TECHNICAL AND COMMERCIAL PROGRESS TOWARDS VIABLE CO_2 STORAGE

A techno-economic investigation commissioned by the members of the

Carbon Dioxide Capture and Conversion (CO_2CC) Program

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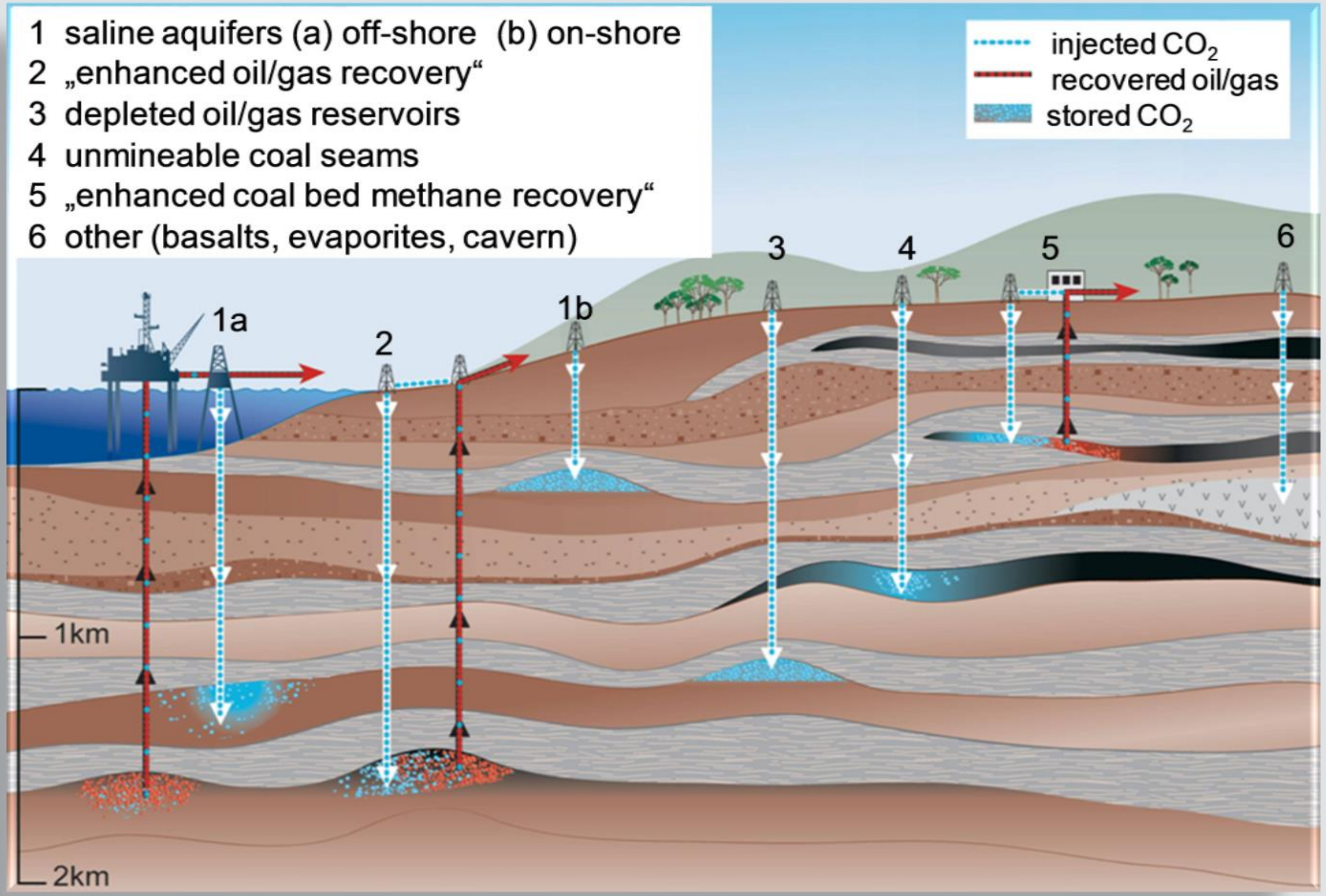
SCOPE

- This report considers the technical and commercial feasibility of Carbon Capture and Storage (CCS) from three critical perspectives: 1) Regulatory, 2) Transportation and 3) Storage.
- It provides a timely synopsis of the major enabling factors that need to be progressed for CCS to move forward.
- It will be of considerable help to existing stakeholders and newcomers looking to understand the status of CCS and provides a view of what is needed to improve its prospects of becoming a significant method for reducing GHG emissions via wide-scale deployment.

