Potential Impact of the Preem-CCS Project

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POTENTIAL IMPACT OF THE PREEM CCS PROJECT

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Abstract

The ongoing Preem CCS project investigates opportunities for CO_2 capture from the Preem refineries in Lysekil and Gothenburg, Sweden, with focus on the Lysekil refinery. The consortium members of this Norwegian-Swedish collaboration are Preem AB, Chalmers University of Technology, SINTEF Energy Research, Equinor Energy and Aker Carbon Capture. In this paper, we present the alternative carbon capture and storage (CCS) value chains that are being studied, together with the potential amounts of direct CO_2 emissions from production that can be captured in each case. We also discuss potential cost reduction factors for CO_2 capture at the Preem refineries, such as heat integration within the refinery and economies of scale, which may also be of relevance for reduction of capture costs for other Northern Lights partners. The implementation of CO_2 capture in the Preem refineries will be an important step not only for Preem but also for Sweden to reach their climate neutrality goals.

Keywords: *Preem, CCS, value chain analysis, Northern Lights, Longship*

1. Introduction

The target for Sweden to reach net-zero emissions by 2045 at the latest [1], [2] is highly likely to require deployment of carbon capture and storage (CCS), especially in the process industry. The proximity to Norway, with its plans to realize a full-scale CCS chain by 2024 [3], [4], presents opportunities to implement CCS from Swedish emission sources despite the lack of established large-scale CO_2 storage capacity in Sweden.

The vision of Preem AB (Publ) – or Preem – is: To lead the transition towards a sustainable society. Preem is the largest oil refiner in the Nordic region, and one of the largest emitters of fossil CO_2 in Sweden, with emissions from production in the order of 2 Mt/y from the refineries in Lysekil and Gothenburg. Preem has a climate neutrality goal for 2045 [5], and values CCS as an important building block for achieving this vision. The geographical location of Preem's operations on the Swedish west coast imply that the company is a potential early mover among possible international CO_2 suppliers to the planned Norwegian CO_2 transport and storage infrastructure.

The Preem CCS project investigates opportunities for CO_2 capture from the Preem refineries in Lysekil and Gothenburg in Sweden, and subsequent transport of the captured CO_2 for permanent storage beneath the seabed on the Norwegian Continental Shelf, within the Northern Lights project, as shown in Figure 1. The consortium members are Preem AB and Chalmers University of Technology, in Sweden, and SINTEF Energy Research, Equinor Energy and Aker Carbon Capture, in Norway.

Figure 1: Location of the Lysekil and Gothenburg refineries, the onshore terminal at Naturgassparken in Øygarden and final sub-sea storage in the Norwegian Continental Shelf. The Preem CCS project considers ship transportation of liquefied CO_2.

Preem CCS activities include:

- Investigation of heat integration opportunities in the Lysekil refinery and design of compact heat exchangers for residual heat utilization.
- Simulation of the CO_2 capture and conditioning process for different scenarios.
- Identification and analysis of possible CCS value chain alternatives integrated into the Norwegian full-scale CCS project.

- On-site demonstration of CO_2 capture from the hydrogen production unit in the Lysekil refinery [6], [7].
- Identification of actions to overcome regulatory barriers for transborder ship transport and storage of CO_2.
- Establishing a roadmap for CO_2 emission reduction pathways at Preem in the context of Swedish national targets (net zero-carbon emissions in 2045) [1], [2].

This paper focuses on the first three points mentioned above, specifically on the CCS value chain scenarios and the role of heat integration as well the potential impact of realizing CO_2 capture from the Preem refineries.

1.1 Structure of the paper

This paper is structured as follows. In Section 2, we present a generalized CCS value chain, the CO_2 capture possibilities in the Preem refineries and an overview of the scenarios studied within the Preem CCS project. In Section 3, we put into perspective the potential impact of Preem CCS within Sweden and in the Northern Lights project by comparing the potential CO_2 capture from the Preem refineries to the Longship project, which will implement CO_2 capture from the Norcem cement plant in Brevik and (probably) from the Fortum Oslo Varme (FOV) waste-to-energy plant. Section 4 presents some final comments.

