipment of CO2, with capacities in the range of 10,000 to 40,000 cubic meters (18-75 tons), is likely to have much in common with the shipment of liquefied petroleum gas (LPG).

LPG, principally propane and butane, is transported on a large commercial scale by marine tankers. CO2 can be transported by ship in much the same way (typically at 0.7 MPa pressure), but this currently takes place on a small scale because of limited demand. The properties of liquefied CO2 are similar to those of LPG, and the technology could be scaled up to large CO2 carriers if a demand for such systems were to materialize.

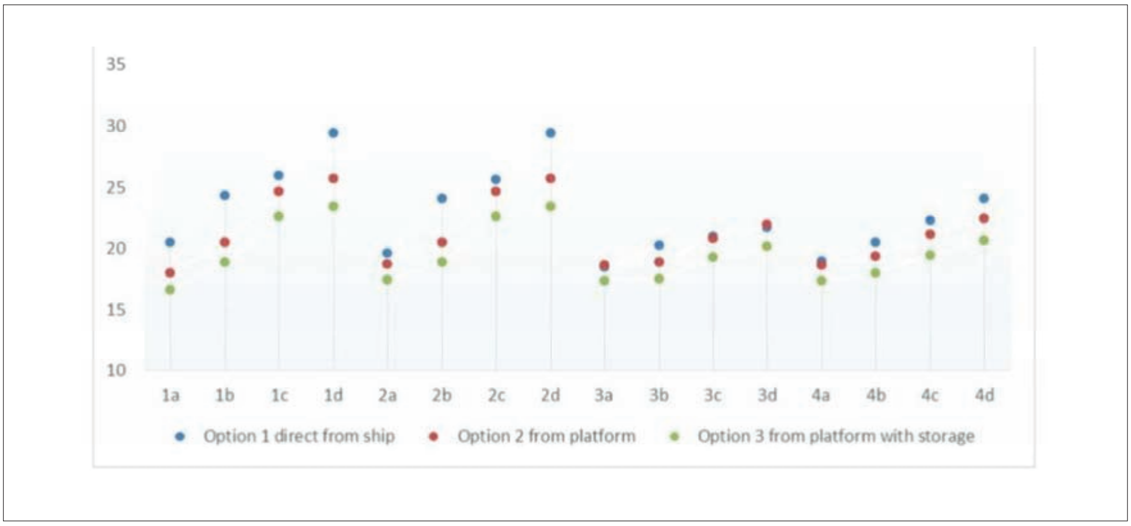

Figure 2 - CO2 Transportation Cost for the Different Reservoir Cases at a Shipping Distance of 800 Km (Source: Filip Neele et al., 2017)

Road and rail tankers also are technically feasible options. These systems transport CO2 at a temperature of -20°C and at 2 MPa pressure. However, they are uneconomical compared to pipelines and ships, except on a very small scale, and are unlikely to be relevant to large-scale CCS.

Closing the knowledge gap

Project risk is one of the key factors holding CCS back and processes to mitigate risk are needed for further deployment, especially as there is very little experience with transporting CO2 outside of EOR projects. The knowledge gap includes the following categories:

- Storage necessities - greater knowledge of storage in tanks, such as buffers or ships;

- Stream composition - study the behaviour and the effects of varying the purity of the CO2 stream in different materials;

- Transient periods - understand the start-up and shut-down routines and other transient periods;

- Negative impacts - confidence would be further enhanced by increased knowledge;

- Monitoring and instrumentation techniques - improve simulation, accuracy and cost-effectiveness; Mitigation and remediation - lack of specific emergency plans for possible accidents, as in the case of an explosion;

- Cost control - improve the knowledge of costs for the project and for regulatory compliance;

- Regulation and responsibility framework - clarify the role of each stakeholder and project.

Effective regulation is also key to managing CCS risks and needs to cover all aspects of the process and specific scenarios. Nevertheless, this regulation needs to be flexible and adaptive, allowing an empirical learning. Guidelines for building an effective regulatory system may be identified:

- Scale of activity - transportation will be larger in scale than most currently covered under legislation;

- Monitoring and instrumentation practices - carbon dioxide demand specific control necessities that should be clearly identified;

- Specific risks management requirements - CO2 poses risks that are different from the other fluids disposed in tanks or pipelines;

- Uncertainties - associated regulation designed to manage transportation of carbon dioxide should be adaptive and emphasize learning-by-doing;

- Provide access to data and public input - transparency across stakeholders and ability to learn sequentially from projects. Moreover, input from the public should be stimulated and taken into account.

CO2 Storage economics

In order for CO2 storage to be viable and economically competitive, the costs have to be reasonable and calculable without major uncertainties. Each storage option has individual characteristics that may be advantageous or disadvantageous for the overall project costs. Besides the dependency of the actual storage reservoir type it is also clear that site-specific categories are key in dictating the economics for an individual storage site/project.

