Business Models for CCS in the Swedish Cement Industry

Master's thesis in Supply Chain Management and Management of Economics and Innovation

RENATO ROOS RADEVSKI
KEVIN ZHAO

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024
www.chalmers.se

Business Models for CCS in the Swedish Cement Industry

Renato Roos Radevski
Kevin Zhao

Department of Technology Management and Economics
Division of Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2024

Business Models for CCS in the Swedish Cement Industry
RENATO ROOS RADEVSKI
KEVIN ZHAO

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Gothenburg, Sweden 2024

Business Models for CCS in the Swedish Cement Industry

RENATO ROOS RADEVSKI
KEVIN ZHAO

Department of Technology Management and Economics
Chalmers University of Technology

SUMMARY
This thesis explores the potential design of a carbon capture and storage (CCS) business model of the Swedish cement industry on Slite, Gotland, a major contributor to Swedish CO_2 emissions. As the industry seeks pathways to achieve carbon neutrality in alignment with the European Union's climate targets, this research identifies and evaluates potential CCS logistics and business models tailored for its unique challenges and opportunities. Utilising a qualitative research methodology, this thesis synthesises data from extensive literature reviews, grey literature, and semi-structured interviews with key stakeholders across the CCS supply chain in the Nordic region. Based on the information collected, a thematic analysis is performed in order to propose a potential design of a business model according to the business model canvas framework for the Swedish cement industry. Thereafter, the discussion focuses on the market dynamics, economic viability, and regulatory considerations affecting the business model.

Our findings suggest that while CCS presents a viable technology for substantial CO_2 reduction in cement production, its successful implementation is currently not possible and contingent on overcoming significant logistical, financial, and regulatory barriers. Notably, the chicken-and-egg causality dilemma is heavily prevalent in CCS in the Nordic region, as high market and supply chain uncertainty have resulted in a deadlock between actors. We propose a potential business model that addresses logistical complexities and provides value to make CCS a sustainable and profitable venture in the Swedish cement industry.

This research contributes to the academic literature by detailing the interaction between CCS logistics and business models, providing a view for industry stakeholders to see the transition towards sustainable cement manufacturing in Sweden.

Keywords: CCS, Business models, Business model canvas, Swedish cement industry, CCS logistics.

Acknowledgements

This thesis has been conducted in collaboration with the Research Institute of Sweden (RISE) and Chalmers University of Technology within the department of Technology Management and Economics during the spring semester of 2024.

We would like to express our deepest gratitude to our supervisor, Ivan Dario Barbosa Cardenas, for his continuous support and guidance throughout the entire project. We would also like to extend our heartfelt appreciation to RISE and Per Wide, who has supported our thesis and provided valuable feedback and guidance. Finally, we would like to acknowledge all the interviewees who has participated in our thesis. Their extensive knowledge and insightful contributions have been fundamental to this thesis. Without their involvement, this work would not have been possible.

Renato Roos Radevski & Kevin Zhao
Gothenburg, May 2024

Table of Contents

List of Abbreviations

BECCS	Bio-Energy with Capture Capture and Storage
BMC	Business Model Canvas
CAPEX	Capital Expenditures
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
EU	European Union
ETS	Emissions Trading System
FEED	Front-end Engineering Design
FID	Final Investment Decision
ISO	International Organization for Standardization
LNG	Liquid Natural Gas
OPEX	Operating Expenses
WHO	World Health Organization

1. Introduction

In this chapter of the thesis, a background is presented along with the purpose of the thesis. In addition, the research questions, scope, and limitations of the thesis are presented.

1.1 Background

The world is facing increasing challenges as a consequence of climate change, a phenomenon resulting from increased CO_2 emissions and recognized by the World Health Organization (WHO) as one of the greatest threats to public health and well-being in the 21st century (World Health Organization, 2023). In response to the challenges regarding carbon emissions, the European Union (EU) has committed to ambitious climate targets, aiming to achieve carbon neutrality by 2050 (European Commission, n.d. -a). One of the cornerstones of the EU's policy to mitigate climate change and EU's key tool for reducing greenhouse gas emissions cost-effectively is the EU Emissions Trading System (EU ETS), a 'cap and trade' system (European Commission, n.d. -b). EU ETS enables the trade of carbon emission allowances, financially punishing heavy emitters who exceed their allowances, and provides an opportunity for sustainable companies to profit from their efforts (European Commission, n.d. -b).

Aiming for carbon neutrality to avoid punitive measures such as EU ETS as an industry necessitates a comprehensive overhaul of energy systems, industrial processes, and transportation practices. The cement industry, as a key actor in construction and infrastructure development, plays a pivotal role in global CO_2 emissions, being the second-largest emitter within the industrial sector (Roussanaly et al., 2021; Andrew, R. M., 2018). Cement production is inherently energy-intensive and relies on high-temperature processes, such as calcination, which release significant amounts of CO_2 into the atmosphere (Barcelo et al., 2014). In Sweden, the cement industry accounts for 4% of the country's emissions, underscoring the sector's importance in CO_2 emission mitigation efforts (Fossilfritt Sverige, n.d). Due to the inherent CO_2 emitting processes of the cement industry, the industry could face high fees and taxation by the EU ETS on their unavoidable CO_2 emissions coming from their production processes.

Carbon capture and storage (CCS) has emerged as a promising technology for mitigating the inherent CO_2 emissions from industrial processes during cement production (Martin-Roberts et al., 2021). CCS involves capturing CO_2 emissions from industrial sources, transporting the captured CO_2 to suitable storage sites, and securely storing it to prevent its release into the atmosphere (Svensson et al., 2004). The captured CO_2 can be stored in geological formations, such as depleted oil and gas reservoirs or deep saline aquifers, where it can be safely stored for centuries (Roussanaly et al., 2021).

Despite being widely regarded as a crucial component of efforts to meet national and international climate change mitigation goals, the widespread adoption of CCS in energy-intensive sectors such as the cement industry have had persistent challenges with few projects implemented to date (Martin-Roberts et al., 2021; Yao et al., 2018; Thepsaskul et al., 2023; Dávila & Aagesen, 2024). One such challenge is the design of appropriate CCS business models, since there are immense costs when implementing CCS, encompassing the capture, transport, and storage of the emitted CO_2 (Kheshgi et al., 2009). The business model details the blueprint to successfully run a business by affecting the firm's possibilities for value creation, value capture, and mapping out the allocation of risks and rewards (Zott & Amit, 2010; Kapetaki & Scowcroft, 2016). Therefore, to counter the costs of implementing CCS and establish a financially viable business case for the Swedish cement industry, there is also a need to explore and find new value propositions and additional revenue streams as a result of implementing CCS (Dávila & Aagesen, 2024).

The possibility to properly design each component to make a viable CCS business model for the Swedish cement industry is heavily dependent on the current situation in the industry. Currently, investing in CCS involves significant uncertainty, particularly regarding future CO_2 prices and policy frameworks (Oei & Mendelevitch, 2016). Gassnova (2020) also identifies the uncertainty regarding business models and how to divide costs between industry and the state as a potential risk to CCS implementation. Some additional challenges regarding investments in CCS include high initial costs, regulatory uncertainties, and the need for supportive policy frameworks (Martin-Roberts et al., 2021).

A viable business model incentivises more companies to enter the market and it provides value to the policymakers as well (Kapetaki & Scowcroft, 2016). Therefore, proper design of a CCS business model is of high importance for many stakeholders, as an inappropriate business model would create undesired economic results, which negatively affects the overall development and adoption of CCS. Thus, exploring a potential business model for CCS in heavy emitting industries such as the Swedish cement industry and what factors are impacting could provide valuable insights for many and aid the effective advancement of CCS adoption.

1.2 Aim and research questions

The aim of this thesis is to explore the potential design of a CCS business model for the Swedish cement industry and understand the impact of current external factors on its implementation. Specifically, the thesis will explore the CCS development in the Nordic region and map out the components of a CCS business model for the Swedish cement industry according to the business model canvas framework and investigate what factors affect the business model.

Therefore, the thesis strives to answer the following research question:

> *Which key components of the Business Model Canvas are necessary for the implementation of CCS for the Swedish cement industry?*

To answer the research question, the following specific research questions are formulated:

1. *What are the current developments in CCS in Sweden and the Nordic region?*

2. *What are the components of a CCS business model canvas for the Swedish cement industry?*
3. *What are the key factors affecting the implementation of the CCS business model in the Swedish cement industry?*

1.3 Scope and Limitations

The scope of this thesis encompasses the business perspective on the logistics of Carbon Capture and Storage (CCS) in the Swedish cement industry, more specifically, the Swedish cement industry on Slite, Gotland, where the vast majority of Swedish cement is produced. Regionally, the scope limits itself to the nordic region.

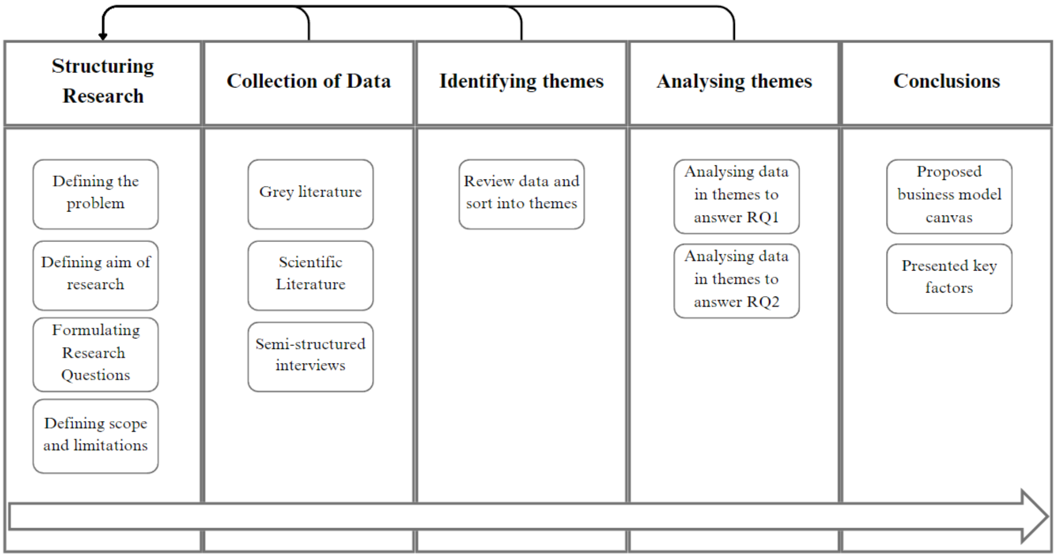
This thesis faces limitations related to its qualitative approach, focusing primarily on semi-structured interviews and reports for data collection with limited amounts of numerical and calculative data. The reliance on these methods may restrict the amount of industry perspectives and the generalizability of findings. Furthermore, since the scope is confined to the Swedish cement industry, it may limit the applicability of conclusions to other sectors or regions. The thesis will primarily limit itself to the dimensions surrounding the logistics setups and will not delve deep into costs and other factors connected to the deployment of CCS technologies at the production facilities.

2. Research Methodology

In order to answer the purpose of the thesis, the thesis has relied on a qualitative research method as can be seen in figure 1, since qualitative research allowed the thesis to capture the intricacies of stakeholder perspectives, operational challenges, and strategic opportunities in CCS business models (Bell et al., 2022). Literature studies of both scientific articles and grey literature together with semi-structured interviews served as the main methods of data collection, which enabled a flexible yet comprehensive exploration of the subject matter by providing relevant information from literature along with the interviewees' perspectives and insights.

The following chapter presents the format of the literature- and interview study as well as the chosen method of analysis. Additionally, a review of the thesis's method and ethical adherences are provided.

Figure 1. *Research methodology*



2.1 Scientific literature study

To ensure that the literature study was based on peer-reviewed scientific articles, the database Scopus by Elsevier was utilised as recommended by Chalmers Library (2024). This database was recommended due to the wide range of important scientific publications within science and engineering areas. The keywords that were used for the articles were, among others, "CO_2 logistics", "Carbon Capture and Storage (CCS)", and "CO_2 transport and storage". These keywords were used independently or together. To increase the flexibility of results in databases, query methods were applied to some keywords. For example, "CO_2 logistic*" presented articles with keywords about "CO_2 logistic" with various inflections. Furthermore, keywords were adjusted and added when deemed both relevant and interesting throughout the thesis.

2.2 Grey literature study

Grey literature such as industry reports, documents and relevant publications were included in the overall literature study and provided the foundation of the findings of this thesis. To find relevant grey literature, content from existing companies in the Swedish cement industry, as well as literature from surrounding projects and activities in the Nordic region were searched for. Additionally, snowballing was used as the interviewees and literature also referred to useful literature within the subject (Bell et al., 2022).

2.3 Semi-structured Interviews

Semi-structured interviews were conducted with key stakeholders who actively participate in the implementation of CCS in Sweden. This method allowed for nuanced results while providing the flexibility to explore emerging themes (Bell et al., 2022). Furthermore, semi-structured interviews promoted insights from the perception of particular events, such as changes in regulations and guidelines within the CCS industry (Bell et al., 2022; Pettigrew, 1985). In order to strengthen the consistency and structure of the interviews, resulting in better research data as mentioned by Bell et al. (2022), an interview guide was created and adjusted throughout the process. The structure of the interview guide consisted of fewer questions of a broader nature focusing on the research questions, which allowed enough flexibility for additional questions and discussions about emerging topics or deeper exploration into specific questions of interest and relevance. The interview guide can be found in appendix A.

According to Eriksson et al. (2008), performing interviews digitally is beneficial in terms of accessibility, interactivity, control, and response rate from the interviewees. Therefore, the interviews were conducted digitally, mostly to gain the benefit of accessibility and response rate. Additional benefits include the potential to record interviews which enables more focus on the conversation instead of notetaking, and being able to limitlessly review the material afterwards, increasing the quality, control, and analysis of the interview (Dovelius, 2000). Permission to record interviews was requested beforehand in order to maintain a good research ethic.

2.3.1 Interviewee selection method

The stakeholders who participated in the thesis were selected using a purposive sampling method (Bell et al., 2022) Purposive sampling is a sampling technique used in qualitative research in order to identify and select knowledgeable stakeholders using limited resources (Palinkas, 2015). This technique can often create variety in the sample so that they differ in terms of key characteristics such as knowledge and roles (Bell et al., 2022; Palinkas, 2015). Additionally, the interviewees availability and their willingness to participate and share information were also assessed during the selection (Palinkas, 2015).

For this thesis, the stakeholders have been separated into different categories: emitters, transporters and storage actors. These categories are based on their respective role within CCS logistics and candidates are chosen from each role. This method ensured that the sample would have a variety in their knowledge so that a holistic perspective could be constructed after the different interviews (Bell et al., 2022).

2.3.2 Interviewees

Interviews were done with interviewees from different companies and organisations, each meeting some of the requirements set by our scope and limitations. An overview of preliminary candidates and performed interviews can be seen in Table 1.