2. CO_2 capture possibilities at Preem refineries

2.1 Emissions baseline

The CO_2 emissions baseline will be used to estimate the potential reduction in direct CO_2 emissions from production that could result from further development based on this project. In 2019 there was a planned 67-day shutdown at the Lysekil refinery [5], and therefore the emissions in 2019 were lower than in a typical year. For this reason, to establish the emissions baseline we consider CO_2 emissions data from all stacks at Lysekil in 2018, which were 1.702 Mt CO_2. Considering direct CO_2 emissions from production, the refinery in Gothenburg emitted 570 kt CO_2 in 2019 and 536 kt CO_2 in 2018 [5]. Considering 2019 data for the refinery in Gothenburg and 2018 for the refinery in Lysekil, the total emissions baseline for the two refineries is 2.272 Mt CO_2/y.

2.2 The Preem CCS value chain

The different CCS value chains evaluated within the Preem CCS project consider CO_2 capture from the Preem refineries in Sweden. The study considers CO_2 capture from the flue gases using an amine absorption process. Two different solvents are considered for modeling the CO_2 capture process: monoethanolamine (MEA) and a blend of piperazine/amino-methyl-propanol (PZ/AMP), suggested as a new benchmark solvent by IEAGHG/CSIRO [8], [9]. Captured CO_2 is then compressed and liquefied, conditioning it for ship transport to the Northern Lights facilities at Naturgassparken, for permanent sub-sea storage in the Norwegian Continental Shelf. Moreover, the effect on costs of selecting 15 bar or a reduced, 7 bar, transport pressure is also investigated [10]. Figure 2 depicts the main building blocks for the CCS value chains to be analyzed within Preem CCS. Note that the CO_2 capture process is assumed to predominantly utilize heat recovered from the refinery and a heat integration study is being performed within the project.

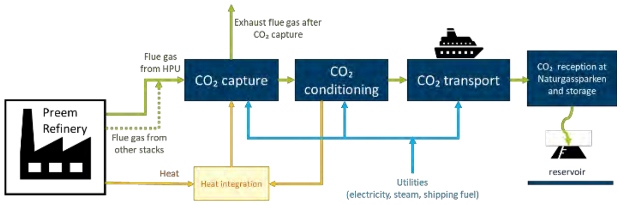

Figure 2: Generic block structure of the proposed CCS value chains evaluated in the Preem CCS project.

2.3 CO_2 capture scenarios

For the CCS chain analysis, several scenarios are evaluated, considering CO_2 capture from both single and multiple sources at the refinery in Lysekil as well as the refinery in Gothenburg. Ship-based transport solutions at 7 and 15 bar, linking up to the Northern Lights CO_2 storage infrastructure, are also considered within Preem CCS.

Table 1 summarizes the potential CO_2 capture with the different CCS scenarios to be analyzed within Preem CCS, considering a capture rate of 90%.

Table 1: Value chains studied within the *Preem CCS* project

Case	CO_2 source	Captured CO_2 [Mt CO_2/y]
A	HPU flue gas in Lysekil	~0.48
B	HPU and low-sulfur stacks in Lysekil	~0.81
C	HPU and all major stacks in Lysekil	~1.44
D	Lysekil HPU and Gothenburg	~0.78

The refinery in Lysekil is the focus of Preem CCS. Case A considers capturing CO_2 from the flue gas from the HPU (Hydrogen Production Unit) in Lysekil. This stack has the highest CO_2 concentration among all stacks in this site and the highest contribution to CO_2 emissions at the refinery. Therefore, Case A is considered the base case. Cases B and C consider capturing CO_2 emissions from other stacks in addition to the flue gas from the HPU. Case B considers capture from the HPU and another low-sulfur stacks. Case C includes the four major stacks and, potentially, up to 1.44 Mt/y could be captured in this case. Some of these stacks have varying sulfur content, which will affect the flue gas treatment requirements to avoid solvent degradation in the CO_2 capture plant [11]. This will impact the total cost [12] and footprint of the capture plant. In cases B and C, different clustering alternatives or configurations for the CO_2 capture facilities within the

Lysekil refinery (e.g. independent vs common equipment) will be considered in order to minimize the cost of capture maximizing captured CO_2. Case D considers capturing CO_2 from the HPU flue gas in Lysekil (as in Case A) and CO_2 from the gas in Gothenburg, which accounts for additional ~300 kt CO_2/y. The focus of Case D will be to estimate the effect of transportation costs on this type of cluster, with sites connected by ship. This case will provide insights for further development and optimization of shared CO_2 transport infrastructure.