Different Storage Options for CO_2



The following slides depict some key take-aways from this recently completed report.

3 **DRIVERS**

Regulations Pertaining to Storage & Transport

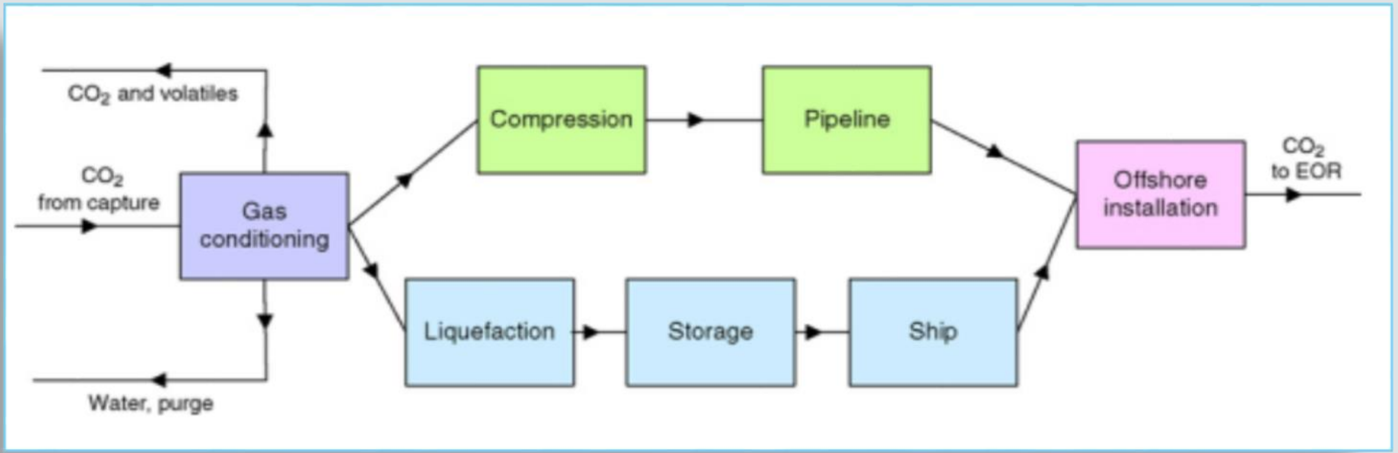
- To meet the goals of the Paris Agreement, CCS storage projects will need to scale at an unprecedented rate. The current developmental pace for policy, legal and regulatory drivers of CCS storage is inconsistent with this need. However, there are enablers that can significantly advance knowledge and scale CCS.
- Important developments are underway as the EU ETS concludes Phase 3. Running through 2030, Phase 4 will increase the Linear Reduction Factor (LRF) to 2.2% and double the intake rate for the Market Stability Reserve (MSR) for the first five years of operation from 12% to 24% if the threshold of 833 million allowances is exceeded.
- Jurisdictions with substantial CO_2-EOR operations (e.g., USA, Canada) have robust legislative frameworks and regulations to govern CO_2 pipelines. Outside of these jurisdictions, there is a distinct lack of policies to govern the permitting and operation of CO_2 transport systems.
- CO_2 pipeline projects require substantial capital investments. Coupled with low oil prices, this factor presents a significant economic barrier to the development of CO_2 pipeline networks. Tax policies such as 45Q that provide economic incentives for CCS projects are needed to improve project economics.

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 CO_2 pipelines will be needed.

The CO_2 Transport Chain

- The CO_2 transport chain starts with the conditioning of a CO_2 rich stream that is received from the capture process and ends with injection to a reservoir.
- Between these two points, transport takes place in pipeline or on ship, as shown in the Figure.

The CO_2 Transport Chain



CO_2 Transport via Pipeline

There is a combined total of over 8,000 km of CO_2 pipelines around the world. This is up from over 6,500 km of CO_2 pipelines in 2014. The initial cost of pipeline is off-putting with the largest project to date (Cortez) costing some US$ 700 million and this has led to much opposition to further projects, particularly in Europe. Cost is currently estimated at around US$10/ ton of CO_2 per 100 km; the need for a booster station is required to transport CO_2 in a supercritical state and this adds 16% to the unit cost of transport.