Table 1. *Overview of conducted interviews throughout the thesis.*

Anonymous Tag	Company	Role in CCS logistics	Interview date	Duration [min]	Transcribed
A	Chalmers University of Technology	Researcher	2024-02-19	66	Yes
B	Heidelberg Materials Brevik	Emitter	2024-04-12	46	No
C	Geological Survey of Sweden	Storage	2024-04-05	58	Yes
D	Växjö Energi	Emitter	2024-03-20	55	Yes
E	Port of Stockholm	Transportation	2024-03-21	61	Yes
F	Nordion Energi / CinfraCap	Transportation	2024-03-08	54	Yes
G	Stockholm Exergi	Emitter	2024-04-12	58	Yes
H	Öresundskraft	Emitter	2024-05-02	53	Yes
I	Heidelberg Materials Slite	Emitter	2024-05-06	63	Yes

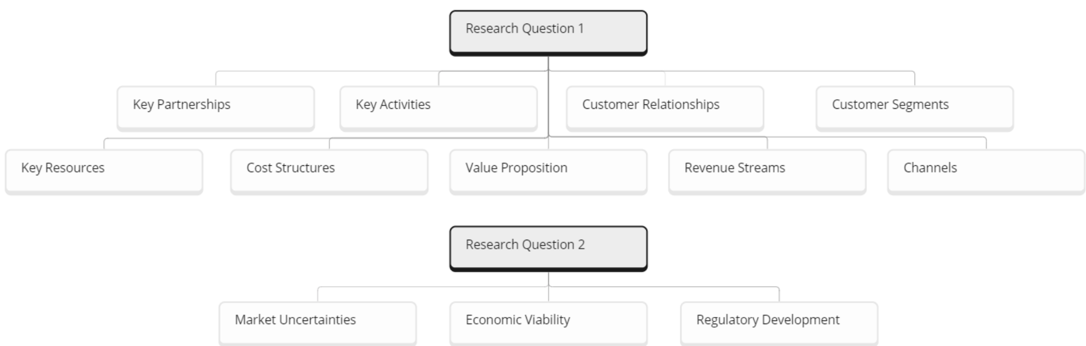
2.4 Analysis of data

During the interview phase, ongoing analyses were conducted to both familiarise with the data and review it. Patel and Davidson (2011) note the benefits of continuous analysis in qualitative research to identify if interviews deviate from expectations. Analysing immediately after each interview kept the content fresh in memory, facilitating a more vivid engagement with the material (Bell et al., 2022). Post-interview, the data was compiled for qualitative analysis. Flick (2018) describes this process as interpreting and classifying linguistic or visual material to reveal its contents. Initial steps include organising and processing the material, such as transcribing recorded interviews and tidying potential notes (Flick, 2018). Any gaps in knowledge deemed necessary to fill were identified and focused on during further literature data collection or interviews, creating a reiterating process. Only one interviewee, Heidelberg Materials Brevik declined the permission to record and transcribe the interviews. This was due to the high level of secrecy that the company had on their CCS activities as one of the pioneering companies and pilot projects in the field, which has a planned start for 2025.

2.4.1 Thematic Analysis

Thematic analysis was used to analyse the collected data. Thematic analysis is a common method of analysis in qualitative research used for identifying, analysing and reporting patterns (themes) within the data (Bell et al., 2022; Braun & Clarke, 2006). A theme is defined as something important about the data in relation to the research question and represents some level of meaning or response pattern within the data (Braun & Clarke, 2006). Themes were identified throughout the data collection process, but only the themes relevant to the research questions for this thesis were kept, which can be seen in figure 2.

Figure 2. *Identified themes in the thematic analysis connected to the research questions*



Once the data from interviews and literature no longer provided new information for the themes, or sub-themes, the data collection phase ended and focus shifted to reviewing the themes and extracting the most relevant data (Braun & Clarke, 2006). The extraction of the relevant data formed the analysis and discussion where each research question is answered and summarised in the conclusion.

2.5 Research Quality

Bell et al. (2022) points out several advantages as well as disadvantages of using secondary data as a method. The advantages of using existing literature, studies and data are the savings in cost and time, accessing high-quality data and the possibility to analyse different subsets of data (Bell et al., 2022). Given the limited timeframe and resources for this thesis, as well as the complexity of the CCS ecosystem, secondary data were used which allowed the thesis to include more aspects of CCS to the business model, offering a more holistic perspective. However, some disadvantages of secondary data include a lack of familiarity with the data, the complexity of the data and having no control of the data quality (Bell et al., 2022). Factors such as reliability and validity become crucial to ensure that the thesis is of high-quality. To address these disadvantages, the usage of trustworthy databases such as Scopus and government agencies were prioritised to enhance reliability and validity.

Risks mentioned by Bell et al. (2022) on interviewing for qualitative research involve the intrusion of own biases and expectations, maintaining focus in asking questions, and adverse effects from dealing with sensitive issues. Moreover, there is always a risk of subjectivity in the answers from the interviewee that has a much larger impact on the overall result of the thesis in a qualitative thesis than quantitative (Svensson, 2015; Wallén, 2008). To prevent mentioned risks, notes and any uncertainty regarding the authors' understanding of the data from the interview were conveyed to the interviewee afterwards for clarity and correction.

2.6 Research Ethics

Adhering to ethical principles in qualitative research, this thesis emphasised informed consent, confidentiality, and the participant's right to withdraw at any time prior to publication. As outlined by Bell et al. (2022), ethical considerations will be rigorously observed, including the handling of sensitive information, especially in environments such as research institutions and companies. Before the interviews began, respondents were fully briefed on how the information will be used, with interview data being shared internally unless consent for broader dissemination is granted. Any personal identifiers from interview participants were only used if explicit permission was obtained, ensuring ethical integrity and respect for privacy throughout the research process.

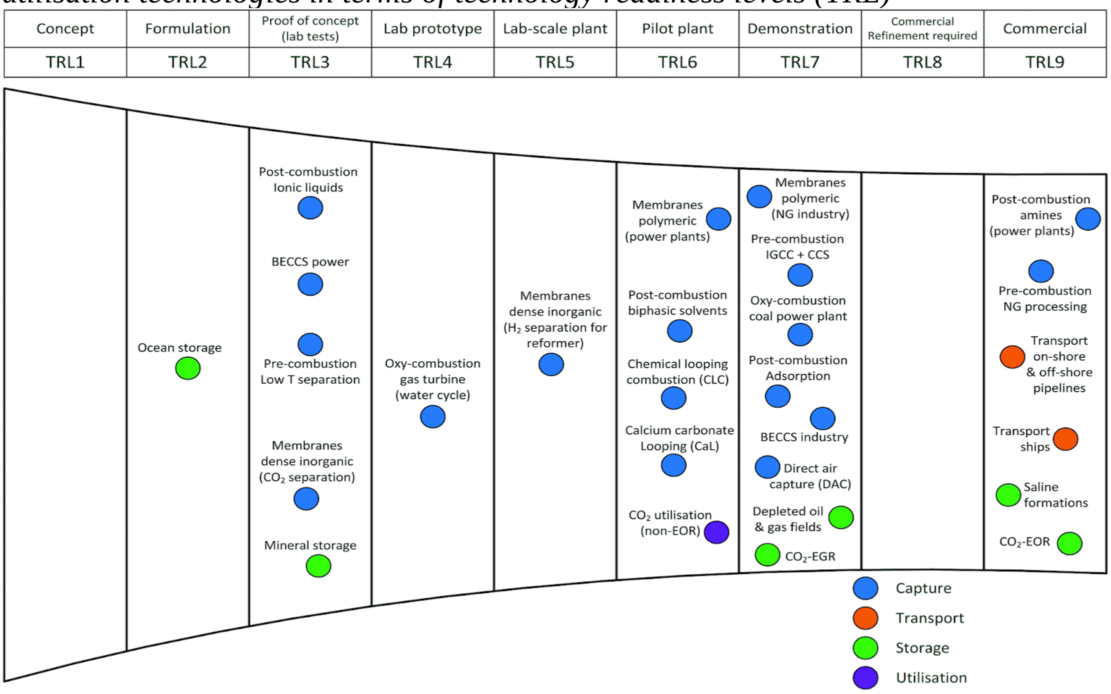
3. Frame of reference

This chapter provides the foundation for the thesis gathered by the extensive literature study of both scientific literature and grey literature, presenting the current situation regarding CCS in the Nordic region and the business model canvas framework applied in the analysis. The findings of this literature study provides depth to the themes identified and necessary information in order to answer the research questions.

3.1 What is carbon capture and storage?

CCS encompasses a range of methods for capturing, transporting, and storing CO_2 (Budinis et al., 2018). Bui et al. (2018) means that the main driver of development of CO_2 capture technology was due to its capability of enhanced oil recovery. Moreover, the technology for capturing CO_2, transport, and storage is mature and available with continuous development by different actors (Bui et al., 2018). Whilst the technology itself is mature as can be seen in Figure 3, one risk associated with the whole CCS chain is the dependency on each successful development and operation of the other parts of the chain (Gassnova, 2020). Recent advancements have focused on improving the efficiency and reducing the costs of CCS technologies, which are crucial for wider adoption (Roussanaly et al., 2021; Rajabloo et al., 2023).

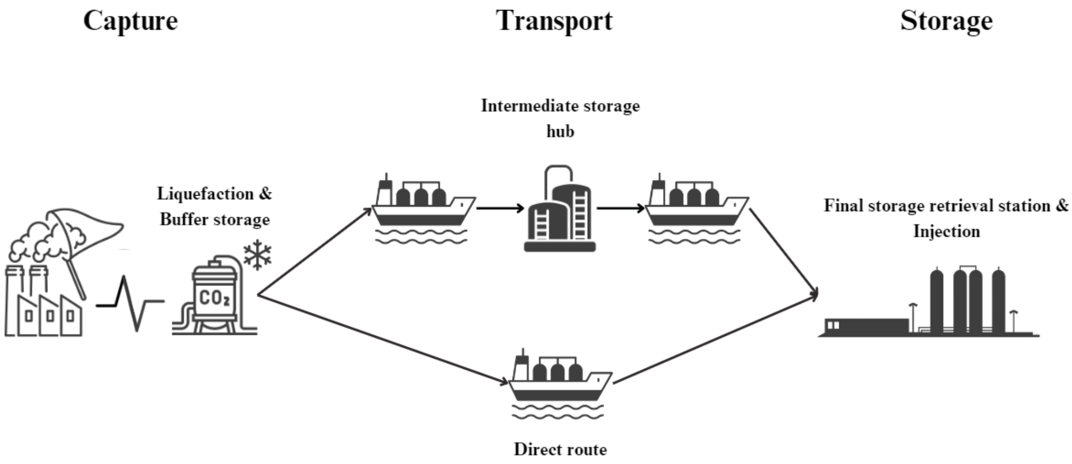
Figure 3. *The current development progress of carbon capture, storage and utilisation technologies in terms of technology readiness levels (TRL)*



Note. The list of technologies is not intended to be exhaustive (Bui et al., 2018) Creative Commons Attribution 3.0.

The economic viability of CCS projects is influenced by various factors, including the costs of capture technology, transportation, and storage (Kearns et al., 2021). Recent studies have aimed at providing more accurate cost evaluations, taking into account the multifaceted nature of industrial emissions and the potential for cost reductions (Svensson et al., 2004; Roussanaly et al., 2021; Knoope et al., 2015). A visualisation of the CCS logistics chain that the thesis has focused on for the Swedish cement industry can be seen in Figure 4.

Figure 4. *Overview of the general CCS logistics sections for the Swedish cement industry*

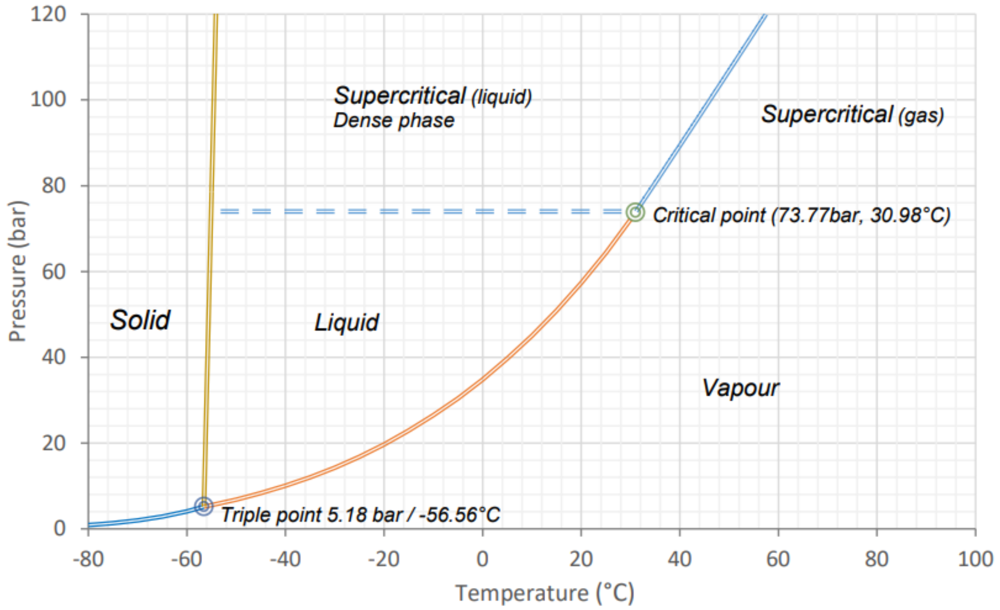


3.2 Carbon Dioxide

Orchard et al. (2020) describes that CO_2 only naturally exists as either a solid or gas at atmospheric pressure, in contrast to natural gas. At normal conditions, CO_2 is lighter than air, which affects the gas' dispersion during leakage (COWI, 2021). Its states are shown in Figure 5, where each field represents gas (vapour) phase, solid phase, and supercritical liquid phase, which is also commonly referred to as the "dense phase". The dense phase is beneficial when transporting for longer distances due to the fact that the density is higher than liquid, and has lower pressure drop than gas (COWI, 2021; Deng et al., 2019).

The triple point is placed where the three main phases meet. At this point, only temperature changes will result in a transition from solid to gas and vice versa (COWI, 2021; Deng et al., 2019). Since CO_2 does not enter a liquid phase at atmospheric pressure, it means that it needs to be pressured to be transported. COWI (2021) explains that any decrease in pressure below the saturation line caused by, for example, malfunctions or leakage will result in the creation of dry ice. Any contamination in the form of other gases mixed with the carbon dioxide will affect the critical point (COWI, 2021; Deng et al., 2019).

Figure 5. *Phase diagram of pure CO_2 based on the Span and Wagner equation of state (Taken from Deng et al., 2019)*



3.3 Capture

The choice of technology for CO_2 capture often depends on the specific industrial process and its inherent CO_2 emission characteristics (Budinis et al., 2018; Rajabloo et al., 2023). Budinis et al. (2018) identifies methods consisting of pre-combustion capture, post-combustion capture, and oxy-fuel combustion. Rajabloo et al. (2023) states that post-combustion capture is currently the most mature alternative to capturing CO_2 and forms the foundation of the current infrastructure of CCS. Post-combustion technology has been implemented by many industries and also by Heidelberg Materials Brevik (Heidelberg Materials, 2023). However, the costs and risks associated with the establishment and running of the capture plants are divided between the Norwegian government and Heidelberg Materials Brevik, these subsidies are a strong factor that contributed to the CCS implementations for the facility in Brevik (Energimyndigheten 2024). Heidelberg Materials Cement Sverige (2023) describes that the Swedish cement industry located around Slite, Gotland, responsible for 75% of Sweden's cement production, aims to capture around 1,8 million tonnes of carbon dioxide per annum, which covers their annual amount of CO_2 emissions. In total, Heidelberg Materials Cement Sverige (2024) plans on making an investment decision of 10 billion SEK for this project.