2.4 Heat integration as an enabler for the Preem CCS project

The existence of residual heat within a facility, and its use for CO_2 capture, compared to the alternative of producing the heat with additional primary energy input has an important impact on the operating costs of the CO_2 capture facility. Therefore, energy efficiency and available or low-cost residual heat for the post-combustion absorption process have been identified as a key cost driver for carbon capture [13]. In other words, the cost of the heat used in the CO_2 capture process is critical for the overall feasibility and potential economic performance of CO_2 capture projects. It will also have an important effect on CO_2 avoidance costs [12]. This has been clearly highlighted in the economical and feasibility evaluations of the projects considered within Longship, the Norwegian full-scale project, which is described in Section 3 [13], [14]. In addition, the choice of heat supplying technologies, together with the overall amount of CO_2 capture, will impact the energy efficiency of the refinery and the CO_2 intensity (scope 1 and 2 emissions) of the refinery products.

For the reasons described above, analyzing the possibility to utilize residual heat and the development of a heat supply cost model are central activities within the Preem CCS project. The heat supply model will be used to investigate the choice of heat supplying technologies in the context of current or future energy and emission price regimes and identify the mix of technologies that supplies most heat at lowest cost and lowest emission impact, satisfying heat requirements of the CO_2 capture plant whilst considering variations of available heat over time. The design of heat collection networks, similar to previous works [15], [16], must be conducted within the context of such energy and emission price regimes and compared to alternative heating options. Biermann et al [17] have identified three potential classes of heat supply:

1. Existing sources of residual heat/steam,
2. unused capacity in boilers/equipment for heat/steam production,
3. new installation of heat supply capacity.

The role of unused capacity was not investigated in previous work by Biermann et al [17] but is being studied by investigating the interplay between switchable drives (electricity/steam) for pumps and compressors and heat recovery steam generators at the Preem refinery in Lysekil.

3. Potential impact of Preem CCS

3.1 Preem CCS within Northern Lights

The Northern Lights infrastructure is a natural option for offloading CO_2 from Preem's refineries, and a Memorandum of Understanding (MoU) has been signed between these two entities [22].

3.1.1. The Northern Lights and Longship projects

The Northern Lights project is part of the Norwegian full-scale carbon capture and storage (CCS) demonstration project and is the world's first large scale "open-source" infrastructure for receiving and storing CO_2 from multiple sources and industries. Equinor is executing the project, while Norske Shell and Total E&P Norge are equal partners [23], [24].

As shown in Figure 3, the Northern Lights project comprises transportation, reception, and permanent storage of CO_2 in a reservoir under the North Sea. The receiving terminal will be located at the premises of CCB Kollsnes AS, in the Naturgassparken industrial area in the municipality of Øygarden (Western Norway). This onshore plant will temporarily store liquid CO_2, which will be pumped from the storage vessels through a pipeline to an offshore injection well. Permanent storage is located approximately 2500 m below the seabed, south of the Troll field. The plant will be operated from Equinor's facilities at the Sture terminal in Øygarden, and the subsea facilities from the Oseberg A platform in the North Sea [23], [25]. The facilities are scheduled to be operational in 2024 [24].

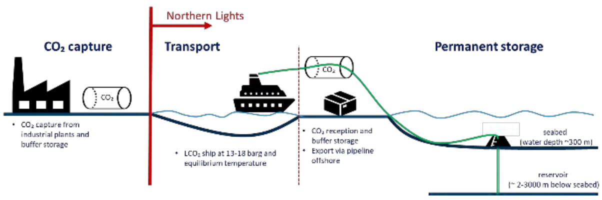

Figure 3 Northern Lights project as part of the Norwegian CCS demonstration project (adapted from [24]).