CO_2 Transportation via Shipping

Ship transportation can be an alternative option for many regions of the world. Shipment of CO_2 already takes place on a small scale in Europe, where ships transport food-quality CO_2 (around 1,000 tonnes) from point sources to coastal distribution terminals. Larger-scale shipment of CO_2, with capacities in the range of 10,000 to 40,000 cubic metres (18-75 tons), is likely to have much in common with the shipment of liquefied petroleum gas (LPG). There is already a great deal of expertise in transporting LPG, which has developed into a worldwide industry over a period of 70 years.

CO_2 Transport via Pipeline

- By 2015, there were 50 individual CO_2 pipelines in the US with a total length of 7,200 km (CO_2 Transportation and Storage Business Models, 2018).
- Europe, meanwhile, had only about 500 km of CO_2 pipelines in 2013 and as of 2015 was moving backwards with two key UK projects being cancelled as well as one in The Netherlands.
- The initial cost of pipeline is off-putting with the largest project to date (Cortez) costing some $700 million (USD) and this has led to much opposition to further projects, particularly in Europe.

CO_2 Pipeline Transport System

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CO_2 Transportation Cost for the Different Reservoir Cases at a Shipping Distance of 800 Km

Comparison of Methods: Pipeline and Shipping

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. Stakeholders, particularly those that are going to invest money in the project, will firstly look into the costs category. If the values differ significantly from ship to pipelines, for instance, it is almost an impossible mission to convince them to prefer the most expensive solution in detriment of the cheapest one. A comparative analysis should, therefore, begin with a costs comparison among the several possible scenarios for each project.

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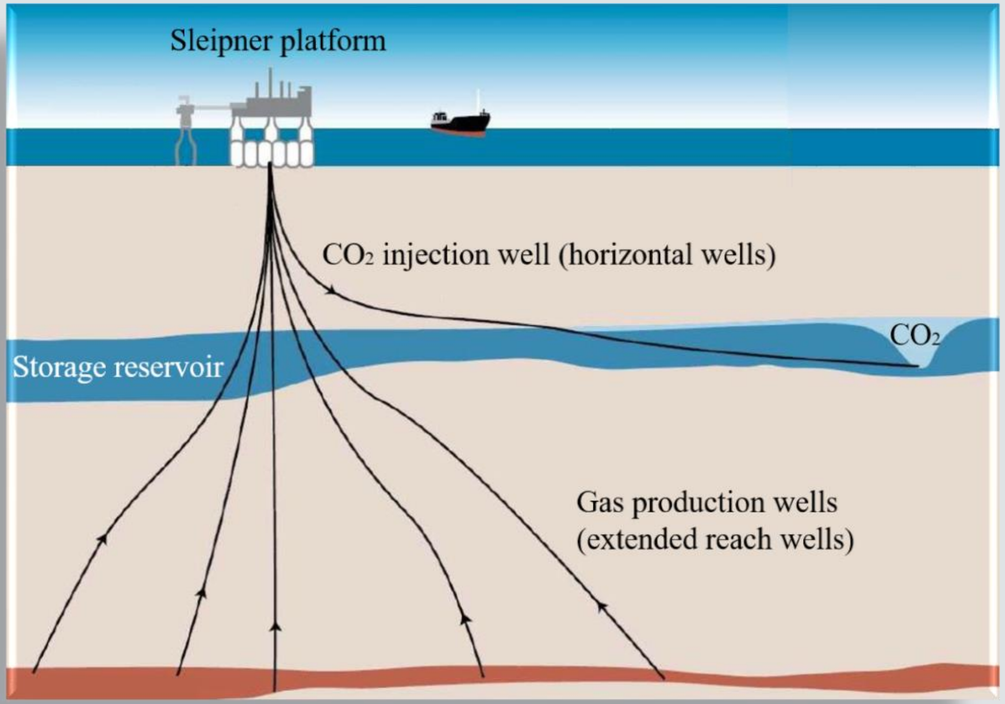
CO_2 Storage

- In order to inject CO_2 into reservoirs, drilling is carried out which creates wells. Vertical wells (directly drilled down vertically), which tend to be onshore, and Extended Reach Wells (drilled at an angle of > 25 °), a subtype of Extended Reach Wells, are drilled at a high angle, commonly > 80 ° from the vertical, (Horizontal Wells).
- Extended reach and horizontal wells are more common in offshore platforms such as that of Sleipner. They provide an economical method for exploiting thinner, low permeability reservoirs.
- However, this has to be counter-balanced against the increased propensity for failure due to low reservoir utilization.

