Lessons learned from the Preem CCS project – a pioneering Swedish-Norwegian collaboration showcasing the full CCS chain

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Abstract

The Preem-CCS project is a Swedish-Norwegian collaboration that investigated CO\textsubscript{2} capture from the Preem refineries in Sweden, and subsequent ship transport of captured CO\textsubscript{2} for permanent storage on the Norwegian Continental Shelf. The project was conducted 2019-2021 and this paper summarizes the key findings of the main project activities:

- demonstration of carbon capture at the hydrogen production unit (HPU) in Lysekil using the Aker Carbon Capture mobile test unit (MTU) for pilot-scale testing of CO\textsubscript{2} absorption,
- in-depth investigation of energy efficiency opportunities along the CCS chain, including the use of residual heat at the refinery site to satisfy the energy requirements for solvent regeneration and reduce the cost of capture
- evaluation of the technical feasibility and cost evaluation of the CCS chain including CO\textsubscript{2} capture and transportation by ship to storage facilities off the Norwegian west coast, and
- investigation of relevant legal and regulatory aspects related to trans-border CO\textsubscript{2} transport and storage and national emissions reduction commitments in Norway and Sweden.

On-site CO\textsubscript{2} capture demonstration

The on-site pilot-scale tests of amine-based CO\textsubscript{2} capture from the flue gases (~18-20 vol\%CO\textsubscript{2}, wet) of the refinery’s HPU (steam methane reformer) were conducted successfully, thereby demonstrating the technical feasibility of the capture process. The tests included a campaign with 30wt\% MEA solvent and Aker Carbon Capture’s proprietary solvent S26 (Askestad \textit{et al.}, 2021): For 90\% capture rate and the same conventional process configuration, the specific reboiler duty (SRD) using S26 was 15-18\% below the SRD of MEA. Table 1 shows that MEA experienced significantly more degradation, as evidenced by solvent miscoloring and high levels of ammonia emissions in the absorber. The S26 solvent showed little degradation (no miscoloring, low ammonia emissions) and as a result, the
amine losses were one order of magnitude lower than those associated with MEA solvent, despite the significantly longer duration of the pilot test campaign.

Heat integration for reduced heat supply cost

A detailed analysis of the site energy system (Biermann et al., 2021, 2022) was conducted and identified three sources of heat supply: 1) extractable residual heat; 2) existing unused steam generating capacities; and 3) new boiler capacities. A multi-period optimization was conducted using mixed-integer-linear programming to find a mix of heat sources that is optimal, e.g., that minimizes external energy demand. Figure 1 shows how heat sources and the resulting heat supply cost (CAPEX and OPEX) vary as a function of steam demand. Furthermore, the figure indicates that residual heat alone could supply ~40% of the heat required to capture (using MEA) most of the site’s CO₂ emissions. Also, the use of residual heat minimizes the import of external energy and, thus, reduces the annual CO₂ capture cost by 29-36% when capturing from all four stacks in Lysekil (80% avoided site emissions), compared to using external energy exclusively.

CCS chain analysis

A CCS chain analysis was conducted similar to (Jakobsen, Roussanaly and Anantharaman, 2017; Roussanaly, 2019). The scope of the analysis is shown in Figure 2 and considers CO₂ capture from Preem refineries in Lysekil and in Gothenburg, CO₂ conditioning (compression and liquefaction), and ship transport to the Northern Lights on-shore CO₂ terminal at Naturgassparken (Øygarden, Norway). The subsequent pipeline transport to the injection well for permanent storage under the seabed was not included. The CCS chain cases investigated, see Table 2, consider capture from the four major stacks in Lysekil (HPU, FCC, combined stacks 1 and 2) as well as the HPU in Gothenburg. For these cases, a capture target of 90% implies captured CO₂ in the range of 0.6 – 1.6 Mt CO₂/a. The analysis indicates avoidance costs of 94–128 €/t CO₂-avoided, as shown in Figure 3. Capturing larger volumes of CO₂ does not lead to economy of scale effects, because 1) stacks with lower CO₂ concentration (~8%, combined stacks) have higher specific capture cost; and 2) the cost of external energy for heat supply and associated emissions outweigh any scale effects related to on-site piping and ship transport to storage. Also, a reduced transport pressure of 7 barg (instead of 15 barg, cf. Case 1A in Table 2) leads to lower cost for buffer storage, loading and shipping of 44% (corresponding to ~4 €/t CO₂ avoided for the full chain in Case 1). Figure 4 shows Preem’s potential CO₂ supply compared to the CO₂ suppliers to the first phase of the Northern Lights project (Fortum Oslo Värme – FOV - and Norcem Brevik). Case 4 could potentially unlock a second phase of Northern Lights, which requires a CO₂ supply of 1.5-5 Mt CO₂/a (Equinor ASA, 2019; Reyes-Lúa et al., 2021).