CCS capturing consists of two main steps outside of the actual capturing of CO_2 done during the production process (Deng et al., 2019). These steps are liquefaction and buffer storing. Once those steps are performed, the liquid CO_2 can be prepared for transportation at the closest port. After CO_2 is captured from a facility, it typically needs to be liquefied for subsequent transport. This liquefaction process involves compressing and cooling the CO_2 to appropriate pressure and temperature levels (Deng et al., 2019). The liquefaction process can be divided into four sections: 1. The CO_2 compression train, 2. The pre-cooler, liquefier and flash tank, recirculation flash and compressor, and lastly, the ammonia refrigeration cycle (Deng et al., 2019). In addition, the liquid CO_2 needs to be conditioned according to the quality requirements of exporting liquid CO_2 to prevent risks such as corrosion or health hazards throughout transportation and final storage (Energiforsk, 2022). According to the requirements for receiving CO_2 by Northern Lights in its first phase, upon arrival at the port in Norway, the CO_2 should have a pressure of about 16 bar and a temperature of approximately -25°C (Energiforsk, 2022). Northern Lights has indicated the possibility of accepting different pressure and temperature levels in a later phase. If the temperature and pressure of the CO_2 are close to the saturation line, a slight increase in temperature or a loss of pressure could cause some of the CO_2 to revert to gas phase, hence CO_2 is often slightly supercooled.

The compression and cooling of CO_2 is highly energy-intensive, with the CinfraCap project estimating an energy requirement of about 40-60 kWh per ton of CO_2, in addition to a cooling need of around 170 kWh per ton of CO_2 (COWI, 2021). The same project notes that liquefaction and buffer storage constitute a significant portion of the investment costs, accounting for about 30-35%. Currently, Heidelberg Materials Cement Sverige (2023) has a maximum load of 45 MW, which is 300 GWh annually, and estimates that the implementation of carbon capturing will increase their electricity needs and power requirements to roughly 1,5 TWh annually and a maximum load of 250 MW.

3.4 Transport

The transportation of captured CO_2 to storage sites is a critical component of the CCS value chain (Kearns et al., 2021). Options include pipelines and shipping, with the choice depending on distance, volume of CO_2, and geographical and logistical considerations (Kearns et al., 2021). Each mode has its advantages and challenges, including investment and operational costs, flexibility, and safety concerns (Svensson et al., 2004). Comparative analyses suggest that a mix of both pipelines and ships may be required to address the diverse needs of CCS projects (Svensson et al., 2004; Knoope et al., 2015). Pipeline transport, while involving higher investment costs, offers lower operational expenses compared to other modes (Svensson et al., 2003; Roussanaly et al., 2021) . However, depending on the length and route, concessions may be required, making pipelines across large land distances in Sweden unlikely, although they could be considered within a facility, an industrial area, a port, or at sea (Roussanaly et al., 2021). Kjärstad et al. (2016) presents the break-even point as a function of distance and volume between both means of transport. The captured CO_2 can be transported either directly to the storage site or via an intermediate storage location, such as a storage hub by a port, using ships, trains, trucks, or pipelines, depending on the capture facility's location (Energiforsk, 2022). CO_2 is not being named as a hazardous substance in the 2012/18/EU Seveso Directive, but its health hazard in high concentrations could necessitate specific handling regulations based on the handled amount, as highlighted by Romson & Steen (2021). Orchard et al. (2020) states that both pressure and temperature affect a large number of the components of the supply chain including material choices, transport volumes and safety considerations. Currently, medium pressure (-30 to -20°C, 15-20 barg) is used for CO_2 transportation with smaller volumes and has been adopted as the transport pressure for early CCS projects (Orchard et al., 2020). However, lower pressures (-55 to -40°C, 5-10 barg) has been proposed by Orchard et al. (2020) to be the most cost-effective and is considered the only viable option for ship sizes above 10000 tonnes of CO_2.

3.4.1 Transboundary CO_2 Transport

Transportation of CO_2 was previously not an option due to the London Protocol (Biermann et al., 2022). Initially established to protect marine environments from waste dumping, the protocol inadvertently created a barrier to offshore Carbon Capture and Storage (CCS) activities as it did not recognize CO_2 as a permissible waste for seabed storage (Biermann et al., 2022). Furthermore, it explicitly banned the transborder transport of wastes, including CO_2, for storage in other countries (Biermann et al., 2022). This restriction hindered the progress of CCS initiatives aiming to store CO_2 beneath the seabed across borders. Recognizing the need for change, amendments were made in 2006 and 2009 to allow for the storage of CO_2 under the seabed and enable transborder shipment of CO_2, respectively (IMO, 2019). However, the 2009 amendment's effectiveness was limited until a provisional application was adopted by the International Maritime Organization (IMO) in October 2019, requiring countries interested in exporting or importing CO_2 for storage to make unilateral declarations. This legal evolution from the original stance of the London Protocol removed significant regulatory obstacles, facilitating the advancement of international CCS projects by establishing a clear legal framework for the cross-border transport and storage of CO_2.

Sweden and Norway are in the final stages of negotiating a bilateral agreement regarding transboundary CO_2 transport, which will strengthen the collaborative capabilities of actors in an international CCS logistics network (European Commission, 2023a). Sweden is in a further stage than the other parties between Norway, such as Denmark and Belgium (European Commission, 2023a). Other countries have also requested storage at Northern Lights but have yet to initiate their talks on the bilateral agreements (European Commission, 2023a; 2023c). Additionally, Sweden and Denmark have also begun their negotiations regarding transboundary CO_2 transport, which together with Belgium, are the only countries to have entered such a stage of agreement with Denmark (European Commission, 2023a; 2023b). Development of infrastructure for cross-transport and storage of CO_2 is also underway as Denmark, Belgium, the Netherlands and Sweden each established an arrangement on cross-border transport of CO_2 with Norway (Government Offices of Sweden, 2024).

3.4.2 Intermediate Storage hubs

CinfraCap, located in Gothenburg, aims to transport their collective CO_2 emissions to Northern Lights. Due to the proximity of Gothenburg to the storage location, it is expected to be a distance of 650 km and a theoretical cycle time of 4-5 days (COWI, 2021). However, a conceptual paper by Kjärstad et al. (2022) suggests that the cycle time could be as low as 3 days, allowing 112 trips annually at full utilisation. The storage capacity of CinfraCap is estimated to be 13 000 tons, this estimate is calculated using the expected transport volume of 7 500 tons per transport and the cycle time (COWI, 2021). The total yearly capacity is expected to be 1 856 000 tons per year by 2040 (COWI, 2021). In order to store the CO_2 at CinfraCap, the CO_2 would first need to be liquefied at the capture location and fulfil the requirements of

15 barg as well as -26,5°C while simultaneously meeting the requirements of the quality needed to be stored at Northern Lights. Based on their pilot study, the project aims to collaborate with local private and public parties using different means of transport such as pipes and railways (COWI, 2021).

CNetSS on the other hand, located in Malmö, also currently aims to transport their CO_2 to Northern Lights due to their advancements but are open for other potential storage locations. Located further away than Gothenburg, the distance is estimated to be 860km and a theoretical cycle time of 5-7 days to Northern Lights (Energiforsk, 2022). As the pilot study has yet to be concluded, with no reports available. There is currently no data on CNetSS's requirements when it comes to CO_2 storage. The location of CNetSS provides opportunities to store the CO_2 at locations closer than Northern Lights with potential CO_2 storage locations such as Greensand, but also Hanstholm and Havnsø (Energiforsk, 2022). The two latter locations would reduce the distance to 460km and 180km respectively, drastically reducing the distance and cycle time of the transport (Energiforsk, 2022).

NICE is an intermediate storage hub that is ongoing in the Stockholm Norvik Port (Port of Stockholm, 2023). The hub aims to facilitate the infrastructure on the east coast cluster, as identified in the Energiforsk report, which clusters the major private and public parties around Stockholm with a total CO_2 emission of over 4,6 million tons (Energiforsk, 2022), making the cluster the largest one in Sweden. However, they are relatively scattered as the majority are district heating plants, so there is limited potential for local collaboration (Energiforsk, 2022). Instead, collaboration focuses on reducing the costs of shipping to the storage site by optimally co-filling vessels (Energiforsk, 2022). Kjärstad et al. (2016) also identifies CO_2 transport by ship is the least costly transportation option for potential cluster combinations.

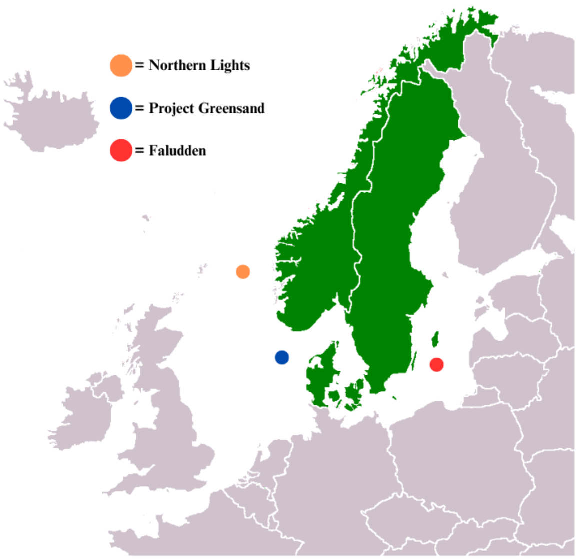
Furthermore, the incentives for CCS projects to be developed as part of a hub, cluster, or network include economies of scale, which creates lower per unit costs for constructing and operating CO_2 transports (Energiforsk, 2022). The costs per project are lower than can be achieved with stand-alone projects by independent emitters, many of which are smaller in size as each emitter would need its own independent and smaller scale transportation or storage system (Energiforsk, 2022). A coordinated intermediate storage can also lower the barriers of entry for all participating CCS projects, including for emitters, that do not need to develop their own separate transportation and storage solutions (Global CCS Institute, 2024).

3.5 Final Storage

Storage of CO_2 is the most downstream part of the CCS chain and is primarily done through deep aquifers or emptied gas and oil reservoirs (Energiforsk, 2022). Leung et al. (2024) highlights the viability of geological storage for large quantities of CO_2, typically capable of storing tens of million tonnes of CO_2 trapped by different physical and chemical mechanisms. When considering appropriate geological storage sites, Leung et al. (2024) mention the general requirements of porosity, thickness, and permeability of the reservoir rock, sealing capability, and a stable geological environment. According to Solomon et al. (2008), porosity and thickness decide the storage capacity and permeability impacts injectivity, while sealing capability and the geological stability affects the integrity and security of the storage site.

In order for a site to be used for CO_2 storage, it is required to be certified by several standards, such as the ISO 27914 and the wells for the injections to the reservoirs need to be drilled to depths around 2600m (Bui et al., 2018). Furthermore, the reservoir needs to be constantly monitored for its seismic activity and the pressure monitoring of the CO_2 is required to prevent leaks (Bui et al., 2018). Some of the key sites that are relevant for the Swedish cement industry can be seen in figure 6.

Figure 6: *Displaying the three sites in the nordic region.*



3.5.1 Northern Lights

The Northern Lights project, a collaboration project between the Norwegian oil and energy firms Equinor, Shell and Total Energies, involves the transportation and storage infrastructure where the CO_2 transporting ship reaches a terminal by Øygarden in western Norway and is stored in their storage areas before injection (Wilhelmsen, 2022). It is required to be pumped up to 35 bars into a dense phase and through a pipeline approximately 100km to the actual injection site located in the Johansen formation south of Troll field (SCCS, 2024). Northern Lights takes responsibility and charges a fee for the collection from the port, freight, storage and injection (Energiforsk, 2022). The port is then required to have everything prepared for collection. Northern Lights' first phase, with a planned start of operation in 2024, is designed to handle 1.5 $MtCO_2$ per year (Wilhelmsen, 2022). Furthermore, their second phase plans a total capacity of 5 $MtCO_2$ per year and operational mid 2026 (Wilhelmsen, 2022). Currently Northern Lights have 18 organisations or companies involved in initiating and operating the Northern Lights project (Wilhelmsen, 2022). Furthermore, there are 22 affiliates which are entities or companies that are beneficiaries of the project (Wilhelmsen, 2022). The promoters are from different countries around Europe, such as France, Belgium, Germany, Sweden and Finland and the capture potential of the actors is around 19 $MtCO_2$ per annum (Wilhelmsen, 2022). Including the affiliates, the potential CO_2 capture amounts to 32 $MtCO_2$ per annum (Wilhelmsen, 2022). The entire Northern Lights project had an estimated cost of 25,1 billion NOK, where the government's share of the costs were estimated to be 16,8 billion NOK (Energimyndigheten, 2024).

Heidelberg Materials Sement Norge’s cement plant in Brevik (henceforth referred to as Heidelberg Materials Brevik), a Norwegian counterpart that is furthest in the CCS developments in the Nordic region for the cement industry, is exempt from the storage costs due to agreements between Heidelberg Materials Brevik, Northern Lights and the Norwegian government and will also be prioritised in case of a shortage of storage space (Energimyndigheten, 2024).

In Norway, the process of securing licences for CCS poses a notable barrier due to its complexity and rigorous requirements involved. In order to be able to inject CO_2 to a storage site, the Norwegian Environmental Agency must have granted permits to four different types of licences; reconnaissance, exploration, exploitation and storage licence (European Commission, 2023c). The reconnaissance licence permits geological mapping over a large area to assess CO_2 storage potential. Progressing from this preliminary stage, the exploration licence, which is an exclusive licence, permits work obligations such as acquiring and interpreting seismic data or drilling exploration wells which is necessary to determine the suitability of a site for storage. In order to develop the site, a third licence, an exploitation licence is required and demands a detailed plan for the development and operation of the storage site. Finally, before injecting the CO_2, the holder must gain a storage permit and approval needs to be done from several authorities, such as the Ministry of Petroleum and Energy, the Norwegian Energy Agency and the Ministry of Climate and Environment. For this reason, there has only been a single storage permit submitted in Norway so far by Northern Lights. (European Commission, 2023c). However, the authorities have not yet received or acquired any information regarding any environmental and/or health risk associated with the storage of CO_2 (European Commission, 2023c).

3.5.2 Faludden

According to the Swedish national reports on the implementation of the CCS directive, Faludden is one of the two locations currently under examination for its potential to store CO_2 in Sweden (European Commission, 2023a). The Geological Survey of Sweden, which conducts the mission under the commission of the Swedish government, is examining whether the saline aquifer is suitable as a storage location (Bengtsson, 2023). However, due to the novelty of the project, their preliminary examination is to be reported in 2026 (European Commission, 2023a). Drilling and developing pipelines to Faludden could pose a challenge due to the existing nature reserve for porpoises, currently classified as a critically endangered species. Based on the current findings of the Geological Survey of Sweden’s drilling in 2023, Faludden meets many of the desirable properties of an aquifer, such as its porosity and permeability and the current outlook is favourable for it being a storage location (Bengtsson, 2023). The presence of cracks, impermeable layers, and variations in porosity and permeability is important to investigate, as these can have a significant impact on the pathways of carbon dioxide dispersion and potential chemical reactions (Bengtsson, 2023).

The EU CCS directive prohibits the storage of CO_2 in any storage site with a storage complex that extends beyond the territory of the Member States, their exclusive economic zones and on their continental shelves within the meaning of the United Nations Convention on the Law of the Sea (European Commission, 2009).