In late 2020, the Norwegian government made a positive investment decision for Northern Lights and Norcem's cement factory in Brevik, Norway, which plans to have a flat capture profile of 400 kt CO_2/y. In addition, Fortum Oslo Varme (FOV), a waste-to-energy plant with the potential to capture additional 400 kt CO_2/y, may get partial funding if the project secures sufficient own funding as well as funding from the EU or other sources. The full-scale project has been named "Longship" [26]. It should be noted that the Norcem Brevik capture costs are lower than Fortum Oslo Varme, mainly due to the low cost residual heat available from the cement process [13], [14].

Northern Lights is planned to be developed in two phases, with storage capacities of up to 1.5 and 5 Mt/y, respectively [23]. Different expansion scenarios, for up to 100 Mt/y have been explored [22]. Given the planned storage capacity and the capture profiles of the Longship project, Northern Lights has the flexibility to receive and store additional 0.7 Mt/y CO_2 from third parties[1], such as Preem, also in the first phase [23]. The access for third parties has in fact been prioritized during the design of the Northern Lights project [13].

3.1.2. Potential impact of Preem CCS within the Northern Lights project

Capture cases analyzed within the Preem CCS project are described in Table 1 in Section 2. Figure 4 compares the CO_2 that could potentially be captured in the alternative Preem CCS cases with the CO_2 to be captured in Norcem Brevik and FOV, the facilities considered in the Longship project. All cases evaluated within the Preem CCS project consider a larger amount of CO_2 captured than the CO_2 captured (individually) at the facilities included in the Longship project.

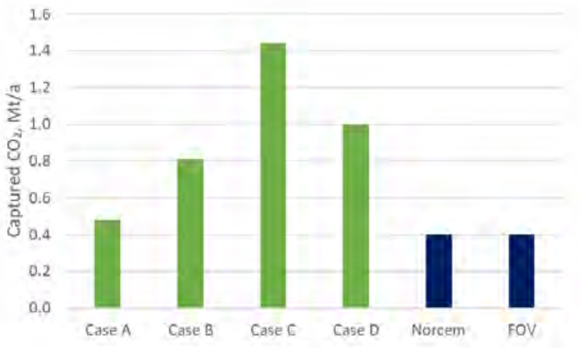

Figure 4: Potential captured CO_2 corresponding to the Preem CCS project cases (Table 1) compared to CO_2 to be captured in the Norcem and FOV projects (Longship project).

Case A, capturing ~480 kt CO_2 /y, which corresponds to ~90% of the CO_2 in the flue gas from the HPU at the Lysekil refinery, is the case with the lowest amount of captured CO_2 among all the possible alternatives considered within the Preem CCS project. This amount of CO_2 is nonetheless higher than the expected 400 kt CO_2/y to be captured at the facilities in the Longship project. Cases B and D correspond approximately to the combined CO_2 captured of the two Longship facilities. Note that if these cases are realized, the excess capacity of the first phase of the Northern Lights project would be exceeded, assuming that the FOV project is implemented. Case C, capturing from all major refinery stacks, has the potential to capture more than 90% of the first phase of the Northern Lights project, which implies that it would need to be implemented in the second phase of the Northern Lights project. Therefore, Preem could potentially be the anchor supplier that could trigger the expansion to 5 Mt/y storage capacity of the Northern Lights project [22].

3.2 The impact of scale

In Section 2 we discussed heat integration for cost reduction as an enabler for the implementation of the results from Preem CCS project. Another important enabler is the scale of the captured CO_2. Roussanaly et al. [12] illustrated that CO_2 transport and storage costs can sharply decrease with higher CO_2 flow rates due to economies of scale considering different scenarios such as transport distances, both via pipeline and shipping, and storage sites.