Sleipner CO_2 Reservoir and Injection Wells



When implemented at commercial-scale, CO_2 storage technology could play a significant role in society's efforts to stabilize atmospheric concentrations of greenhouse gases by the middle of the 21st century

Potentially viable reservoirs for geological CO_2 storage are depleted oil and gas reservoirs, deep saline aquifers and unmineable coal beds.

Key advantages for CO_2 storage in depleted oil and gas fields are 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.

CO_2 Storage Summary

Economics & Sustainability

- In order for CO_2 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.
- Potential economic benefits due to the utilization options during CO_2 storage are limited. The recovery of methane during CO_2-ECBM operations could make this whole technology viable after all, and individual projects could even generate profit per t of CO_2 stored. In contrast, the utilization potential of the produced brine during CO_2 storage in deep saline aquifers is restricted to niche applications, such as fresh water generation and extracting valuable species.
- Based on storage efficiency and safety, depleted oil and gas fields are most suitable reservoirs. This mainly relates to the favorable reservoir (low pressure) and caprock characteristics (proven integrity). In the context of sustainability, deep saline aquifers are also very suitable reservoirs. Storage efficiency and safety can further be increased when reservoir brine will be extracted from the reservoir and several injection wells will be used to improve CO_2 migration in the reservoir.

To date it is uncertain how regulatory constraints (i.e. large-scale long-term monitoring) will impact storage efficiency in deep saline aquifers. The storage of CO_2 in unmineable coal beds is likely to be the least sustainable option. 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 CO_2 storage in unmineable coal beds viable.

FUTURE DIRECTIONS

The Knowledge Gap

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 CO_2 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 behavior and the effects of varying the purity of the CO_2 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
- ✓ **Costs Control** – improve the knowledge of costs for the project and for the regulatory compliance
- ✓ **Regulation and Responsibility Framework** – clarify the role of each stakeholder and project

OUTLOOK

In order for CO_2 storage to be viable at commercial-scale, various challenges have to be conquered. The main challenges include:

- ✓ 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

In order to make commercial-scale CO_2 storage projects viable unbiased information has to be provided to the public. Local stakeholders and communities have to be included into the engagement process. This also includes clear communication of the risks and benefits of CO_2 storage.

Without improved public perception, further implementation of the CO_2 storage technology at the commercial scale will not be viable.

Carbon Dioxide Capture and Conversion (CO_2CC) Program

The **Carbon Dioxide Capture and Conversion (CO_2CC) Program** is a membership-directed consortium, launched in January 2010, whose members are involved in developing, monitoring and utilizing the "State-of-the-Art" in technological progress and commercial implementation of carbon dioxide capture and conversion.

The program's objective is to document and assess technically and commercially viable options for the capture/clean-up/utilization of CO_2 and its mitigation via energy efficiency gains which meaningfully address the challenges posed by CO_2 life-cycle and overall sustainability issues. Included in the program's scope are:

- CO_2 capture and/or separation
- CO_2 concentration, purification and/or other post-treatment
- CO_2 utilization/conversion (e.g., CO_2 as a feedstock) for use as a fuel or intermediate, including enhanced oil recovery (EOR)
- Energy requirements (and other costs), including energy efficiency
- Industrial process improvements and energy saving initiatives which mitigate CO_2 production
- Bottom-line financial (income) impacts resulting from CO_2 reduction programs
- Life-cycle considerations and sustainability of CO_2 applications
- GHG/CO_2 regulation and "cap and trade" developments

By the direction of the member companies (through balloting and other interactive means) and operated by TCGR, the program delivers weekly monitoring communications via email (**CO_2CC Communiqués**), three techno-economic reports (highly referenced and peer reviewed) and scheduled meetings of members (either in-person or via webinar).

In addition to the program deliverables, TCGR works with members to identify and foster competitive advantage and opportunity.

Access to Deliverables is Exclusive to Members

Contact & More Information

More information about this and other services of the **CO_2CC Program** can be seen at http://www.catalystgrp.com/php/tcgr_co2cc.php.

Call +1-215-628-4447 or e-mail John Murphy, President

jmurphy@catalystgrp.com, and we'll be happy to discuss these and other interesting membership benefits.

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