3.5.3 Project Greensand

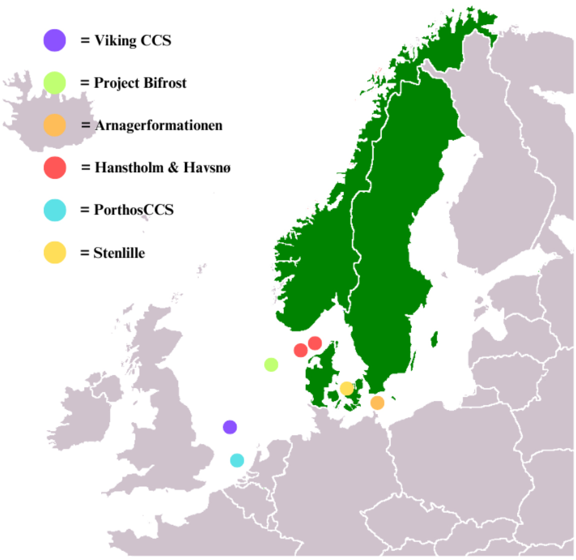
Greensand, a carbon storage project based in Denmark, is the first off-shore carbon storage that is available cross-border (Szabados et al., 2022). It is currently one of the most mature projects for storage of CO_2 along with Project Bifrost in Denmark with an expected capacity of 1,5 million tons of CO_2 per year by late 2025 when its intended operations will initiate and 4-8 million tons by 2030 (Szabados et al., 2022).

The project is currently composed of 23 different partners and led by INEOS, a Danish energy firm that owns several oil infrastructures which facilitates their role in the CCS as they rely on their oil fields for storage (Global CCS Institute, 2023). One of their oil fields, Nini, located 175 km offshore, is the first storage point which has had a pilot injection from an international source in 2023. The FID is expected to take place soon after (SCCS, 2024).

3.5.4 Other Storage Areas

There are several projects being developed in the Nordic region that could be considered as alternatives. These sites can be seen in Figure 7.

Figure 7. *Displaying the other storage sites in the nordic region*



The number of projects about geologic storage surrounding the North sea and Skagerak has increased substantially during the recent years (Heidelberg Materials Cement Sverige, 2023).
In total there are over 27 CCS projects in the Nordics (SCCS, 2024), however there are only a handful of other projects that are being developed and relevant storage areas. The Swedish CCS report mentions another potential storage site, Arnagerformationen near Bornholm in Denmark (European Commission, 2023a). Other storage sites include project Bifrost in Denmark, currently under the licence of

Total Energies; PorthosCCS, a CCS project in Netherlands combining three of their largest ports; VikingCCS in the UK and two potential storage areas in Denmark, Havsnø and Hanstholm. Despite offering little information at the moment, several of these sites plan to be operational by 2026 and onwards, offering potential storage locations (SCCS, 2024).

3.6 Cement and CO_2-free Cement

Rootzén and Johnssons (2017) study on the cement industry highlight how compliance costs, encompassing both internal abatement costs and the expenses for emissions allowances substantially influence the break-even production costs and consequently, the selling price of cement. For instance, with the carbon price set at 40€ per tonne of CO_2, production cost would rise by about 40 percent without CCS and between 65-90 percent with CCS-equipped kiln systems (Rootzén & Johnsson, 2017). A higher carbon price of 100€ per tonne of CO_2 would increase the production cost by 90 percent without CCS and 70-95 percent with CCS. Another finding by Emanuelsson and Johnsson (2023) suggests that the price increase for cement could be up to 200 percent. Despite these significant increases in production costs, the overall impact on total construction costs remains marginal, potentially less than 1 percent even if the price of cement nearly doubles according to Rootzén and Johnsson (2017). Rootzén and Johnsson explains that the minimal effect is due to the small proportion that the cost of concrete represents within the total expenses of building production. The research suggests that while the introduction of CCS and the adjustments in carbon pricing affects the cement industry's operational costs, their direct impact on the broader construction sector's costs would be small. However, Rootzén and Johnsson nonetheless highlight the complexity of transparently passing these increased costs along the value chain is not straightforward.

Furthermore, The Swedish Energy Agency found that 35-40 percent of the Swedish cement production goes to public construction and infrastructure projects where the Swedish Transport Administration, municipalities and regions are crucial end customers (Energimyndigheten, 2023a). Thus, public procurement of CO_2-free cement could be an important tool to create demand for climate neutral construction material, such as cement that has implemented CCS activities (Energimyndigheten, 2023a). Another initiative that could drive the demand for CO_2-free cement is the Concrete Initiative, which states that all concrete used in Sweden should be climate neutral by 2045 (Hallquist, 2022).

Heidelberg Materials Brevik (2019) highlights that the current situation for CCS will significantly impact cement manufacturing cost, where capture costs will be in the same range as existing production costs for cement. Heidelberg Materials Brevik have launched their pilot product, EvoZero, which offers a range of different CO_2-free cement where it can range from 0-100 percent CO_2-free (EvoZero, n.d). This product will be Heidelberg Materials Groups pilot test to see how attractive the CO_2-free cement is on the market (EvoZero, n.d). Four identified customer segments for cement in the Norwegian cement industry are residential buildings, commercial buildings, civil engineering and infrastructure, and concrete products. For each segment, the cement cost's impact on the total cost varies (Heidelberg Materials Brevik, 2019).

Residential buildings' total cost is typically impacted by 1-2% from the cement cost. Due to the segment's characteristics of mostly being composed of single family owners, the willingness to compensate for increased product cost resulting from CCS is very low (Heidelberg Materials Brevik, 2019).

The impact of cement cost on commercial buildings' total cost is lower than residential buildings. For the private owners in this segment, Heidelberg Materials Brevik (2019) believes that the willingness to compensate is very low. However, there is an increasing interest in sustainable solutions and willingness to compensate from public owners.

Civil engineering and infrastructure projects will have a higher impact on the total cost from the cement cost, usually in the range of 4-8% of the total project cost (Heidelberg Materials Brevik, 2019). The public owners show an increasing focus on developing using sustainable construction solutions (Heidelberg Materials Brevik, 2019). Due to the segments' commitment to long term targets on CO_2 emission reduction, Heidelberg Materials Brevik (2019) states that it appears to be the most mature segment in terms of willingness to compensate for costs resulting from CCS.

Cement costs have the most significant impact on concrete products according to Heidelberg Materials Brevik (2019), where the impact on total cost can be roughly 25%. In this segment, the private owners have no willingness to compensate for the increased cost of CCS (Heidelberg Materials Brevik, 2019). However, the public owners, mainly local municipalities, have varying focus on sustainability regarding construction which affect their willingness to compensate (Heidelberg Materials Brevik, 2019).

Heidelberg Materials Brevik (2019) states that generally, cost increases of cement production resulting from CCS without losing competitiveness will not be possible without government support and incentives. The proposed incentive mechanisms will have to focus on CCS cement's competitiveness along the value chain for concrete construction, as a measure to secure the competitiveness against imported non-CCS products and other less sustainable construction solutions in all supply decision processes along the value chain (Heidelberg Materials Brevik, 2019). Additionally, developed incentive mechanisms must ensure that the competitiveness towards other construction materials like steel, plastics and timber, are not affected in favour of less durable and CO2-lean construction solutions (Heidelberg Materials Brevik, 2019)

The massive emissions of CO_2 per dollar of revenue is much higher in the cement industry in comparison to other manufacturing industries, where the cement industry on average releases 6,9 tonnes of CO_2 per 1000$ revenue (McKinsey & Company 2020). This is a strong contrast to the other industries such as the iron and steel industry with 1,4 tonnes and the chemical industry with 0,3 tonnes (McKinsey & Company 2020). In combination with the increasing cost of emission allowances, this incentivizes cement companies to pursue ways to find reductions in CO_2 emissions and finding new value streams whilst simultaneously reducing their own costs (Rootzén & Johnsson, 2017).

Additionally, according to the Industrial Analytics Platform by UNIDO (2024), demand for cement is expected to increase more than one-third by 2050 as there is a need to expand the urban environments, where UNIDO claims that an equivalent of a New York City will be built every month for the next four decades. To accommodate for this expansion, cement industries need to find value in the CCS activities as even technologies that are driving the energy transition, such as renewable energy systems, require cement (UNIDO, 2024).

3.7 Regulatory Policies

In order to enable the CCS implementation and other carbon reducing technologies, governments, as well as the EU, have set up different policies to incentivise companies.

3.7.1 EU ETS

The EU Emissions Trading System (EU ETS) is a "cap-and-trade" system where companies can receive or buy emission allowances (European Commission, 2023d). The allowances can be traded between different actors and each allowance gives the holder the right to emit one tonne of CO_2 or the equivalent amount of other powerful greenhouse gases, nitrous oxide and perfluorocarbons (European Commission, 2023d). In order to prevent double counting of the captured CO_2, requirements are set for manufacturers covered by the EU ETS to surrender their emission allowances at the production stage for the CO_2 that the fuel generates upon combustion (Energimyndigheten, 2024). The current price of each allowance is 61 euros per tonne and can vary depending on market circumstance (Intercontinental Exchange, 2024). However, the price is not always paid by polluters, as many of them receive free allowances. From 2021, around 57 percent of the allowances are auctioned and the rest is provided for free (European Commission, 2023d). The EU continues their decrease of issued ETS allowances over time, which at the current stage is a linear reduction of 2.2% annually (European Commission, 2024a).

EU ETS has historically recognized the subtraction of captured and transported CO_2 emissions from an entity's overall emissions, primarily considering pipeline transport. The ambiguity regarding CO_2 transportation by ship necessitated clarification, leading Norway to seek guidance from the European Commission in 2019. The Commission's agreement in July 2020 with Norway's stance allows captured CO_2 intended for offshore storage to be deducted from an entity's emissions, emphasising the need for meticulous monitoring plans and accountability for CO_2 losses during transportation. This clarification implies that entities like Heidelberg Materials Slite remain liable for CO_2 losses until delivery to the storage facility, such as Northern Lights, underlining the importance of contractual agreements to manage emissions responsibilities during transport. This is contrary to Heidelberg Materials Brevik' facilities, where the Norwegian government is responsible for all of the costs and risk associated with the transport and storage of the captured CO_2 (Energimyndigheten, 2024).

Shifts in responsibility have been attempted with the European Commission confirming in 2019 that shipping and trucking CO_2 is equivalent to pipeline transport, assigning emission responsibility during transport to the capturing facility (Energiforsk, 2022). Thereafter, a proposed amendment to the EU ETS in July 2021 aimed to include CO_2 transport by ship and truck within its scope, shifting the responsibility for emissions during transport to the operators of these transport modalities (European Commission, n.d. -b). In 2021, the EU's Fit for 55 package proposed revisions to include CO_2 emissions from all transport means, including ships and trucks, within the EU ETS scope, shifting emission responsibility to transporters, not the capture facility owners/operators (European Commission, n.d. -b). Despite these changes, the EU ETS revisions don't alter how facility owners account for stored CO_2, due to the MRR regulation's Article 49, which ties CO_2 quota deductions to CO_2's transfer to a designated geological storage (European Commission, 2009). The CCS directive's current definition, focusing solely on pipelines, restricts deduction of captured CO_2 until delivery to the storage site, considering potential CO_2 losses during transport (European Commission, 2009).

Dávila and Aagesen (2024) suggest that the current EU ETS allowance prices are insufficient to stimulate the investment in CCS, as the cement plant in their case study expected a capture capability of 1,2 $MtCO_2$ per annum resulting with a potential loss of 690 million euros annually due to their CCS activities. Furthermore, they found that a subsidy of 50% of the CAPEX would offer a high probability that the net present value of the CCS investment would be positive, and a subsidy of 50 euros per ton of CO_2 would be required to reach breakeven. Dávila and Aagesens findings underscores the importance of supportive regulatory frameworks and innovative business models to enhance the investments in CCS, suggesting that cement producers reposition their products as high-value, low carbon options in order to improve market perception and investment viability.

3.7.2 Bio-Energy CCS

Bio-energy carbon capture and storage, also known as BECCS, involves capturing and permanently storing CO_2 from processes where biomass is converted to fuels or burned to generate energy (Energimyndigheten, 2023b). The implementation of BECCS technology could be a valuable revenue stream for the cement industry (Zetterberg et al., 2021). By incorporating biomass as an alternative fuel and capturing it as a part of their CCS activities as intended by Heidelberg Brevik’s *Zero Vision 2030*, Heidelberg Materials could reduce their emissions and in combination with voluntary markets and reverse auction, could not only reduce their costs but simultaneously use the negative emission credits as a new stream of revenue (Heidelberg, 2019; Heidelberg, 2023). In order for BECCS to be incentivised, Zetterberg et al. (2021) proposes that it should be state supported in the beginning and rely on direct control through quotas and voluntary markets over time. Karlsson et al. (2024) also states that BECCS can reduce the net present cost of the CCS system by 5-50 percent depending on the size of the emission budget. Heidelberg Materials Cement Sverige (2023) identifies one driver in the Nordic region being that companies have comparatively easier access to biogenic fuel sources, which according to Heidelberg Materials will be crucial to the implementation of CCS in the foreseeable future.

3.7.3 Voluntary Carbon Market

The voluntary carbon market is a proposed system in the private market where companies can purchase negative emissions through bio-CCS for goodwill purposes (Energimyndigheten, 2024). This market is favoured by many different stakeholders such as Stockholm Exergi due to its possibilities as additional revenue streams (Energimyndigheten, 2023b). The expected market size for the BECCS voluntary market is expected to be 1,8 billion euros per year and contribute up to 24 billion SEK to the Swedish GDP (Implement Consulting Group, 2022). The Swedish Energy Agency (2023) suggests that the voluntary market could lead to the reduction of bio-CCS costs as well as increase the willingness to implement bio-CCS in a company's strategy. However, in order for the voluntary market to take off, facilitation from the state would be required (Zetterberg et al., 2021).

3.7.4 Governments Grants and Support

Reversed auctions, proposed in 2021 by The Swedish Energy Agency, is a system where actors submit bids on who can offer the lowest compensation per tonne for their BECCS services and receive support that covers both the investment and operational costs (Energimyndigheten, 2024). The first reverse auction was proposed to be held at the end of 2022, with a volume of 0,6 $MtCO_2$ (Lundberg & Fridahl, 2022). However the auction was delayed until november 2023 and limited to the production of hydrogen gas (Energimyndigheten, 2024).

The EU is also investing into initiatives within climate change mitigation technologies such as CCS through the Innovation Fund (European Commission, 2023b). The total fund is expected to be around 40 billion euros in total, spread over several (European Commission, 2023b; Interviewee H). The funds are financed by the monetisation through EU ETS. By providing the funds through grants and auction to relevant companies, it can help them offset the cost of implementing and operating their CCS activities. Another cement plant in Germany, Heidelberg Material's Geseke, recently received a grant for 190 million euros for their full-scale CCS operation which enters into operations 2029, one year prior to the Swedish cement industry (European Commission, 2024b). Similar funds have been allocated to cement plants in Croatia, Greece, Belgium (European Commission, 2024b).

Additionally, the Swedish government is investing into initiatives such as Industriklivet, including 1 457 million SEK aiming to reach the climate goals set by the state by, for example, supporting the process industry's attempt to lower their carbon emissions through investments in state-of-the-art CCS technologies (Energimyndigheten, 2023a). The initiative provided roughly 63 million SEK to the conductance of Heidelberg Materials Cement Sverige's CCS pre-study and ongoing feasibility study (Heidelberg Materials Cement Sverige, 2023). However, Energymyndigheten (2024) states that the budget will gradually decrease to 665 million SEK by 2026.

