

TECHNICAL AND COMMERCIAL PROGRESS TOWARDS VIABLE CO₂ STORAGE

A techno-economic investigation commissioned by the members of the
Carbon Dioxide Capture and Conversion (CO₂CC) Program

Report Completed: June 2019

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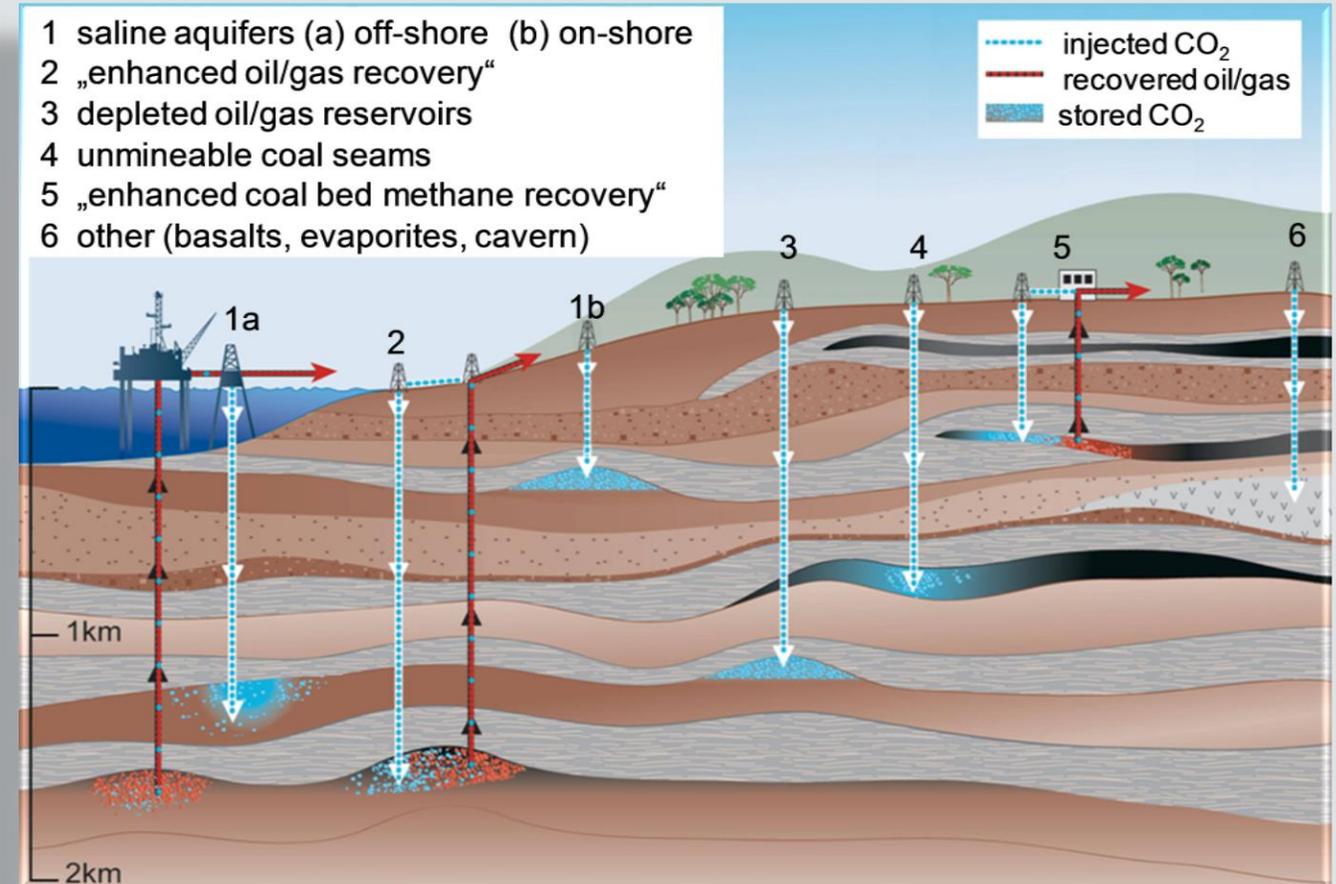