The specific costs of the Norwegian full-scale project are relatively high compared with estimated costs for future developed full-scale capture sites and value chains. This is due to an overcapacity and costs are expected to be brought down by several factors. The cost per ton of CO_2 is expected to decrease significantly when the value chain capacity is fully utilized from 0.8 to 5 Mt CO_2 per year. Therefore, utilizing third party volumes is regarded as a key driver for more affordable CCS for all Northern Light partners [13]. As quantities of CO_2 to be captured from the Preem refineries are higher than the CO_2 captured from the facilities in the Longship project, cost per ton for Preem's CO_2 is expected to be lower than the initial cost for the Longship project. This will also reduce the average unitary costs, which might be especially beneficial for small emitters [12], which may also use the Northern Lights facilities.

It should also be noted that in Cases A and D, CO_2 would be captured (at least partly) from flue gas from HPUs and the cost of capture from processes for hydrogen production from fossil methane is expected to be lower than the cost of capture from cement and waste to energy plants [13], further contributing to reducing the cost per ton for Preem's CO_2.

3.3 Impact of Preem CCS for achieving Sweden's sustainability goals

In 2017, Sweden announced the goal of reaching net zero emissions by 2045 at the latest and passed a new Climate Act legally binding this commitment [2], [18]. This target responds directly to the United Nations' sustainable development goal (SDG) 13, which is to "take urgent action to combat climate change and its impacts" [1].

In 2018, the total CO_2 emissions in Sweden were ~41.8 Mt [19], [20], of which ~16.4 Mt corresponded to the industrial sector [21]. As described in Section 2, Preem's CO_2 emissions from production are in the order of 2 Mt/y. Figure 5 illustrates the industrial CO_2 emissions in Sweden and Preem's contribution.

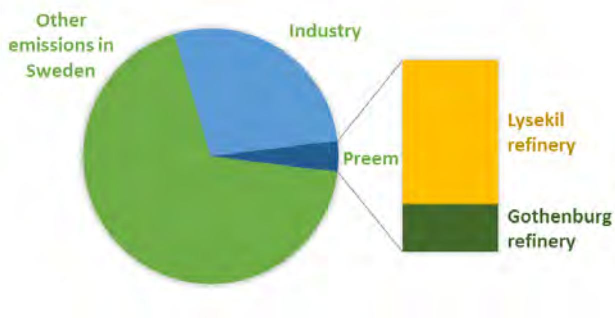

Figure 5: Contribution of Preem's CO_2 emissions to total fossil emissions in Sweden in 2018.

[1] This value considers that the FOV project will be financed.

Reducing these will be a major enabler to reach Sweden's sustainability goals. It should be noted that the CO_2 captured will depend on which case, among those described in Table 1, is implemented. Preem is pursuing an increase in advanced biofuels production, in both their refineries in Lysekil and Gothenburg. This will bring an increased possibility for Bio-CCS with *negative* CO_2 emissions as more renewable feedstock is used at the two refinery sites, which will enable reaching Preem's climate neutrality goal for 2045 [5]. This will also contribute to reaching Sweden's goal for net zero emissions by 2045.

4. Final comments

The Preem CCS study and subsequent implementation of CO_2 capture from Preem's refineries differs from the Longship project in the following aspects:

a) The possibility of CO_2 capture from different stacks, each from different processes and with different compositions and CO_2 content. This enables analyzing and comparing different clustering configurations of the CO_2 capture facilities.

b) The cost of heat is known to be critical for the overall feasibility of CO_2 capture [13], [14]. Preem CCS will quantify the effect of heat integration in a refinery environment, which will bring valuable insights for similar projects.

c) From the transport point of view, Preem CCS will bring quantitative insights with respect to the 7 and 15 bar options, as well as the convenience of joint transport of CO_2 from different locations (Lysekil and Gothenburg). In addition, the implementation of the project will bring experience with respect to cross-border transport of captured CO_2 from Sweden to Norway.

Therefore, Preem CCS brings additional insights compared to other projects considered within Northern Lights, and thus can be considered as a first of a kind project and the lessons learned from Preem CCS and the full-scale implementation of CO_2 capture in the Preem refineries will enable future CCS projects.

The outcome of the Preem CCS project will be to establish a roadmap for CO_2 emission reduction pathways at Preem's two refineries in Sweden in the context of national emission reduction commitments, considering the strategic implementation of CO_2 capture in relation to possible future development pathways at the refinery.

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