Heidelberg Materials Cement Sverige (2023) emphasises that the commitment of the Norwegian state has played a decisive role in the success of Norwegian CCS projects such as Longship since it increased the industry actors' level of trust for the project regarding investment decisions of cooperation agreements. Longship covers the capture, transport, and storage of CO_2 from Heidelberg Materials Brevik and from Hafslund Oslo Celsios's (previously Fortum Oslo Varme) waste-to-energy plant in Oslo (Gassnova, 2020). The captured CO_2 is shipped in a liquid state to a receiving terminal in the west coast of Norway. Afterwards, the Gassnova (2020) describes that the CO_2 is transported by pipeline to an offshore storage location under the North Sea for permanent storage as a part of the Northern Lights project. Furthermore, the Longship's proposed carriers have a capacity of 8000 tonnes of CO_2 and are ready for delivery mid-2024 (Wilhelmsen, 2022). These carriers are purposefully built for CO_2 transportation and will use LNG as fuel for the transportation.

Heidelberg Materials Cement Sverige (2023) concluded that when creating new CCS value chains, the government plays a central part to make the involved actors feel secure. In contrast, Heidelberg Materials Cement Sverige (2023) mentions as a part of their proposed “10 things that should be put on the political to-do list”, that the Swedish government needs to establish trust in investing in “one of the most extensive industrial transformation projects in Sweden”. Increased governmental support provides appropriate conditions for commercial actors to commit to agreements (Heidelberg Materials Cement Sverige, 2023). This governmental support can involve providing stability over terms of office with clear and time scheduled missions entrusted to government agencies that provide clear priorities. Moreover, Heidelberg Materials Cement Sverige (2023) points out that the government must attempt to significantly shorten lead times for ongoing permit matters and authority decisions.

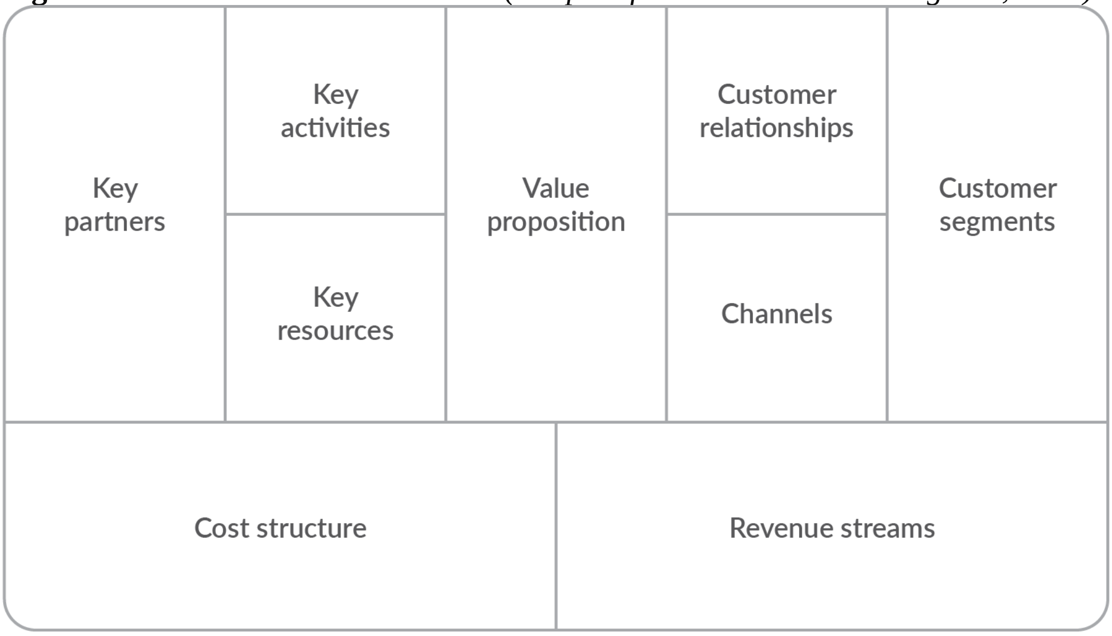
A crucial barrier currently limiting Heidelberg Materials Slite is the relatively slower expansion of a robust and correctly dimensioned electrical system (Heidelberg Materials Cement Sverige, 2023). Heidelberg Materials Cement Sverige (2023) mentions that the development of Sweden’s transmission system for electricity to and from Gotland needs to accelerate which is organised by both government-owned and private energy companies. Lead times for expanded energy production in Sweden are shortened drastically by the implementation of relevant EU-policies (Heidelberg Materials Cement Sverige, 2023).

Heidelberg Materials Cement Sverige (2023) states that in order to reduce the climate impact in construction and civil engineering projects, functional environmental product declarations for building products are required. Today, there is no possibility to fully account for captured fossil or biogenic emissions in the product regulations, which limits the producers from bringing new products with low or positive carbon footprint to the market (Heidelberg Materials Cement Sverige, 2023). Heidelberg Materials Cement Sverige argues that the government needs to push in the EU to ensure that environmental product declarations fully include CCS and BECCS. Financial incentives for BECCS are also currently lacking at the EU level (Heidelberg Materials Cement Sverige, 2023). Industries with process emissions, such as the cement industry, depend on concrete incentives to transition to solid, sustainable biofuels where emissions can also be captured (Heidelberg Materials Cement Sverige, 2023). At the same time, it must remain possible to introduce products to the market with low or positive carbon footprints (Heidelberg Materials Cement Sverige, 2023). Heidelberg Materials Cement Sverige (2023) proposes that the starting point should be that the incentives for CCS and BECCS are harmonised and that the price signals are thus linked to the value of the emissions within the EU ETS to avoid market distortion for the CCS and BECCS value chain. The issue must be resolved at the EU level, and the government and relevant authorities need to push in the EU for this to happen (Heidelberg Materials Cement Sverige, 2023).

3.8 Business Model Canvas

The Business Model Canvas (BMC), conceptualised by Osterwalder and Pigneur (2010), is a strategic management tool for visualising, designing, and scrutinising business models across nine critical dimensions. As presented in Figure 7, this framework aids businesses in mapping out their value propositions, customer segments, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure, facilitating a comprehensive understanding of how they deliver value to customers and generate revenue (Osterwalder & Pigneur, 2010).

Figure 7. *The Business Model Canvas (Adopted from Osterwalder & Pigneur, 2010)*



Value proposition is the core of the BMC, highlighting the unique value a company offers to its customers. It answers why customers should choose this company over others by detailing the products or services' unique features, benefits, and solutions to customers' problems. A strong value proposition is clear, specific, and addresses the customer's main problem or need.

Customer segments specify the different groups of people or organisations the business targets. Understanding the customer segments helps tailor marketing strategies, products, and services to meet the specific needs of each segment.

Customer relationships specify the nature of the interactions between the business and its customers. It encompasses the strategies employed to acquire, retain, and grow customers. This could range from personal assistance to automated services, community engagement, or self-service platforms, depending on what suits the customer segments and value proposition.

Channels specify the touchpoints through which businesses communicate and deliver their value proposition to customers. This includes marketing, sales, and distribution channels. Effective channels ensure that the value proposition is accessible to the target customer segments in the most convenient and efficient way possible.

Revenue streams specify the area of how the business makes money through various channels. It describes the specific ways in which the company generates income from each customer segment. Revenue streams can include direct sales, subscription fees, leasing models, advertising revenues, and others, indicating the business's financial health and sustainability.

Key resources specify the assets essential to make the business model work. Key resources can be physical (buildings, vehicles), intellectual (brands, patents), human (staff, talent), or financial (cash, credit). Identifying and managing key resources is vital for delivering the value proposition, reaching markets, maintaining customer relationships, and generating revenue.

Key activities specify the most important tasks a company must perform to operate successfully fall into this category. Key activities could involve production, problem-solving, or platform/network management. These activities are crucial for creating and delivering the value proposition, reaching markets, and maintaining customer relationships.

Key partnerships specify the network of suppliers and partners that contribute to the business model, including strategic alliances, joint ventures, or buyer-supplier relationships.

Cost structure specifies the total costs involved in operating the business model. It is essential for determining profitability, pricing strategies, and identifying areas where efficiencies can be improved.

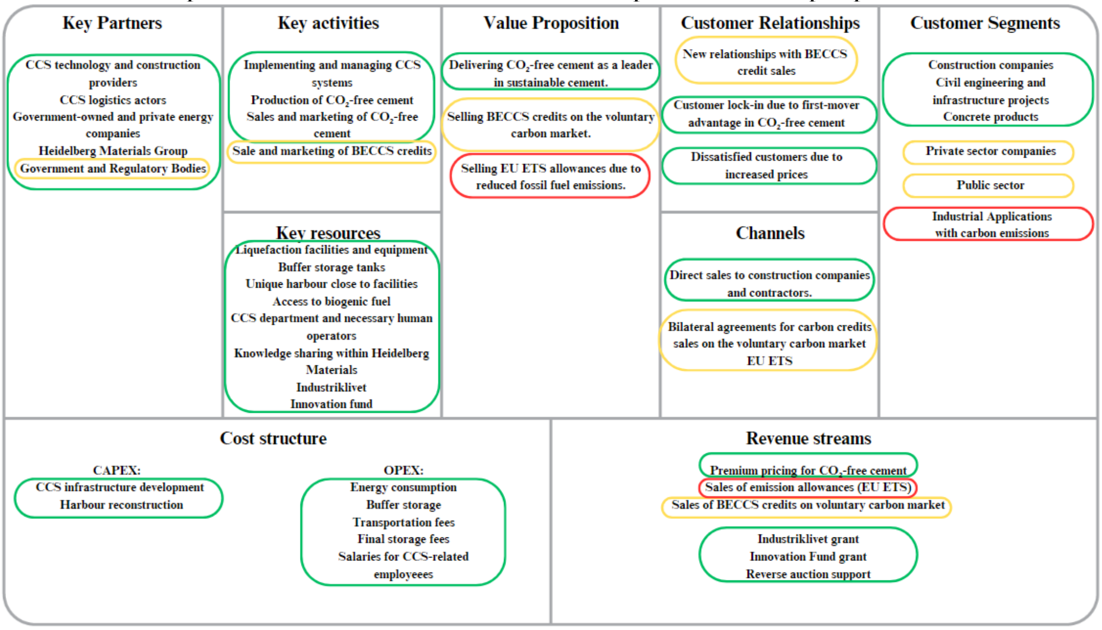
Expanding on the BMC's application and theoretical underpinnings, Zott and Amit (2010) offer an activity system perspective on business model design, emphasising the significance of the activities and their interconnections within a company's business model. This perspective highlights the importance of how companies create value through the configuration and coordination of their activities, suggesting that the value creation process is as critical as the components of the business model itself (Zott & Amit, 2010).

Similarly, DaSilva and Trkman (2014) contribute to the discourse by clarifying the distinction between a business model and business strategy, arguing that the business model acts as a blueprint for the strategy. They emphasise that while the business model outlines the logical framework of value creation and capture, the strategy defines the choice of business model based on competitive positioning and market dynamics (DaSilva & Trkman, 2014).

4. Results and analysis

This chapter analyses the themes identified connected to the research questions and data collected from interviews to design a potential CCS business model for the emitters in the Swedish cement industry by using the business model canvas framework, resulting in an illustrated business model canvas in figure 8.

Figure 8. *Business model canvas for the Swedish cement industry in Slite, Gotland. Each colour represents the associations to the respective value proposition.*



4.1 Value Proposition

The Swedish cement industry's main value proposition from establishing CCS is delivering CO_2-free cement as a leader in sustainable cement. Interviewee B highlights the potential of allowing cement to be offered in different ratios, providing 0-100% CO_2-free cement, which is also applicable for the Swedish cement industry. However, the price of the cement is most likely to be multiples higher than the current standard cement in Sweden as production costs are heavily affected by the implementation of CCS, affecting the market and sale strategies. Heidelberg Materials Slite estimates that the impacts of CO_2-free cement on production costs, pricing, and the market segments will be roughly similar to Heidelberg Materials Brevik (Interviewee I).

At Heidelberg Materials Slite, 60% of carbon emissions from cement production stem from limestone calcination, and 40% from fuels (Interviewee I). Furthermore, 40% of the fuel is provided by biogenic fuel sources, resulting in a potential capture of 16% negative carbon emissions and is expected to steadily increase, as the Swedish region has good access to biogenic fuel sources (Interviewee I). However, Interviewee I does mention that Heidelberg Materials Slite does not intend to have 100% biogenic fuel sources. Instead, the focus lies on decreasing the plant's overall emissions by, for example, modifying the calcination process and replacing limestone, enlarging the share of negative carbon emissions (Interviewee I). Therefore, the Swedish cement industry can provide additional value as a seller of negative emission credits which could be sold on the voluntary carbon market, or by selling their allocated EU ETS allowances as they would have reduced fossil fuel emissions. However, as EU ETS costs increase with the decrease of emission rights being issued over time, it would entail that their unique position is an unsustainable competitive advantage, as every cement actor presumably needs to become carbon neutral to stay afloat. A potential alternative to a CCS business model for the Swedish cement industry would be a cement product not based on limestone and uses either biogenic fuel sources or electrified heating from sustainable energy. However, both interviewee B and I state that limestone based cement will be a central component in concrete for the foreseeable future, meaning that the entry of such competitors to the cement market is unlikely. Interviewee B and I suggest that the price increase for cement could be up to more than 200 percent as a result.

Ultimately, delivering CO_2-free cement is the key value proposition of the Swedish cement industry, as it eliminates the need to utilise EU ETS emission allowances and is a direct link to their ambition to reach carbon neutrality. The other value propositions, the selling of the negative emission credits and EU ETS allowances, are derived from the key value proposition of CO_2-free cement, as they cannot exist without the former.

4.2 Key resources

In order to meet the requirements of the value proposition for the Swedish cement industry, a cement manufacturing plant primarily needs physical resources. To transport the CO_2, it is cooled and pressurised into the Swedish cement industry's desired state for temporary storage and transport, requiring liquefaction facilities and equipment (interviewee I; A). Since cement plants will continuously emit CO_2, there is a need to have buffer storage at the facilities to store between shipments (Interviewee A; I). Depending on the lead time of the transportation, the storage size will vary (Interviewee A). The buffer storage technology is already mature according to interviewee F where the options are either spherical or cylindrical storage tanks. The buffer storage in the case of both Heidelberg Materials Brevik and Slite consists of storage tanks, both carrying a total capacity to fit a planned vessel size and some added safety stock as it is not unusual for ships to be a few days delayed (Interviewee B; I). Interviewee B mentions that they need to keep the tanks cooled by always keeping some liquid CO_2 in the tanks. If the tanks are not always cooled, ambient temperature will raise the temperature of the tanks after outputting to the vessels, and will cause structural shock and damage to the tanks when cold liquid CO_2 flows in. Therefore, the safety stock that both Heidelberg Materials Slite and Heidelberg Materials Brevik have planned might be theoretically sufficient, but since Interviewee B mentions that the tanks cannot be fully emptied nor filled, the real capacity could be significantly lower. This is highly important to estimate correctly as uncertainties during CO_2 transport can lead to uncaptured CO_2 due to the buffer storage being full, resulting in EU ETS-related costs, or unnecessarily high storage costs. In these situations, since the Swedish cement industry continuously emits CO_2, they could potentially utilise nearby intermediate storage hubs as additional temporary storage for safety stock when other industries such as the district heating plants have lower emissions due to their industry's seasonality. That way, the Swedish cement industry can create discounted buffer storage for unexpected situations.

Another very important key resource specifically needed by Heidelberg Materials Slite is the development of a new harbour in order to accommodate the new CCS activities and increased demand for shipping. This can be seen not only with Heidelberg Materials Slite but also with Port of Stockholm who are expanding their quay (Interviewee I; E). The new harbour consists of new berths and necessary loading equipment.