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SCOPE

- 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 CO₂



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

DRIVERS

Regulations Pertaining to Storage & Transport

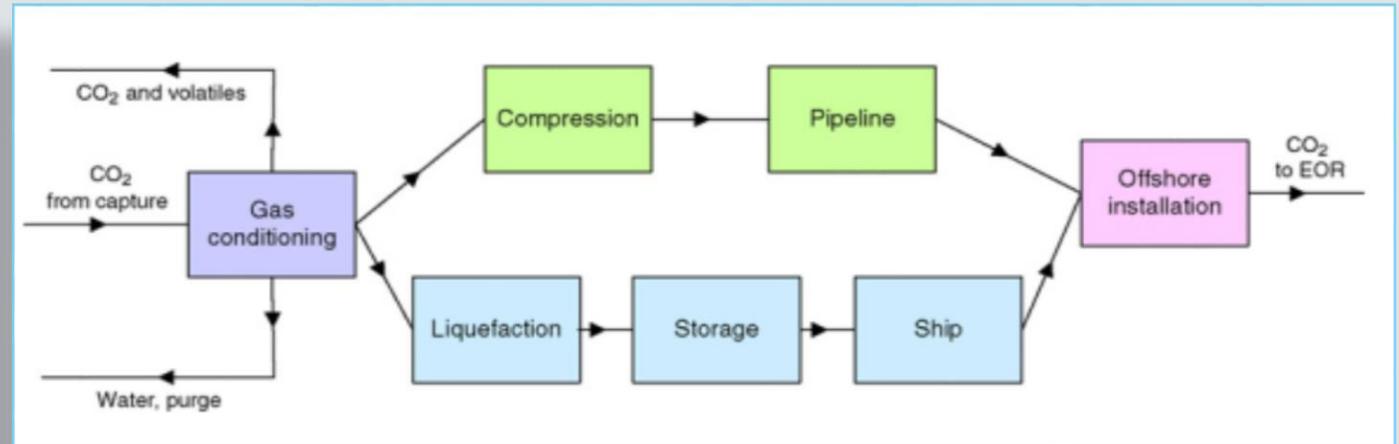
- ▶ To meet the goals of the Paris Agreement, CCS storage projects will need to scale at an unprecedented rate. The current developmental pace for policy, legal and regulatory drivers of CCS storage is inconsistent with this need. However, there are enablers that can significantly advance knowledge and 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 CO₂-EOR operations (e.g., USA, Canada) have 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. Coupled with low oil prices, this factor presents a significant economic barrier to the development of CO₂ 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 CO₂ pipelines will be needed.

The CO₂ Transport Chain

- The CO₂ transport chain starts with the conditioning of a CO₂ 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 CO₂ Transport Chain



CO₂ Transport via Pipeline

There is a combined total of over 8,000 km of CO₂ pipelines around the world. This is up from over 6,500 km of CO₂ 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 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.

CO₂ Transportation via Shipping

Ship transportation can be an alternative option for many regions of the world. Shipment of CO₂ already takes place on a small scale in Europe, where ships transport food-quality CO₂ (around 1,000 tonnes) from point sources to coastal distribution terminals. Larger-scale shipment of CO₂, 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.

CO₂ Transport via Pipeline

- By 2015, there were 50 individual CO₂ pipelines in the US with a total length of 7,200 km (CO₂ Transportation and Storage Business Models, 2018).
- Europe, meanwhile, had only about 500 km of CO₂ 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.

