Norway’s Sleipner and Snøhvit CCS: Industry models or cautionary tales?

Examining the geologic storage risks of CSS in Norway

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Industry hype for Norway’s CCS

Industries and governments alike, worldwide, cite these two Norwegian projects at proof that subterranean carbon dioxide (CO$_2$) storage works.

Glowing testimony and citations have been read into public record in parliamentary and congressional committees globally.

Hundreds of offshore CCS projects are proposed or under development globally, representing 240mtpa of CO$_2$ injections and projected to cost $100s of billions.
Premise for this research

There has been little in the way of objective debate on the cost and risks of the geologic storage, particularly on a holistic, lifecycle basis.

Most discussion of the Norwegian pair’s operational performance is confined to academic papers and technical journals.

Are these two projects actually well-performing models for CCS? Or is there more to know? The answer has great implications for the world.
Norway CCS Project Overviews
Sleipner Project Overview

- August 1996
- Natural gas production field with 4% to 9% CO$_2$ content
- 250 km offshore
- 80m-100m water depth
- Dedicated CO$_2$ process platform offshore
- 12km CO$_2$ pipeline
- Single injection well
- 0.9mtpa CO$_2$ injected currently
- About 22Mt CO$_2$ underground now
- $92m investment cost
- Driven by Norway CO$_2$ tax initiated 1991
Sleipner: schematic of CO₂ storage operations

Source: Geological storage of CO₂: project design and global scale-up. Ringrose. March 29, 2021. IEEFA
Shøhvit Project Overview

- April 2008
- Natural gas production field with 5% to 8% CO₂ content
- 143km offshore
- 300m water depth
- Onshore CO₂ processing
- 143km CO₂ pipeline
- 0.7mtpa CO₂ injected
- Using third CO₂ storage site now
- About 8-9Mt CO₂ underground in aggregate
- $191m investment

Snøhvit: schematic of CO$_2$ storage operations

Sleipner’s Challenges
Eight CO₂ storage layers become nine

- Original geophysics concept was that CO₂ would gradually percolate up through a number of shaly layers over a period of many years.
- This configuration was identified through preliminary seismic studies and calculations.
- Instead, in less than three years, CO₂ had moved all the way up to underneath the caprock.
- CO₂ accumulated in a previously unidentified layer 9.
- At some point after 2004, this accumulation accelerated to large volumes.
- The horizontal boundaries of Layer 9 remain unknown.
How much CO$_2$ is actually stored and where?

- Repeated seismic imaging studies have seen the CO$_2$ plume remain centered above the injection point but grow in horizontal area.
- Depth of the plume has proven challenging to measure.
- Only calculations based on the seismic data can verify whether the CO$_2$ injected is actually stored there.
- Equinor and national technical universities have been engaged in developing "benchmark" models of the plume and geology in an attempt to figure out how much CO$_2$ is there.
- More data is being collected and more models are being created.
- Analysis is essentially being crowdsourced.
Snøhvit’s Challenges
Snøhvit experiences trouble very early

- CO₂ injections commenced August 2008
- Targeted formation is meant to have 18 years capacity
- Only 18 months into operations, pressure in the storage space rose precipitously, risking geologic failure
- Storage needed to be suspended and a well intervention conducted to find out what is causing the trouble
- The entire nearly $7bn Snøhvit-Hammerfest value chain project is in jeopardy because of this.
Caution required due to In Salah, Algeria experience

What happened?

• Massive pressure rise happened early on in operations
• Jeopardized gas production
• Kept injecting
• Detected geologic failure due to pressure drop
• Injections permanently suspended
• Was deemed okay since it was voluntary storage activity
• CO₂ again vented to atmosphere

Sketch illustrates main geomechanical observations around injection well KB-5C2
Source: Energy Procedia. The In Salah CO₂ storage project: lessons learned and knowledge transfer.
Snohvit’s target storage layer rejects CO2

Interventions List

X Blocked well?
X Salts forming at interface?
X Reperforate well to reduce pressure?
✓ Plug well
✓ Try new perforations in a shallower stratum?
⚠️ But try not to interfere with gas producing layer

Reduced storage capacity necessitated finding new storage space.