When operating the plant, there is a need for new human capital, since the goal is to run the plant without too much support from the providers, which will require the recruitment of new operators, new departments and human resources (Interviewee I). Additionally, new human resources will be necessary for the maintenance and safety aspect of running the CCS plant, as the Swedish cement industry will be working with pressures and temperatures different from their current expertise (Interviewee I). Thus, a CCS business model for the Swedish cement industry will need new expertise, new departments, and recruit new operators that can handle running the CCS aspects of the facility. In addition, there is a need for competence regarding maintenance and safety for the capture, liquefaction, buffer storage, and any infrastructure surrounding the mentioned physical resources such as pipelines.

Luckily, financial resource initiatives such as Industriklivet exist that help facilitate the establishment of necessary facilities, providing a key resource for the Swedish cement industry. However, as the initiative is planned to decrease over time, and with a minimal amount of financial support compared to the total investment cost of 10 billion SEK that Heidelberg Materials Slite will invest in their CCS plant, it might seem insufficient. In contrast, the Norwegian government and Heidelberg Materials Brevik have a closer collaboration, dividing both costs and risks more evenly, which appears to be a vital component to their success and has proved to be a key resource, especially when attempting to tilt the status quo. These resources are temporary to incentivize first movers and provide aid to industries. However, once the market is developed and more actors are involved the business model needs to be self-sustained without financial funding from these initiatives or EU’s innovation fund.

4.3 Key partnerships

When constructing the facilities at Heidelberg Materials Brevik, Interviewee B mentions that they work with many various contractors, each responsible for different construction areas such as demolition and groundwork. Additionally, they have a close collaboration with the providers of the capture technology in order to make the plant operational. At Heidelberg Materials Slite, they aim to have a single supplier to construct and install the necessary technology and facilities to make CCS operational from capture all the way to bringing it out to the loading arms at the pier (Interviewee I). Preparation of the plant beforehand will be conducted by other contractors (Interviewee I). Interviewee I explains that conducting a FEED study with a supplier, resulting in a potential EPC contract, is a huge commitment as you get locked in with the supplier very easily, and is expensive to conduct. Heidelberg Materials Slite will be conducting two FEED studies with two different suppliers which can be compared to Heidelberg Materials Brevik who only conducted one (Interviewee I; B). Conducting two FEED studies can foster competition, potentially resulting in improved quality and increased bargaining power, particularly given the scale of Heidelberg Materials Slite’s planned CCS plant, which positions them as a significant and influential customer. However, there is a possibility that the option to conduct two FEED studies is exclusive to the Slite plant, due to the substantial costs involved and the size disparity between Heidelberg Materials Brevik and Slite. To conclude, the construction of the infrastructure and capture facilities for CCS in the Swedish cement industry can require several partnerships with construction contractors, as well as various technology providers, as seen by the development at Heidelberg Materials Brevik and Heidelberg Materials Slite. Technology providers both include the capture technology, but also the providers of liquefaction technology, buffer storage, and construction to bring liquid CO_2 to specified locations, for example, to the loading arms at the new harbour at Heidelberg Materials Slite. These partnerships would only exist during the initial stages of the CCS facilities. One key partnership that emitters in the Swedish cement industry, for example, Heidelberg Materials Slite, can have is the Heidelberg Material group which include amongst others Heidelberg Materials Brevik. Sharing knowledge between the actors can prove to be highly beneficial.

Interviewee D mentioned that in order to proceed with many CCS-related projects, Swedish agencies such as the Swedish Energy Agency need to provide various decisions and permits. These communications with agencies are going slower than hoped, especially for emitters who have the ambition to start collection of CO_2 before 2030. Furthermore, these regulations and decisions that need to be provided also create the foundation of trade of CO_2. Interviewee D explains that until regulations are in place, no actor is willing to be the first one to put out a CO_2 trade offer, as pricing could be heavily impacted. Additionally, in Heidelberg Materials Slites' case, development of Sweden's transmission system for electricity to and from Gotland needs to accelerate which means deeper collaboration with relevant government-owned and private energy companies.

Interviewee D and G highlighted several challenges associated with commercial CCS investments. One significant challenge is the misalignment of timelines and development plans among actors, which introduces additional risks to investment decisions and the formulation of business models. As an emitter, if there is no available transport or storage operator by the time the actor is ready to capture CO_2, the business model will fail. This dependency on other parts of the CCS chain means that a capturing actor cannot fully commit to their project without ensuring that their captured CO_2 can be promptly transported and stored. High storage costs further complicate this issue, making key partnerships with transport operators and final storage operators essential for both the feasibility and the viability of the CCS business model.

Conversely, final storage projects are not initiated due to the uncertainty of the market potential and demand from emitters (Interviewee D; G). Some interviewees mention the concern of the capacity not meeting the high demand of storage and discussions regarding how actors should respond is of importance (Interviewee C; D; F). The result is a deadlock that the interviewees commonly referred to as a chicken-and-egg causality dilemma. (Interviewee D; G). The CCS business model, therefore, remains heavily dependent on the resolution of these uncertainties and the establishment of robust partnerships across the entire CCS chain.

When transporting the CO_2, the Swedish cement industry has the option to either go directly to the storage site or through an intermediate storage hub. Going through an intermediate storage hub would entail tight collaboration with the hub owners and involved stakeholders. Interviewees have emphasised the importance of proper allocation of risk between actors, both contractually but in practice as well. Most interviewees related to emitters mention that, ideally, the assigned risk from an emitter's perspective should be from capture to loading on port. Currently, as mentioned by interviewee F, the intermediate storage hubs in Sweden do not plan to act as a coordinator of transport after intermediate storage which means that the emitter has to organise transport to the hub and from the hub to the final storage, further emphasising the collaboration between emitter and transporter.

Selection of a final storage actor is a highly important decision as the commitments are long-term and quality specification between them can vary. For that reason, they are a key partner for an emitter in the Swedish cement industry and require high levels of collaboration. All interviewees agree that final storage actors are one of the most crucial actors in the CCS logistics chain, but also one of the most uncertain ones. Depending on the choice of final storage actor, transport services can be provided which would remove the need to interact with shipping companies. Interviewee I explains that Norwegian final storage actors are more likely to include transportation and it's less likely with Danish final storage, further emphasising the importance of selecting correctly.

Faludden is a final storage location affected by geopolitical factors since the reservoir overlaps territorial waters between states (Interviewee A; C). Notably, the reservoir extends into Russian territorial waters in the Baltic sea (Interviewee A; C). There are currently no actors willing to operate the storage site at Faludden (Interviewee C). A potential solution could be outsourcing the operation to foreign actors from countries with territorial water that Faludden's reservoir also are part of (Interviewee C). However, despite its proximity, there are no plans at Heidelberg Materials Slite to be involved with Faludden as the timelines are currently not aligned between the two (Interviewee I).

4.4 Key activities

The key activities for an emitter in the Swedish cement industry in the beginning is implementing and thereafter managing the CCS systems. The production of CO_2-free cement also requires meticulous monitoring of the emissions, and CCS-related activities tied to the plant such as capturing, liquefying and storing the liquid CO_2. Additionally, in order to meet the specific requirements of either an intermediate storage hub or a final storage actor, there is a need to perform quality control on the liquid CO_2 before transporting it if it is not the other actor's responsibility. In order to gain as much benefit as possible, Interviewee A and Interviewee I both propose that the non-fossil based carbon dioxide should be captured first since it is deemed as negative emissions when captured. When capturing CO_2, 95% maximum of the emissions can be captured which means that the leakage can be compensated by the captured negative emissions (Interviewee A; I).

In order to sell the CO_2-free cement and negative emission credits gained from BECCS, there is a need for sales and marketing activities to both sell the CO_2-free cement to customers, and establish bilateral agreements for CO_2 emission rights sales.

4.5 Cost structures

The largest impact of CCS from the emitter's perspective is the necessary development of the infrastructure needed to liquefy and transport the CO_2. Developing the infrastructure along with equipment for liquefaction and buffer storage appears to be the largest CAPEX that the Swedish cement industry will face (Interviewee A; I). The new operation seems to also require further expansion of a harbour to accommodate CCS-related transportation activities, with Heidelberg Materials Slite's harbour reconstruction project, Stockholm Hamnar with their new quays, as well as Stockholm Exergi's potential strategy mentioned by interviewee G if they decide to not participate in a cluster.

Operating the built facilities requires large amounts of energy which Heidelberg Materials Slite claims will quintuple the energy consumption when the facilities are fully operational, and constitutes a large portion of the OPEX (Interviewee I). This explains why Heidelberg Materials Slite highly prioritises further development of the electric grid and dimensioning by nearby power plants. It also highlights the importance of costs associated with energy needing to be competitive, especially now that CCS-implementing companies will have a cost basis consisting even more of electricity costs. As an emitter, interviewee D highlights the challenge of providing enough data about costs for the investment to be accepted by the leadership. In addition to energy consumption, salaries for the CCS-related employees and departments will also be a part of the OPEX.

Additionally, the logistics of the transport and storage will also be a substantial part of the OPEX. The transportation with the cargo vessels and the final storage fees not only have a direct cost but are also affected by the lead time of transport. The risk of eventual delays and queues can heavily affect the transport and buffer storage costs as the storage is bigger due to the increased safety stock. There is an indication from industries regarding what Northern Lights is asking for, between 50-100 euro per tonne of CO_2 depending on the distance from the terminal to the port, with the area of Slite possibly being on the upper echelons of the price (Interviewee A). Interviewees that represent emitters mention that Northern Lights is their preliminary choice of storage, but say that Northern Lights is very booked and haven't provided a price offer yet.

Pipelines to Faludden could be economically advantageous as Heidelberg Materials Slite can continuously pump without additional handling activities that occur with other transportation options (Interviewee A; I). Additionally, since it is continuously active, assuming that the injection rate is higher than the capture rate, there would be no need for buffer storage at the facilities at all, removing a large component of the CAPEX (Interviewee A; I).

Furthermore, the cost of EU ETS will reduce as the company will need to buy less emission allowances. At the current price of 61 euros per tonne and Interviewee A estimated that the allowance price will increase to about 150-200 euros by 2030. the implementation of CCS would largely affect their cost structures and potentially save the company a substantial portion of their operating expenses.

4.6 Channels

The distribution channels for the CO_2 free cement is expected to remain the same for emitters in the Swedish cement industry such as Heidelberg Materials Slite, through direct sales to construction companies and contractors (Interviewee I). However, the implementation of CCS opens up a new sales channel, as in order to sell their negative emission credits, channels are required for the voluntary carbon market to facilitate the trade of the credits (Interviewee G). As there are no current platforms for the carbon market at the moment, one option is to start by bilateral agreements with other firms that are interested in the negative emission credits (Interviewee G).

4.7 Customer segments

Construction projects within residential buildings, commercial buildings, civil engineering and infrastructure could all potentially benefit from the carbon neutral cement as the price impact would be between 1-2 percent across residential and commercial buildings and 4-8 percent across civil engineering and infrastructure projects. For concrete products, CCS can impact the total cost by roughly 25% and the private owners have no willingness to compensate for that increased cost. Heidelberg Materials Slite is optimistic towards an expanded market size and increased demand after their transition to CO_2-free cement (Interviewee I). With the expected increase in the demand for cement, combined with stricter regulations, one can expect the general customer segments to grow with the implementation of CCS. This can also be highlighted from the Concrete Initiative, where several actors propose that all cement procured in 2045 should be CO_2 free.

The excess EU ETS allowances can be sold to industrial application companies that still engage in carbon emission due to inherent processes such as other cement manufacturers (Interviewee G). This opens up new customer segments that are business-to-business, where the Swedish cement industry can freely trade their excess allowances.

Furthermore, CCS would open up new customer segments as the cement industry could sell their excess negative emission rights on the voluntary carbon market to companies in both the private sector and public sector. Potential customers in the private sector are primarily large technology companies such as Microsoft, Stripe and Shopify due to their CSR policies (Interviewee A; G). Smaller regional actors might also be interested in reducing their corporate carbon footprint and are prioritised by some interviewees (Interviewee D; H). Customers in the public sector include regional and state actors (Interviewee G; D; H).

4.8 Customer relationships

The effects of CO_2-free cement is largely expected to have a positive impact on their current customer relationships as the construction companies are in demand for lower CO_2 cement due to its enormous carbon footprint. The CO_2-free cement could potentially increase brand loyalty and increase their current market as they could gain a first-mover advantage due to their early transition to carbon neutrality and create a lock-in effect. As interviewee I noted, there are no known customers that might be negatively affected by the transition to carbon neutrality and thus will not risk cannibalising on their existing product lines. However, Interviewee B states that the market is currently unknown and there could potentially be dissatisfied customers due to the increased prices, and that their EvoZero product will be used to test the market.

With the addition of BECCS credits, the Swedish cement industry can also expect new customer relationships that are strong as they can provide carbon neutrality for their customers that have inevitable emissions, such as technology companies, further bolstering their customer relationships as the Swedish cement industry aids in the transition towards sustainability (Interviewee G; H). The possibility to purchase negative emission credits would offer a strong relationship if the transactions are bilateral but could be weaker if a platform existed for the voluntary carbon market.

4.9 Revenue streams

There are three main forms of revenue streams that arise from the implementation of CCS, the added value from the CO_2-free cement, selling of excess allocated EU ETS allowances and the selling of negative emission rights. Additionally, whilst not considered a revenue stream, the implementation of CCS grants the Swedish cement industry several sources of funding and grants that reduce their cost structure, such as the Innovation Fund, Industriklivet and state funding through the reverse auctions. Several companies are heavily reliant on the fund to make the business model viable as it substantially reduces their cost structures and acts as a stream of revenue for their CCS activities (Interviewee H; G).

The implementation of CCS means that the cement will be partially or fully CO_2-free and considered a premium product on the cement market as many construction companies want to reduce their carbon footprint (Interviewee B; I). This means that the manufacturer can sell the CO_2-free cement at a premium price (Interviewee B; I). However, the cost of CCS also affects the production cost of the cement which further increases the price (Interviewee B; I). Should an emitter in the Swedish cement industry not consider implementing CCS, they would instead need to manage the repercussions from the EU ETS costs. As the allowances are slowly decreasing and expected to cap at 0 by 2039 (Interviewee G), the Swedish cement industry would not only need to take into consideration the increasing cost of the emission allowances, but also how to manage their production once the allowances cease to exist. Furthermore, with the Concrete Initiative, not implementing CCS would affect their future market as the initiative's goal is for carbon neutral concrete to be on the market by 2030 and for all concrete to be carbon neutral by 2045. This would mean that refraining from CCS activities causes them to have a longer time-to-market and risk losing market share to large, public actors.

Selling of EU ETS allowances could prove to not only be an opportunity to reduce the cost structures but also become a revenue stream as the cement industry receives a portion of their allowances for free (Interviewee I).

Currently there is no clear agreement on the accounting of CO_2 emissions between states and industries, which heavily affects the incentives for utilising CCS and the resulting negative emission credits which can be sold on the voluntary market (Interviewee G; H). For companies that are engaging in the use of BECCS, the sales of the credits are a substantial part of their revenue stream (Interviewee D; G; H).