Legal/regulatory aspects and barriers

No barrier from the London Protocol: In October 2019, the International Maritime Organization decided to allow a provisional application of the amended Article 6 for transboundary ship transport of CO₂ for the purpose of geological storage. The provisional application of the amended Article 6 requires Sweden and Norway to deposit a Unilateral Declaration and enter a bilateral agreement about export and import of CO₂.

A recent proposal for a revised EU-ETS 1), allows other transport modes than pipeline and 2) clarifies liability for CO₂ leaked during transport/injection whereby the operator of the transport/injection system is responsible. With this suggested change, Preem will not be able to subtract emissions until the CO₂ reaches the Northern Lights terminal. Furthermore, any CO₂ emitted during the transport from Preem to Øygarden cannot be subtracted from the Preem emissions even though it has been captured by Preem. A contractual agreement between Preem and Northern Lights will need to account for this.

Outlook onto next steps for CCS at Preem refineries

Preem has announced their goal of net-zero CO₂ emissions by the Year 2035 (Preem, 2021), including scope 3 emissions. This implies, inter alia, a vast ramp-up of biogenic feedstock, thus allowing for bio-CCS and negative emissions. The results of the Preem-CCS project have led to initial planning of full-scale CCS implementation by Year 2026-2027. The next steps include a detailed presudy followed by FEED study and to initiate the EPC phase starting sequentially from 2022.
Table 1: Results of test campaign with Aker Carbon Capture’s mobile test unit (MTU). The unit captured CO2 from a slip stream of the flue gas of the steam methane reformer at Lysekil (CO2 content: 18-20vol% wet).

<table>
<thead>
<tr>
<th>Solvent campaign</th>
<th>Hours of operation [h]</th>
<th>Captured CO(_2) [t CO2]</th>
<th>Capture rates targeted [%]</th>
<th>Ammonia emissions [ppm]</th>
<th>Amine losses [kg/t CO(_2)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA</td>
<td>508</td>
<td>57</td>
<td>90;</td>
<td>20-100</td>
<td>1.1</td>
</tr>
<tr>
<td>S26</td>
<td>3047</td>
<td>363</td>
<td>90;</td>
<td>1-2</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Figure 1: Source of heat for amine solvent regeneration (a), the resulting heat supply cost when minimizing external energy demand (b) for CO\(_2\) capture at the Lysekil refinery. Adapted from (Biermann et al., 2022)

Figure 2: System boundaries of the CCS value chain analysis.
Table 2: CCS value chain cases considered in Preem CCS based on CO₂ sources: flue gas from the hydrogen production unit (HPU) via steam methane reforming (SMR), flue gas from the fluid catalytic cracker (FCC) regenerator; flue gas from two combined stack. Assumed baseline of CO₂ emissions for Lysekil: 1.855 Mt CO₂/a; for Gothenburg: 0.570 Mt CO₂/a

<table>
<thead>
<tr>
<th>Case</th>
<th>CO₂ source at the Preem refineries</th>
<th>Approx. capture (90% of yearly emissions of corresponding stacks) [Mt CO₂/a]</th>
<th>Transport pressure [barg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Lysekil: HPU flue gas (SMR)</td>
<td>~0.616</td>
<td>15</td>
</tr>
<tr>
<td>Case 1A</td>
<td>Lysekil: HPU flue gas (SMR)</td>
<td>~0.616</td>
<td>7</td>
</tr>
<tr>
<td>Case 2</td>
<td>Lysekil: HPU+ combined stack 2 (low sulphur)</td>
<td>~0.940</td>
<td>15</td>
</tr>
<tr>
<td>Case 3</td>
<td>Lysekil: HPU + FCC</td>
<td>~0.799</td>
<td>15</td>
</tr>
<tr>
<td>Case 4</td>
<td>Lysekil: HPU + FCC + combined stack 1 + 2</td>
<td>~1.581</td>
<td>15</td>
</tr>
<tr>
<td>Case 5</td>
<td>HPU flue gas in Lysekil and Gothenburg</td>
<td>~0.916</td>
<td>15</td>
</tr>
</tbody>
</table>

Figure 3: Avoidance cost, cost distribution, and annual CO₂ avoidance for the value chain cases 1-4. Case 1: HPU; Case 2: HPU + combined stack; Case 3: HPU + FCC; Case 4: HPU + both combined stacks + FCC

Figure 4: Potential captured CO₂, corresponding to the Preem CCS project cases compared to CO₂ to be captured in the Norcem and Fortum Oslo Varme (FOV) projects, which are part of the Longship Project (Norwegian Ministry of Petroleum and Energy, 2020; Regjeringen (Norwegian Government), 2020). Case 1+ GOT corresponds to Case 5 in Table 2.
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References


Preem (2021) We are bringing forward our climate target by ten years – from 2045 to 2035.


Keywords: CCS chain analysis; heat integration; full-scale CCS; pilot testing; post-combustion; Preem; Northern Lights; legal/regulatory aspects