The largest overall impact on the economics of CO2 storage operations is the scale of operation. Economies of scale dictate that the cost per ton of CO2 stored are lower for larger, commercial-scale storage operations with reservoir storage capacities > 200 Mt CO2. Cost sensitivities show a scale benefit for large storage reservoirs that can lead to a reduction of up to 40 % for cost per ton of CO2 stored.

Potentially viable reservoirs for geological CO2 storage are depleted oil and gas reservoirs, deep saline aquifers and unmineable coal beds. The lowest overall minimum and maximum costs are associated with depleted oil & gas fields. Here, the costs for onshore storage range from 1.6 to 11.0 US$ /t CO2 stored, when existing infrastructure can also be reused.

Depleted oil and gas fields have some key advantages, including large storage capacities in a depressurized reservoir, proven long-term caprock integrity as well as the potential for reusing existing infrastructure. Main drawbacks include unknown number, location and condition of abandoned wells, and the cost for retrofitting existing infrastructure. However, if these drawbacks are manageable with reasonable efforts, CO2 storage in depleted oil and gas reservoirs is very promising and could be implemented at commercial scale with lead times of a few years only.

	Depleted oil and gas reservoirs	Deep saline aquifers	Unmineable coal beds
Lower Estimate for Global CO_2 Storage Capacity (Gt)	675	1000	3-15
Upper Estimate for Global CO_2 Storage Capacity (Gt)	900	possibly > 10^4	200
Reservoir characteristics	+++	+^{a}	+
Caprock characteristics	++^{b}	+	+
Operational characteristics	+	++	+
Regulatory constraints	+	+-	+-

aThe efficiency (and safety) of storing CO2 in deep saline aquifers can significantly be increased by the extraction of reservoir brine and the use of several injection wells. bThe safety (and efficiency) of storing CO2 in depleted oil and gas reservoirs is governed mainly by presence and status of old (abandoned) wells.

Table 1: Storage capacities and efficiencies of the three main geological CO2 storage options (after IPCC, 2005)

For deep saline aquifers located onshore, the costs are slightly higher ranging from 3.1 to 18.8 US$ /t CO2 stored, the main reason for the difference being the initial exploration, characterization and development phase prior to storage operation.

Deep saline aquifers have the advantage of enormous storage capacities and widespread geographical distribution resulting in good source-sink matching. Drawbacks include long lead times of approximately 15 years, pressure build-up during CO2 injection and the requirement to monitor an extensive area. However, these drawbacks are manageable and commercial-scale CO2 storage is likely to be viable in deep saline aquifers.

The largest range for costs is associated with unmineable coal beds. In these reservoirs, costs can range from -30 to 174 US$ /t CO2 stored, although negative costs may occur when large volumes of methane can be sold at significant commodity prices.

Unmineable coal beds have the lowest storage capacities for CO2 compared with the other two potential storage candidates, and while methane recovery may provide an economic offset, they are are therefore not suitable for the large-scale implementation of CO2 storage. However, if advanced injection procedures, such as hydraulic fracturing, can be used to effectively manage reservoir permeability, storage efficiency may be high enough to make CO2 storage in unmineable coal beds viable.

Based on storage efficiency and safety, depleted oil and gas fields are most suitable reservoirs and are the most significant during the early phase of commercial activity. This mainly relates to the favourable reservoir (low pressure) and caprock characteristics (proven integrity). In the context of sustainability, deep saline aquifers are also very suitable reservoirs and will be the most suitable for the next phase of development.

Storage efficiency and safety can further be increased when reservoir brine is extracted from the reservoir and several injection wells are used to improve CO2 migration in the reservoir. The storage of CO2 in unmineable coal beds is likely to be the least sustainable option.

The largest source of uncertainty related to long-term CO2 storage is the limited availability of empirical data from commercial-scale projects. On the one hand, empirical data is important to understand and precisely predict the CO2 trapping mechanisms over the long-term. On the other hand, it is also necessary for generating sophisticated and site-specific monitoring and verification strategies for the long-term post-injection period.

The storage of large quantities of CO2 in geological reservoirs produces environmental risks. These risks must to be addressed by law and regulatory frameworks. At present, these frameworks are not well developed. However, when regulations are set in place that precisely define post-injection monitoring, long-term stewardship as well as project liability, also the uncertainty of economic estimates for commercial-scale CO2 storage will be reduced.

In the next issue

This is the first in a series of articles summarising key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program.

The next issue will feature “Compact Light-Weight CO2 Capture Technologies for Small to Medium scale CO2 Emitters” and the following issue “Advances in Direct Air Capture of CO2”.

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More information

More information about this and other services of the CO2CC Program can be found at:

www.catalystgrp.com/php/tcgr_co2cc.php