Furthermore, discussions regarding the format of reverse auctions are ongoing, where some parties propose that leftover costs of CCS not covered by other sources of funding, can be covered by the reverse auctions, but the government will own those emission rights (Interviewee H). The actors would then be able to purchase those rights from the government. Additionally, the implementation of CCS in the reverse auctions are currently uncertain and decisions will not be made until 2025 (Interviewee H; G). Interviewee D and F claims that the reverse auctions will be pivotal for the CCS implementation of industries in Sweden. Actors such as Stockholm Exergi claim that they could start operations in 2025 or 2026 if they secured sufficient funding and are one of the most ambitious actors for reverse auctions (Interviewee G).

Conclusively, in order for CCS to be profitable for the Swedish cement industry, their added value from CCS such as their CO2-free cement, the trading of negative emission rights and allocated EU ETS allowances must exceed their CAPEX and OPEX. The Swedish cement industry could gain additional revenue streams if they manage the Faludden storage as proposed by interviewee C and A, which would simultaneously increase their expenditures. This, however, as according to several interviewees, would not be probable for the next 10-15 years due to the barriers in creating a storage site and the industry's investment opportunities.

5. Discussion

Based on the results and analysis, this chapter presents three key factors identified as market uncertainty, economic viability, and regulatory development that affect the implementation of the CCS business model in the Swedish cement industry. This discussion is crucial to consider as there are many contingencies with the business model for CCS as it is dependent on a variety of actors and regulatory stakeholders on multiple levels, such as the Swedish government and the EU. Table 2 presents the key factors, the issue that the factors cause the business model and a proposed solution for each issue in order to make the business model viable.

Table 2: *Overview of how the key factors affect the business model and a proposed solution.*

Factor:	Issue:	Solution:
Market Uncertainty	Chicken-and-egg dilemma in the supply chain	Government involvement through subsidies and risk ownership
Market Uncertainty	Late-mover disadvantages due to other actors having first-mover advantages	Establishing key partnerships and key resources early
Economic Viability	Reverse auctions and voluntary carbon market still uncertain	Prioritise key value proposition of selling CO_2-free cement
Economic Viability	CO_2-free cement market uncertainty	Observe market for EvoZero and conduct market research for CO_2-free cement
Economic Viability	Energy price uncertainty	Close collaboration with energy companies to secure fair prices long-term.
Regulatory Development	Unclear guidelines regarding counting of negative emissions	Government agencies needs to align their policies on emissions
Regulatory Development	State funding through reverse auctions	Put higher emphasis on BECCS and incorporate more biomass in combustion

5.1 Market Uncertainties of CCS in the Nordic region

Although the Nordics are in the forefront of CCS, with multiple areas of storage on its way and many industries in the midst of their transition, many uncertainties in the market still remain and clarity is required to facilitate the transition to carbon neutrality.

As mentioned by the majority of interviewees during this thesis, there is a strong chicken-and-egg causality dilemma where no individual actor can complete their part of the CCS logistics as they are dependent on the remaining logistics chain. Thus, every actor becomes suspended in a state of immobility as the risks are too great for any single actor to bear. The Norwegian CCS actors have managed to bypass this dilemma through heavy subsidising by the government. By taking on several costs of developing CCS, such as the construction cost of the capturing and storage facility which could be up to 35% of the total costs according to the study by COWI (2021), as well as subsidising the transportation and storage cost for the two Norwegian emitters. Furthermore, the risks associated with CCS such as CO_2 leakage are also covered by the government rather than the actors.

A high degree of government involvement therefore seems to be pivotal as it also aligns with the findings of Dávila and Aagesen (2024) who looked at the level of subsidy required. However, it is likely that the amount of necessary involvement by the government, especially in financial aspects, will decrease in the future as revenue streams and actors along the CCS supply chain are established and in operation.

In the case of CCS logistics and discovering CCS-related value, being a first mover poses great challenges due to the chicken-and-egg causality dilemma. For the Swedish cement industry, it could prove to be beneficial as their Norwegian counterpart has a timeline for 2025 and other CCS actors within Sweden plan to be ready prior to 2030. This means that the Swedish cement industry can mitigate many of the uncertainties by observing the first movers and imitating the solutions. However, being a follower in this regard could also have its negative consequences as the storage capacity might already be allocated to the first movers and due to the Swedish cement industry’s large volumes of CO_2, might lead to inefficiencies or issues in the logistics chain. Interviewees that represent emitters have highlighted this issue and stated that they have not yet received any price offers from Northern Lights, possibly due to a lack of capacity. Therefore it is crucial to establish agreements with the key partners and secure key resources early in order to reduce the uncertainty.

While the Swedish cement industry seem to be optimistic about an expanded market size and increased demand after their transition to CO_2-free cement, this finding deviates from the opinion of their Norwegian counterpart, Heidelberg Materials Brevik (2019) states that the transition to CO_2-free cement will result in a loss of competitiveness unless the government provides support and incentives. It remains uncertain which opinion is more correct, but one can presume that unless forced or incentivized, customers will choose the most economical option, even if it is not as sustainable or durable.

5.2 Economic viability of business model

In order for a business model to be working self-sustainably, the revenues need to exceed the costs. Since many actors seem to be in the phase of discussing a FID, the uncertainty regarding profitability is still high. Important revenue streams such as reverse auctions haven’t been conducted yet, and the voluntary markets are still relatively immature. The most crucial part of the business model to achieve economic viability for the Swedish cement industry is their value proposition of selling CO_2-free cement, since they are not expecting the sale of emission rights or negative emissions to fund their entire CCS operations. Therefore, correct assumptions regarding market size and willingness to pay for considerable increases in price for CO_2-free cement is pivotal. To make these assumptions, more market research is required and the Swedish cement industry must observe the progress of Heidelberg Materials Brevik's success with their EvoZero cement as they are a forerunner within CCS.

For Heidelberg Materials Slite's CO_2-free cement to take off, the Swedish government and municipalities would need to support the transition as the price increase of the cement due to its CCS activities would affect their end customer demands, as emphasised by Heidelberg Materials Brevik (2019) could be more than double the current price. However, as Rootzén and Johnsson (2017) found in their study, a doubling in the cement price could have a total impact as low as 1 percent due to its proportion of cost compared to the total expenses of building production. Since 35-40 percent of the cement production goes to public construction and infrastructure projects, the cement industry should have a reduced risk of losing market share of the public procurement. Additional price increases for cement can come from the quintupled increased energy consumption. Considering the strongly fluctuating energy prices recently, this poses an uncertainty that can drastically affect the Swedish cement industry's OPEX. In order to mitigate said impact, the Swedish cement industry needs to have close communication with energy companies, which is already needed for expanding the necessary electricity grid, to secure competitive energy prices long-term or find more energy efficient production methods.

Additionally, for the investment costs to be manageable by having a reasonable payback time, the Swedish cement industry needs to rely on grants to reduce the capital expenditures of the company. Grants such as Industriklivet have been pivotal for the Swedish cement industry to conduct their feasibility study, but in order for the full-scale CCS implementation to become a reality, support through reverse auctions and grants from the EU's Innovation Fund would be required, as evident from the cement plant in Germany. This argument lies in line with the findings of Dávila and Aagesen (2024) who looked at the level of support needed to have a self-sustaining CCS plant in the cement industry and found that a high level of support is needed.

5.3 Regulatory developments in Sweden and EU

Regulatory developments remain the main bottleneck for CCS. As noted by many interviewees, companies tend to be faster with change and decision making than regulatory bodies such as the Swedish government and the EU. Even countries with history with oil extraction and CCS such as Norway are still slacking behind with the regulatory developments, as exemplified with their licences for CCS storage where only a single storage permit has been handed out to date. However, due to the government's extensive support and involvement in the Longship project, Norway has still managed to be in the forefront of CCS. Sweden on the other hand has only recently begun the exploration of suitable final storage areas and no emitters are interested in the potential solutions due to its long timeline of 2035-2040. As interviewee D mentioned, the government must attempt to significantly shorten lead times for ongoing permit matters and authority decisions, which also aligns with the statement from Heidelberg Materials Cement Sverige (2023). In general, as interviewees have described, the overall problem that an emitter faces aside from high investment costs is the slow communication between actors and government agencies, especially the Swedish energy agency. With various investment decisions having to be made in the upcoming years, slow issuing of permits and licences poses a challenge that needs to be resolved.

In order for CCS to be economically viable for companies, a voluntary carbon market needs to exist where the negative emission rights can be traded through a channel between companies. Although the Swedish government changed the policy regarding how emissions are counted within companies and the country, thus enabling the trading of negative emissions, the Swedish Energy Agency has yet to update their own regulatory policies due to conflicting views despite being a state owned agency, further highlighting the bottlenecks of CCS. Furthermore, for companies to be able to capture carbon in the first place, state funding through reverse auction is necessary to reduce their cost structures. The first reverse auction was supposed to be held in 2022, but has been delayed and narrowed down to hydrogen gas and no confirmation of a reverse auction for CO2 has yet to be decided. As one of the main issues of CCS being the large costs associated with the installation of the equipment and construction of facilities, this could cause many companies to postpone their CCS plans as they need to secure the funding for it. In order for the Swedish cement industry to secure funding, they need to incorporate more biomass to their combustion processes to lower their cost per captured tonne of bio-CO_2.

Similar issues exist with the EU ETS as no clear indicator of how the emission allowances are allocated and when the last allowance will be issued. The interviewees have mentioned several different timelines, which is likely caused by the different phases proposed by the EU. In the current phase, the allowances are decreasing at a linear rate of 2.2% per annum but could be subject to change, and according to interviewee G, expected to reach zero in 2039. Since the Swedish cement industry is heavily reliant on the EU ETS due to their high emission-to-revenue ratio, clear guidelines are required. However, despite the uncertainties, the Swedish cement industry should focus on reducing their overall emission by finding improved calcination solutions and incorporating more biomass in their combustion processes.

6. Conclusion

This thesis has through qualitative research provided a potential design for how a CCS business model could look for the Swedish cement industry through the business model canvas. The thesis has also identified three key factors which could affect the implementation of CCS business models in the Swedish cement industry.

The main findings of the thesis conclude that in the current situation, a business model for the Swedish cement industry is not feasible as some components of the business model, such as the key partnerships, resources and revenue streams are still immature. Necessary infrastructure specifically for the Swedish cement industry, such as an improved electricity grid is not yet done and requires support and attention from regional agencies and private energy companies. Final storage locations and transportation partners are not ready for commercial use, negotiations with CCS suppliers are still at an early stage, and revenue streams are not clear on the regulatory side. Nevertheless, increasing development of CCS and the necessary logistics is ongoing in the Nordic region, with many actors along the CCS supply chain estimating completion between 2025 and 2030. Once completed, there are clear signs of a CCS business model being viable. Some major uncertainties still remain regarding trade of negative emission rights on voluntary markets as well as the EU ETS allowances where clear regulatory guidelines are required.

The findings of the thesis propose that when things are fully developed, a potential business model for the Swedish cement industry can exist and the key value proposition is providing value by supplying CO_2-free cement to existing and new customer segments. Additional value can be provided through the selling of negative emission rights and EU ETS allowances. To enable the business model, the Swedish cement industry needs heavy investments within physical resources, human resources, and financial resources, as the plant needs to be built, operational expertise is required, and financial resources such as grants and support facilitate the construction and operations in the early phases.

Ultimately, in order for CCS to develop and be managed by private actors such as the Swedish cement industry. It is imperative that regulatory bodies such as the Swedish government and the EU which sets the climate target goals to enable and facilitate its development through extensive support rather than being the bottleneck which inhibits it.

This thesis adds to existing literature surrounding business models for the CCS field by providing insights from different stakeholders within the Nordic region in the midst of their CCS transition as well as presenting a holistic overview of various CCS stakeholders in the region. The thesis provided insights within business models and CCS to explore the intricacies of the Swedish cement industry and its ambitions to reach carbon neutrality.

7. The thesis's limitations and implications for future research

The authors realise that there are several limitations of the thesis that should be addressed for future research. Firstly, the thesis has a lack of depth surrounding the necessary partnerships and resources as many actors in the Nordic region are not fully established and are unable to give out any relevant information due to non-disclosure agreements. This was especially true for the Swedish cement industry, since their plans for CCS were planned for 2030, a few years after other actors such as the district heating plants. This led to limitations in the findings and ultimately the presented business model canvas. Secondly, supplementing the data through interviews proved to be more difficult than the authors originally accounted for. Future researchers should be aware that due to being in the midst of the CCS transition, the availability of interviewees can be limited and the lead time from the initial outreach to interview could extend to several months as can be seen in Table 1. Additionally, the contents of the interview could be insufficient due to many organisations being in an early phase, secrecy, and non-disclosure preventing access to information. Finally, throughout the conducting of this thesis, new information and literature have surfaced which the authors have tried to include, but given the dynamic nature of the CCS environment at the moment of writing, there may have been several updates and publications which the authors have missed.

In regards to the limitations of the thesis, the authors leave some suggestions for future researchers. As the information that companies can disclose is limited, the reliance on published FEED and FID studies should be the main focus as they contain most of the information about the company's plans for CCS. Additionally, there are several projects ahead of the Swedish cement industry in the CCS race such as the German cement plant Geseke and the Greek cement project IFESTOS. These CCS projects were outside the scope of the thesis, but which could have provided valuable data if used during the data collection as these projects are closer in timeline and offer more information. Starting with these sources would have provided broad information about specific CCS projects for companies, and can give a detailed overview of both technical, but more notably, commercial aspects regarding CCS for the cement industry, which in turn can lead to an improved design for a business model. Interviews should not be used to gather factual information, as much of the information interviewees can disclose are already in published FEED and FID studies, but rather to gain perspectives and opinions on the details gathered from the diverse studies. Furthermore, the subject of CCS is becoming more and more relevant, with more than 450 papers published on Scopus in four months which approximates to an addition of 5 percent of the total literature on the platform. With more information and prior publication to rely on, future researchers should rely on more contemporary data as it is becoming increasingly abundant.

Due to the rapid development in the CCS field in the Nordic region, the authors encourage future researchers to look into the following subjects:

Logistics of CCS in Sweden: When exploring different alternatives for transportation, the authors interviewed several stakeholders within different intermediate storage hubs such as CinfraCap, CnetSS, and NICE. Along with the plenitude of storage locations underway, the authors find great interest in exploring different logistical routes and specifically, if any company were to implement CCS in Sweden, what the cost-optimal route would be for any given location.

Finding the value of CCS: Although the authors explored several different sources of revenue that can be derived from the implementation for CCS, heavy subsidising from governments are still required, especially for industries with a high emission-to-revenue ratio such as the cement industry as in line with the findings of Dávila and Aagesen (2024). As Sweden plans to be carbon neutral by 2045, more companies will need to capture their emissions and the economic feasibility will need to be further explored as the transition to CCS should not only rely on the support from governments.

Cost-optimisation of CCS in the Swedish cement industry: Whilst this thesis is of qualitative nature, an equally important thesis topic is the quantitative aspect of implementing CCS in the Swedish cement industry. To make the business model as viable as possible, many optimisations should be performed throughout the business model components. One suggestion from the authors is optimising the trade-off between the costs of CO_2 stock levels at the buffer storage and the EU ETS penalty fees, alternatively, the price for negative emission rights. Risking the potential leakage of CO_2 from production due to storage capacity being full as a result of logistical delays and therefore paying the EU ETS cost or buying a negative emission right to compensate could potentially be less expensive than the cost of increasing the storage capacity, deviating from the most cost-efficient stock levels. Therefore, the authors find this an interesting quantitative problem to make the business more cost-efficient.

Reference list

Andrew, R. M.: Global CO_2 emissions from cement production, Earth Syst. Sci. Data, 10, 195–217, https://doi.org/10.5194/essd-10-195-2018, 2018.