CO₂ Pipeline Transport System



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CO₂ Transportation Cost for the Different Reservoir Cases at a Shipping Distance of 800 Km



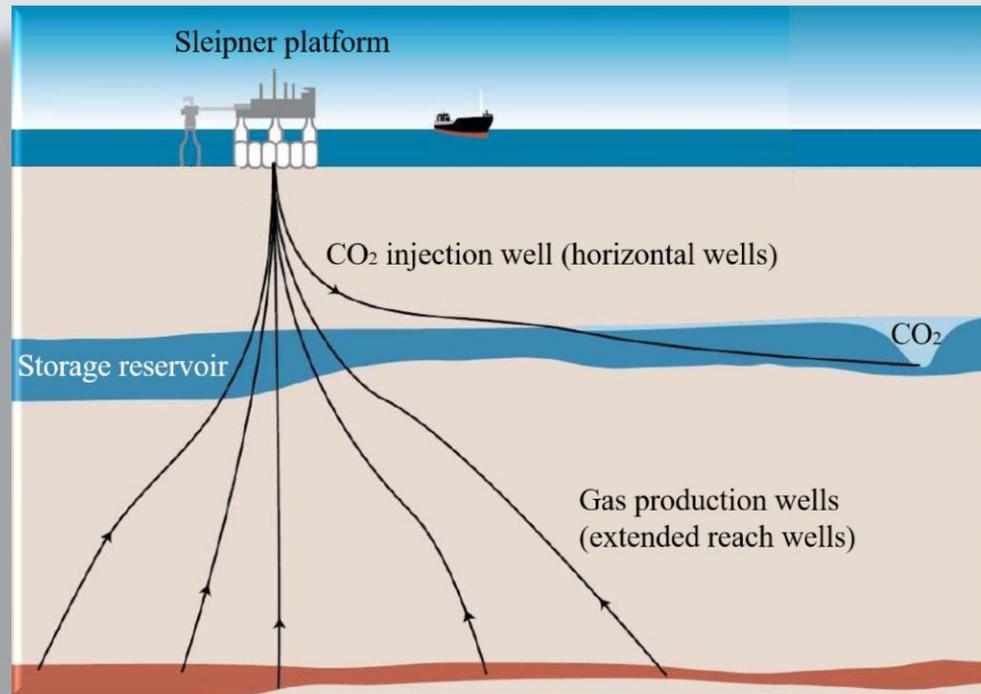
Comparison of Methods: Pipeline and Shipping

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.

CO₂ Storage

- In order to inject CO₂ 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 CO₂ Reservoir and Injection Wells



When implemented at commercial-scale, CO₂ 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 CO₂ storage are depleted oil and gas reservoirs, deep saline aquifers and unmineable coal beds.

Key advantages for CO₂ 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.

CO₂ Storage Summary

Economics & Sustainability

- 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.
- Potential economic benefits due to the utilization options during CO₂ storage are limited. The recovery of methane during CO₂-ECBM operations could make this whole technology viable after all, and individual projects could even generate profit per t of CO₂ stored. In contrast, the utilization potential of the produced brine during CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 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 behavior 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
- ✓ **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 CO₂ 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 CO₂ 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 CO₂ storage.

Without improved public perception, further implementation of the CO₂ storage technology at the commercial scale will not be viable.

Carbon Dioxide Capture and Conversion (CO₂CC) Program

The **Carbon Dioxide Capture and Conversion (CO₂CC) 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 CO₂ and its mitigation via energy efficiency gains which meaningfully address the challenges posed by CO₂ life-cycle and overall sustainability issues. Included in the program’s scope are:

- ▶ CO₂ capture and/or separation
- ▶ CO₂ concentration, purification and/or other post-treatment
- ▶ CO₂ utilization/conversion (e.g., CO₂ 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 CO₂ production
- ▶ Bottom-line financial (income) impacts resulting from CO₂ reduction programs
- ▶ Life-cycle considerations and sustainability of CO₂ applications
- ▶ GHG/CO₂ 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 (**CO₂CC 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 **CO₂CC Program** can be seen at http://www.catalystgrp.com/php/tcgr_co2cc.php.

Call +1-215-628-4447 or e-mail Chris Dziedziak cdziedziak@catalystgrp.com, and we'll be happy to discuss these and other interesting membership benefits.

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