**Original Plan**
- Inject in safe formation underneath gas producing area
- Sufficient capacity for about 18 years of production
- Use time to find suitable follow-on storage space
- Switch over to new area once original layer is full

**Remedial Plan**
- Find a quick fix layer for storage to resume operations
- Determined only good for about 4-6 years of operations, i.e. to about 2016
- Immediately prospect for new CO2 storage, starting 2011
- Invest in developing new well and infrastructure, 2016
- Invest additional at least US$225 million

### Indicative timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
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<tbody>
<tr>
<td>2008</td>
<td>Commenence operations</td>
</tr>
<tr>
<td>2008</td>
<td>Identify Bring extra incremental capacity online</td>
</tr>
<tr>
<td>2018-2020</td>
<td>End operations</td>
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### Actual timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
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<tbody>
<tr>
<td>2008</td>
<td>Limited capacity issue identified</td>
</tr>
<tr>
<td>2010</td>
<td>Additional storage exploration advanced</td>
</tr>
<tr>
<td>2011</td>
<td>New well drilled and backup storage brought online</td>
</tr>
<tr>
<td>2011-2015</td>
<td>Well intervention</td>
</tr>
<tr>
<td>2016</td>
<td>Remedial capacity tapped</td>
</tr>
<tr>
<td>~2030</td>
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Challenges and Implications
Challenging conclusions

• Putting CO$_2$ back into the ground is proving to be far more technically complex and filled with uncertainty

• Geophysicists and engineers admit is more difficult to put something back in the ground than to extract it

• The ongoing costs of monitoring, studying and contingency plans are material

• In the event of a performance deviation, need for action may be immediate, requiring high levels of technical and financial resources as well as specialist equipment

• Even with the best talent and resources, experts still don’t know whether the CO$_2$ will behave as needed.
Technical implications

• Storage sites require extensive exploration, engineering and contingency planning – before, during and after closure
• Even using the most advanced tools available, surveying and modelling are inherently inaccurate; the possibility of missing critical subsurface features is always present
• Multiple forms of surveying, monitoring and modeling are required at regular intervals
• Vigilance must be maintained constantly, including after closure
Scale implications

- It is challenging to see how Sleipner or Snøhvit can be used as proxies for projects 10 time or larger in storage capacities.
- The number of geologic anomalies encountered at a storage site is more likely to be proportional to its area.
- This means larger-scale sites will require larger-scale engineering and monitoring efforts with more points where things could go wrong.
- There are direct implications for the costs and resource requirements.
- As the tonnage injection rates of CO2 increase so does the risk of failures, leakage.
Regulatory implications

- Only a handful of countries have any form of CCS regulation
- Some considering CCS do not
- Each of those reviewed has recognized the need for long-term bonding provisions to cover the cost of monitoring, maintenance and intervention post well closure
- Most have provisions to waive those bonds at the regulators’ discretion

Source: IEEFA compilation from laws in Australia, the EU, Norway and the U.S.
Regulatory implications

- Potential for rapid and/or large-scale variations of CO$_2$ storage site performance mean that regulation needs to be proactive.
- Regulators’ vigilance needs to be maintained across lifecycle.
- Regulators need to be staffed and equipment with a commensurate level of sophistication as those they oversee.
- Carbon taxes made Sleipner and Snohvit worthwhile investments; finite budgeted subsidies may not work the same way.
- Leakage from subsurface storage areas, meant to permanently dispose of CO$_2$, has impacts both on a company’s decarbonization targets, but, more importantly, directly upon a country’s Paris Agreement net zero commitments.
Conclusions

Sleipner has proven that, even after steadfast study and monitoring using top-level technology and engineers, injected CO₂ can move to unexpected places and behave in unexpected ways even years after what appears to have been nominal operations.

Snøhvit has proven that, even after steadfast study and monitoring using top-level technology and engineers, actual behavior of what has been studied can turn out to be substantially different and replacement plans may need to be implemented with speed in order to avoid catastrophe.

Sleipner and Snøhvit, have proven that, to assure long-term secure CO₂ storage:

- Ongoing monitoring and verification of storage site integrity is imperative.
- Backup plans must always be available in case storage formations do not behave as anticipated.
- Companies that invest in and operate these fields need to have the financial and technical resources at the ready to address deficiencies, deviations and unexpected performance.
- Clear regulations and requirements are necessary across the entire CCS life cycle to maintain integrity.
- Keeping CO₂ securely in the ground, permanently, cannot be guaranteed.
IEEFA Carbon Capture and Storage Research

- The carbon capture crux: Lessons learned
  Compendium of global CCS projects across applications and technologies
  Bruce Robertson and Milad Mousavian

- Gorgon carbon capture and storage: The sting in the tail
  Bruce Robertson and Milad Mousavian

- Carbon capture’s methane problem
  David Schlissel and Dennis Wamsted

- The ill-fated Petra Nova CCS project: NRG Energy throws in the towel
  Suzanne Mattei and David Schlissel

- The CCUS entourage in Southeast Asia: A convenient ride to delay the hard questions?
  Putra Adhiguna

- Proposed CCS projects need careful review for cost, technology risks
  Dennis Wamsted and David Schlissel

- CCS for power yet to stack up against alternatives
  Christina Ng and Michael Salt

- Carbon capture to serve enhanced oil recovery: Overpromise and underperformance
  Bruce Robertson and Milad Mousavian

- For additional research, reporting and commentary refer to IEEFA Carbon Capture and Storage Analysis
Norway’s Sleipner and Snøhvit CCS

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