Barcelo, L., Kline, J., Walenta, G. et al. Cement and carbon emissions. Mater Struct 47, 1055–1065 (2014). https://doi.org/10.1617/s11527-013-0114-5

Bell, E., Bryman, A., & Harvey, B., (2022) Business Research Methods. 6th edition.

Bengtsson, K. (2023). Geologisk karaktärisering av den kambriska Faluddensandstenen i Östersjön och dess lämplighet för koldioxidlagring.

Biermann, M., Harvey, S., Kjärstad, J., Anantharaman, R., Fu, C., Jordal, K., ... & Seglem, H. E. (2022). Preem CCS.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101.

Budinis, S., Krevor, S., Mac Dowell, N., Brandon, N., & Hawkes, A. (2018). An assessment of CCS costs, barriers and potential. Energy strategy reviews, 22, 61-81.

Chalmers Library. (2024). *Databasinformation*. https://www.lib.chalmers.se/soek/databasinfo/Scopus/12296561

COWI AB. (2021). CinfraCap – Gemensam infrastruktur för transport av koldioxid: Förstudierapport (A209494-4-06-REP-0001).

DaSilva, C. M., & Trkman, P. (2014). Business model: What it is and what it is not. Long range planning, 47(6), 379-389.

Dávila, J., & Aagesen, M. (2024). How to Accelerate Ccs Deployment in the Cement Industry? Assessing Impacts of Uncertainties on the Business Case.

Deng, H., Roussanaly, S., & Skaugen, G. (2019). Techno-economic analyses of CO_2 liquefaction: Impact of product pressure and impurities. *International Journal of Refrigeration*, 103 , 301-315. https://doi.org/10.1016/j.ijrefrig.2019.04.011.

Dovelius, J. (2000). Att samla in och bearbeta data. Skolverket. https://www.skolverket.se/publikationer?id=717

Emanuelsson, H, A., & Johnsson, F. (2023). The Cost to Consumers of Carbon Capture and Storage—A Product Value Chain Analysis. Energies, 16(20), 7113.

Energimyndigheten. (2023a). *Industriklivet.* https://www.energimyndigheten.se/forskning-och-innovation/forskning/industri/industriklivet

Energimyndigheten (2023b) *Bio-CCS: bokföring och rapportering av negativa utsläpp samt disposition av dessa.* https://www.energimyndigheten.se/492ae9/globalassets/klimat--miljo/ccs/promemoria-bio-ccs-bokforing-och-rapportering-av-negativa-utslapp-samt-disposition-av-dessa.pdf

Energimyndigheten (2024a). *Styrmedel för CCS och CCU* ER 2023:26. ISBN: 978-91-7993-146-9.

Energimyndigheten (2024b). *Stöd för bio-CCS genom omvänd auktion.* Retrieved 22nd April 2024 from https://www.energimyndigheten.se/klimat--miljo/ccs/statligt-stod-for-bio-ccs/

Eriksson, L. T. & Wiedersheim-Paul., F., & Abrahamsson, A. (Red.). (2008). Rapportboken.
Liber.

European Commission. (2009). *Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.* http://data.europa.eu/eli/dir/2009/31/oj

European Commission. (n.d. -a). *2050 long-term strategy.* https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

European Commission (n.d. -b). *EU Emissions Trading System (EU ETS). https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en*

European Commission. (2023a). Policy CCS Country Report 2023: Sweden. Retrieved from https://ec.europa.eu/assets/clima/ccs/2023/policy_ccs_country_report_2023_sweden_se.pdf

European Commission. (2023b). Policy CCS Country Report 2023: Denmark. Retrieved from https://ec.europa.eu/assets/clima/ccs/2023/policy_ccs_country_report_2023_denmark_en.pdf

European Commission. (2023c). Policy CCS Country Report 2023: Denmark. Retrieved from https://ec.europa.eu/assets/clima/ccs/2023/policy_ccs_country_report_2023_norway_en.pdf

European Commission. (2024a). Emissions cap and allowances. Retrieved from https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/emissions-cap-and-allowances_en

European Commission. (2024b). Innovation Fund

Deploying innovative net-zero technologies for climate neutrality. https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund_en

European Union. (2012). Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC. https://eur-lex.europa.eu/eli/dir/2012/18/oj

EvoZero. (n.d.). EvoZero product information [PDF document]. Retrieved 08 April 2024 from https://www.evozero.com/docs/evozero-product-en.pdf

Flick, U. (2018). *An Introduction to Qualitative Research*. (6 uppl.). SAGE.

Fossilfritt Sverige. (n.d). *Cement industry*. Retrieved 15 April, 2024, from https://fossilfrittsverige.se/en/roadmap/the-cement-industry/

Gassnova. (2020). *Developing Longship – Key lessons learned*. https://ccsnorway.com/publication/developing-longship-key-lessons-learned/

Global CCS Institute. (2024). *Understanding CCS: Transport.* Retrieved 15 April, 2024, from https://www.globalccsinstitute.com/wp-content/uploads/2022/07/Factsheet_CCS-Explained_Transport.pdf

Global CCS Institute. (2023) *Denmark's Project Greensand Begins Groundbreaking Cross-border CO_2 Injection.* Retrieved 15 April, 2024 from https://www.globalccsinstitute.com/news-media/latest-news/denmarks-project-greensand-begins-groundbreaking-cross-border-CO_2-injection/

Government offices of Sweden. (2024). *Five northern European countries conclude international arrangements on transport and storage of carbon across borders.* https://www.government.se/press-releases/2024/04/five-northern-european-countries-conclude-international-arrangements-on-transport-and-storage-of-carbon-across-borders/

Hallquist, L., Mellquist, A. C., Johnsson, F., & Rootzén, J. (2022). Finansiering av omställning till klimatneutralt betongbyggande.

Heidelberg Materials Brevik. (2019). *Redacted version of FEED Study (DG3) Report.* https://gassnova.no/app/uploads/sites/6/2020/07/NC03-NOCE-A-RA-0009-Redacted-FEED-Study-DG3-Report-Rev01-1.pdf

Heidelberg Materials Cement Sverige. (2023). *Färdplan för cementbranschen- vägen till nettonollutsläpp 2030.* https://www.cement.heidelbergmaterials.se/sv/fardplan-for-cementbranschen-vagen-till-nettonollutslapp-2030

Heidelberg Materials Cement Sverige. (2024). *Tidslinje bortom nettonoll.* Retrieved 15 April, 2024, from https://www.sliteccs.se/sv/tidslinje

IMO. (2019a). *Carbon Capture and Sequestration.* Retrieved 15 April, 2024, from https://www.imo.org/en/OurWork/Environment/Pages/CCS-Default.aspx

Implement Consulting Group. (2022). The Economic Impact of BECCS in Sweden. Retrieved 11 April, 2024, from https://www.stockholmexergi.se/content/uploads/2022/02/BECCS-Economics-Sweden-final.pdf

Industrial Analytics Platform (IAP) by UNIDO. (2024). Steel and cement can drive a decade of action on climate change: How?. Retrieved 15 April, 2024, from https://iap.unido.org/articles/steel-and-cement-can-drive-decade-action-climate-change-how

Intercontinental Exchange. (n.d.). EUA futures. Retrieved 15 April, 2024, from https://www.ice.com/products/197/EUA-Futures/data?marketId=7642445

Kapetaki, Z., & Scowcroft, J. (2017). Overview of carbon capture and storage (CCS) demonstration project business models: risks and enablers on the two sides of the Atlantic. Energy Procedia, 114, 6623-6630.

Karlsson, S., Normann, F., & Johnsson, F. (2024). Cost-optimal CO_2 capture and transport infrastructure—A case study of Sweden. International Journal of Greenhouse Gas Control, 132, 104055.

Kearns, D., Liu, H., & Consoli, C. (2021). Technology readiness and costs of CCS. Global CCS institute, 3.

Kheshgi, H., Crookshank, S., Cunha, P., Lee, A., Bernstein L., Siveter, P. (2009). *Carbon capture and storage business models.* Energy Procedia. Volume 1. Issue 1. 4481-4486, ISSN 1876-6102. https://doi.org/10.1016/j.egypro.2009.02.265.

Kjärstad, J., Skagestad, R., Eldrup, N.H., Johnsson, F. (2016). Ship transport—A low cost and low risk CO_2 transport option in the Nordic countries. International journal of greenhouse gas control, 54, 168-184.

Kjärstad, J., Johnsson, F., Eldrup, N. H., Skagestad, R., & Haugen, H. A. (2022). The Evolvement of a CCS-Hub at the port of Gothenburg, Sweden. Sweden (September 1, 2022).

Knoope, M. M. J., Ramírez, A., & Faaij, A. P. C. (2015). Investing in CO_2 transport infrastructure under uncertainty: A comparison between ships and pipelines. International journal of greenhouse gas control, 41, 174-193.

Leung, D. Y., Caramanna, G., & Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. *Renewable and sustainable energy reviews*, *39*, 426-443.

Lundberg, L., & Fridahl, M. (2022). The missing piece in policy for carbon dioxide removal: reverse auctions as an interim solution. Discover Energy, 2(1), 3.

Martin-Roberts, E., Scott, V., Flude, S., Johnson, G., Haszeldine, R. S., & Gilfillan, S. (2021). Carbon capture and storage at the end of a lost decade. One Earth, 4(11), 1569-1584.

McKinsey & Company. (2020). Laying the foundation for zero-carbon cement. Retrieved 15 April, 2024, from https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement

Oei, P. Y., & Mendelevitch, R. (2016). European scenarios of CO_2 infrastructure investment. The Energy Journal, 37(3_suppl), 171-194.

Orchard, K., Hay, M., Ombudstvedt, I., Skagestad, R., Joos, M., Nysæter, G., Sjøbris., Jarøy, A.G., Durusut, E., Craig, J. (2021). The Status and Challenges of CO_2 Shipping Infrastructures.

Osterwalder, A., & Pigneur, Y. (2010). Business model generation: a handbook for visionaries, game changers, and challengers (Vol. 1). John Wiley & Sons.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research. *Administration and policy in mental health*, 42(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Patel, R & Davidson, B (2011). *Forskningsmetodikens grunder: att planera, genomföra och rapportera en undersökning. 4. uppl.* Lund: Studentlitteratur.

Pettigrew, A., (1985) The Awakening Giant: Continuity and Change in Imperial Chemical Industries. Oxford: Blackwell

Port of Stockholm (2023). Stockholm Norvik Port potential CCS hub in Sweden. Retrieved 2024-04-12 from https://www.portsofstockholm.com/about-us/news/2023/stockholm-norvik-port-potential-ccs-hub-in-sweden/

Rajabloo, T., Valee, J., Marenne, Y., Coppens, L., & De Ceuninck, W. (2023). Carbon capture and utilization for industrial applications. Energy Reports, 9, 111-116.

Romson, Å. & Steen, L., 2021. Miljötillstånd i kedjan för bio-CCS. PM inom arbetspaket 3. Slutlig version 2021-07-02.

Rootzén, J., & Johnsson, F. (2017). Managing the costs of CO_2 abatement in the cement industry. Climate Policy, 17(6), 781-800.

Roussanaly, S., Berghout, N., Fout, T., Garcia, M., Gardarsdottir, S., Nazir, S. M., ... & Rubin, E. S. (2021). Towards improved cost evaluation of Carbon Capture and Storage from industry. International Journal of Greenhouse Gas Control, 106, 103263.

SSPA Maritime Center. (n.d.), *Logistics for Carbon Capture and Storage in the cement industry (LoCCS)* . https://www.sspa.se/en/logistics-carbon-capture-and-storage-cement-industry-loccs

Scottish Carbon Capture & Storage [SCCS]. (n.d.). Project Information: Northern Lights Initiative. Accessed April 2, 2024, from https://www.geos.ed.ac.uk/sccs/project-info/2142#

Svensson, R., Odenberger, M., Johnsson, F., & Strömberg, L. (2004). Transportation systems for CO_2—application to carbon capture and storage. Energy conversion and management, 45(15-16), 2343-2353.

Svensson, P. (2015). *Kvalitativ och kvantitativ undersökningsmetodik* [Powerpoint-presentation]. https://dokumen.tips/documents/kvalitativ-och-kvantitativ-metod-kvalitativ-och-kvantitativ-underskningsmetodik.html?page=37

Solomon, S., Carpenter, M., & Flach, T. A. (2008). Intermediate storage of carbon dioxide in geological formations: A technical perspective. *International journal of greenhouse gas control*, *2*(4), 502-510.

Suarez, F., & Lanzolla, G. (2005). The half-truth of first-mover advantage. Harvard business review.

Szabados, A., Al Khatib, H., Ahmad, N., Dominek, K., Burachok, O., Roth, T., & Schovsbo, N. (2022, November). Greensand focused seismic monitoring for offshore CO_2 pilot injection. In EAGE GET 2022 (Vol. 2022, No. 1, pp. 1-5). European Association of Geoscientists & Engineers.

Thepsaskul, W., Wongsapai, W., Sirisrisakulchai, J., Jaitiang, T., Daroon, S., Raksakulkan, V., ... & Wattakawigran, G. (2023). Potential Business Models of Carbon Capture and Storage (CCS) for the Oil Refining Industry in Thailand. Energies, 16(19), 6955.

United Nations, *The Paris Agreement.* https://www.un.org/en/climatechange/paris-agreement (Accessed 2024-02-23).

Wallén, G. (2008). *Vetenskapsteori och forskningsmetodik*. (2. uppl., Vol.13). Studentlitteratur.

Wilhelmsen, T. (2022, December 13). Northern Lights: CO_2 transport & storage at scale [Presentation slides]. Nordic Energy Research. PDF.

World Health Organization. (2023, 12 October). *Climate change.* https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

Yao, X., Zhong, P., Zhang, X., & Zhu, L. (2018). Business model design for the carbon capture utilization and storage (CCUS) project in China. Energy policy, 121, 519-533.

Zetterberg, Johnsson, Möllersten (2021): Incentivizing BECCS—A Swedish Case Study. Front. Clim. 3:685227. doi: 10.3389/fclim.2021.685227 https://www.frontiersin.org/articles/10.3389/fclim.2021.685227/full

Zott, C., & Amit, R. (2010). Business model design: An activity system perspective. Long range planning, 43(2-3), 216-226.

Appendix A: Semi-structured interview guide

Introduction

1. Introduction of the study.
2. Description of the interview process and request permission to record and transcribe.
3. Short introduction of interviewee.

Topic 1: Background

4. Can you describe your role within CCS logistics?
5. Can you describe what activities you plan to perform within CCS logistics?

Topic 2: Capabilities

6. What kind of resources are necessary for your required CCS activities? (e.g equipment, facilities, knowledge / skills, infrastructure etc.)
7. What partnerships do you think you need in order to operate your part of the CCS logistics chain?

Topic 3: Drivers and barriers

8. What driving forces do you think will facilitate your role within CCS logistics?
9. What obstacles do you perceive that your role in CCS logistics have at the moment?

Topic *4*: Additional Questions for Emitter actors

10. How do you think CCS will affect your current customers in terms of:
a. price
b. relationship
c. product offerings
11. What market opportunities do you think CCS could lead to?
a. negative emission rights
b. EU ETS allowances
c. others

Topic *5*: Additional Questions for Storage actors

12. What is your current planned CO_2 storage capacity?
13. What has market demand and negotiation with emitters looked like?

Topic 6: Additional Questions for Transport actors

14. What infrastructures are the customers required to have in order to utilize your CCS transportation services?
15. Do you have any strategies to maximize fill rates of your vessels during transportation back and forth?

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY