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Scaling Technologies To Enable Giga-Tonne/Year CO2 Storage

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Summary

Carbon Capture and Storage (CCS) is a key climate mitigation technology required to meet the Paris Agreement goal of limiting global warming. Commercial-scale demonstration projects such as the Quest project in Alberta, Canada, or the Illinois Basin-Decatur project in Illinois, USA, have shown that the technology is feasible and safe. These projects demonstrate that existing technologies are sufficient for the successful implementation of CCS at the mega-tonne/year scale. However, scaling these technologies to meet the future need for giga-tonne/year storage remains a shared industry challenge. Responding to it demands addressing the low-probability, high-impact storage risks that cannot always be avoided within a large and diverse portfolio of CO2 storage projects. These include the risk of induced seismicity and fault reactivation, pressure management to improve storage security, exposure to legacy wells, and lowering the cost of large-scale containment monitoring. We propose four technology development pathways to address these giga-ton/year challenges, highlighting key focus areas.

Introduction

One of the key challenges for humanity is to match increasing energy demand due to global prosperity and population growth with major reductions in our GHG emissions. To achieve the goal of limiting global warming as set out in the Paris agreement, society must realise net-zero emissions from energy and other sources (Bentham, 2015) before the end of the century (Bentham, 2018). Such a world would be offsetting emissions with 'negative' emissions elsewhere. Figure 1 shows the rise of global CO_2 emission/day (left) and a plausible emissions balance in an emerging net-zero emissions world (right).

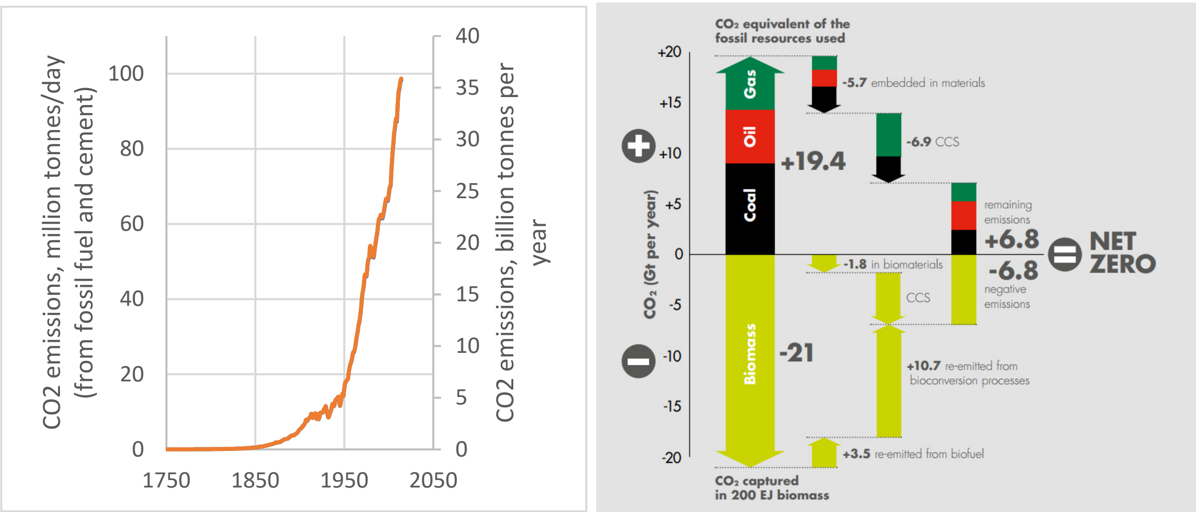

Figure 1 Left: *CO_2 emission has risen to 100Mt/day (Source: Fossil fuel combustion and cement production emissions: Boden, TA, Maryland, G and Andres, RJ 2015. Global, Regional, and National Fossil-Fuel CO2 Emissions, Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.).* ***Right:*** *A plausible emissions balance in an emerging net-zero emissions world.*

Scale-up challenge

To achieve this net-zero emission ambition, CCS technology will have to be deployed at giga-tonne/year scale. (see Figure 1, right). Existing CO_2 storage technologies are sufficient to support mega-tonne/year CO_2 storage projects where there is the freedom to avoid the identified risks to secure long-term storage through careful site selection. Commercial-scale demonstration projects such as the Quest project in Alberta, Canada (Luc Rock, 2016), or the Illinois Basin-Decatur project in Illinois, USA (Traci Rodosta, 2017), have shown that the technology at this scale is feasible and safe. However, scaling CO_2 storage capabilities to deliver giga-tonne/year storage remains a CCS industry challenge. Storage at this scale demands a large portfolio of geologically diverse and variable-quality storage sites, with more vulnerable geological structures exposed to higher subsurface fluid pressures. This requires significant new technologies to actively control rather than simply avoid these low-probability, high-impact geological storage risks (Figure 2). We propose technology development pathways designed to step-up CO_2 storage capabilities from mega- to giga-tonne/year.

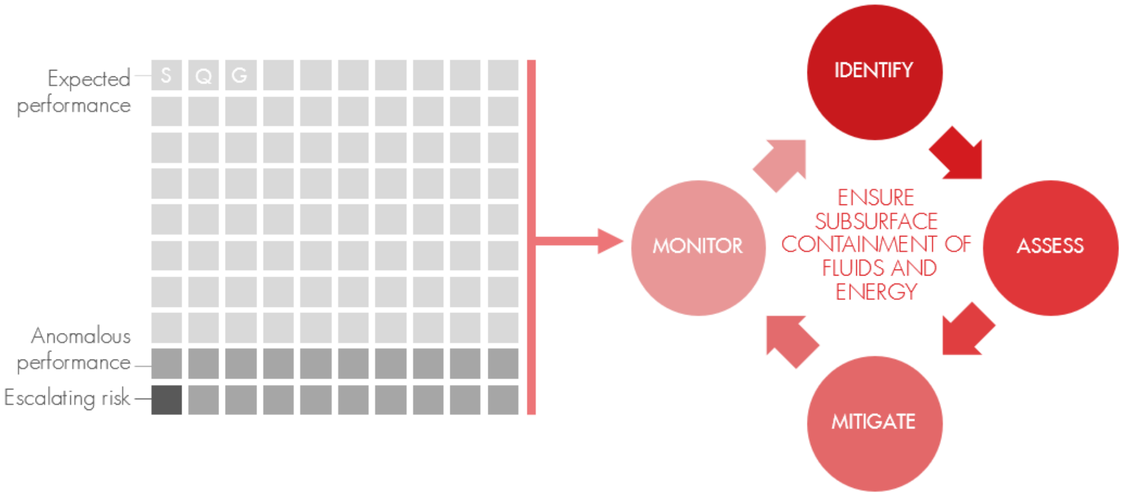

Figure 2 *Left: Low-probability, high-impact storage risks cannot be ignored in a giga-tonne/year portfolio. Right: Technical framework for managing subsurface storage risks.*

CO_2 storage technology development to enable giga-tonne/year CCS deployment

CO_2 storage technology developments will be successful when they deliver trusted and cost-effective methods to identify, assess, mitigate, and monitor (see Figure 2, right) all credible subsurface threats to long-term storage security across a large and diverse storage portfolio. These technologies will be critical for gaining and maintaining regulatory permits and public acceptance, reducing life-cycle storage costs and long-term liabilities whilst accessing sufficient storage capacity across a range of challenging geological settings.

Table 1 shows existing CO_2 storage technologies to support mega-tonne/year deployment and developing technologies for giga-tonne/year deployment. The methods are sorted according to the four phases (identify, assess, mitigate, and monitor) in the technical framework Shell follows for managing subsurface storage risks. The goal of this approach is to ensure subsurface containment of fluids and energy.

Table 1 *CO_2 storage technologies ensuring subsurface containment of fluids and energy.*

Framework stage	Existing technologies for mega-tonne/year deployment	Developing technologies for giga-tonne/year deployment
IDENTIFY Screening	• Capacity & injectivity appraisal • Risk register & bowties • Rank & select storage sites	• Global storage atlas considering technical and non-technical risks
ASSESS Characterisation	• Geological analysis of formation & seals • Geochemical analysis of fluids isolation • Environmental analysis of potential impacts	• CO_2 plume & pressure forecasting • Geomechanical analysis of faults, seals, wells • Induced seismicity risk analysis
MITIGATE Safeguards & Corrective Measures	• Remediate well, seal or environmental integrity • Adapt injection/production plans	• Optimize injection/production plans • Leak path reactive transport modelling • Low-cost well remediation
MONITOR Monitoring & Verification	• Show conformance & containment • Verify no environmental affects	• Lower costs, lower uncertainties • Site closure monitoring • Reliable early warning logic • Automated, integrated data analysis and exception diagnostics

To address the key challenges to subsurface storage security for large-scale CCS implementation, we propose future CO_2 research to focus on the following technology development goals sorted into four pathways:

1. **Induced seismicity and fault reactivation due to large-scale CO_2 injection**
    - Mitigate the geomechanical risk of fault instability due to injection rates and volumes. Giga-tonne/year CO_2 storage will induce larger stress loads on more geological faults.
    - Develop seismicity threat assessment and probabilistic hazard analysis tools to manage induced seismicity threats.
2. **Pressure management to enable large-scale storage capacity and containment**
    - Optimise fault and seal stability with pressure management.
    - Develop sub-sea, autonomous water production from CO_2 storage formation and disposal.
    - Mitigate capacity constraints, injection impairment, CO_2 breakthrough in water producers.
    - Validate performance of CO_2 flow modelling technology against demonstration projects.
3. **Monitoring for storage conformance and containment on a massive scale**
    - Increase the reliability and reduce the cost of monitoring systems for leak detection and characterisation.
    - Develop exception diagnostics tools, test data analytics and machine learning methods, minimising missed and false alerts.
    - Develop site closure sensors to continue storage site monitoring below geological seals after well abandonment.
4. **Characterize and mitigate well integrity threats**
    - Assess leak threats unique to legacy wells and develop cost-effective sealing measures.
    - Characterize and mitigate geomechanical threats to long-term injection well integrity.

Conclusions

Many demonstration projects around the world, including the Quest CCS project, have shown that CCS is feasible and safe. If society decides to significantly mitigate global warming, CCS will have to be deployed at giga-tonne/year scale covering a large and diverse portfolio of CO_2 storage sites. In such a scenario, low-probability, high-impact storage risks must be addressed. We propose several technology development pathways and focus areas with the goal to effectively mitigate these challenges.

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