GASSNOVA

Report

Full chain CO2 footprint

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SUMMARY:

Gassnova appointed DNV GL and Carbon Limits to develop a tool to calculate the amount of CO_2 emitted when capturing and storing a certain amount of CO_2. The tool is a spreadsheet-based model built following the principles of ISO 14040 "Life Cycle Analysis – principles and framework" and ISO 14044 "Life Cycle Analysis – requirements and guidelines" and equipped to calculate CO_2 equivalents in a 100-year perspective.

The functional unit of the system studied is 1 tonne of CO_2 stored.

This tool has been used to explore the CO_2 footprint of the full-scale capture, transport and storage value chain of the Norwegian Carbon capture and storage Demonstration project (NCD). In the project, CO_2 is captured from two capture sites, Norcem in Brevik and Klemetsrud in Oslo, transported by ship to a land-based terminal in Øygarden near Bergen and further transported in offshore pipeline to the Aurora CO_2 storage licence area near the Troll field for final geological storage.

Results are presented as total CO_2 footprint in tonnes of CO_2 equivalent per tonne CO_2 stored for the value chain of each capture site separately and for both capture sites combined. In other words, results show the impact on storage efficiency linked to the setup of the value chain.

Storing CO_2 for the state support period of 10 years as well as for the duration of the plant operating lifetime of 25 years are calculated. A case of allocating the CO_2 footprint of the storage infrastructure on the full storage capacity of 1.5 Mt/yr has also been included.

Cases/chains calculated (t CO_2 equivalent emitted/t stored)	Norcem chain	FOV chain	Norcem+FOV chain
25 years capture + storage 1.5 Mt storage capacity used	0.047	0.103	0.077
10 years capture + storage Only 400/400/800 kt stored	0.087	0.14	0.10
25 years capture + storage 1.5 Mt storage capacity and BioCCS incl.	-0.053	-0.397	-0.223

The Norcem value chain has a CO_2 footprint around half the footprint of the FOV value chain irrespective of considering a 10 or a 25 years period of capture and storage; 0.047 and 0.087 $t_{CO2,e}$ for Norcem versus 0.103 and 0.14 $t_{CO2,e}$ for FOV; both measured per tonne of CO_2 stored. The main difference between the Norcem and the FOV project is the possibility to use waste heat from the flue gas at Norcem while FOV must extract steam from the district heating cycle and replace this with electricity consumed in large heat pumps.

However, if the fact that half of the waste incinerated at Klemetsrud is of biological origin is taken into consideration, the FOV chain is extracting approximately 0.4 $t_{CO2,e}$ from the atmosphere for each tonne stored. Norcem has a much smaller portion of biological waste in their fuel mix and thus a much smaller portion of CO_2, approximately 0.050 $t_{CO2,e}$, is extracted from the atmosphere per tonne stored. Capturing CO_2 from both capture sites for 25 years and allocating the storage infrastructure also to other CO_2 sources up to 1.5 Mt storage capacity will all together extract more than 0.2 $t_{CO2,e}$ CO_2 from atmosphere per tonne stored. It is also worthwhile to mention that the footprint of the studied value chains will decrease when CCS is introduced in production facilities for the steel, concrete, chemicals and energy consumed to establish the CCS value chains.

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Content

1 INTRODUCTION

In 2018 Gassnova engaged DNV GL and Carbon Limits in developing a calculation tool for the CO_2 footprint of a full chain capture, transport and storage value chain to be used to evaluate the Norwegian Carbon capture and storage Demonstration project (NCD). The project at present consists of the two capture sites - Norcem cement facility in Brevik and Fortum Oslo Varme's waste to energy plant at Klemetsrud in Oslo - transport of CO_2 by ship to an onshore terminal at Naturgassparken in Øygarden near Bergen and transport of CO_2 by offshore pipeline to the Aurora site for final storage in the Johansen formation in the North Sea (Figure 1). Transport and storage are the responsibility of the Northern Lights project a cooperation between the three oil companies Equinor, Shell and Total.

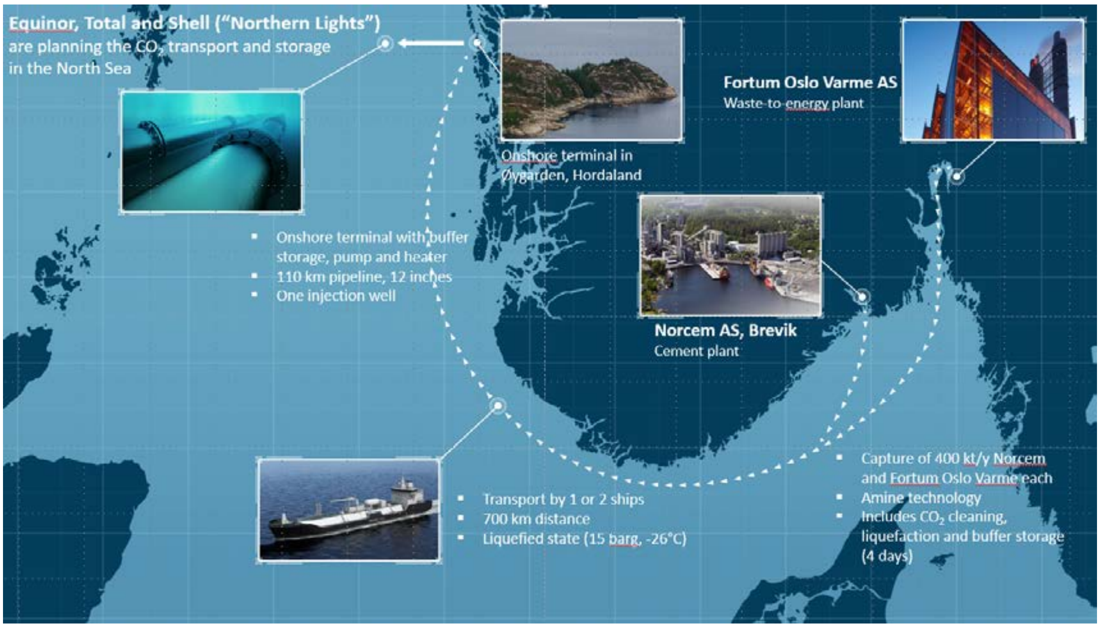

Figure 1: Overview of the NCD project

Carbon footprint is a measure of the total amount of greenhouse gas emissions expressed in terms of CO_2-equivalents, that is directly and indirectly caused by an activity or is accumulated over the life stages of a product.

The tool is a spreadsheet-based model built on the principles of ISO 14040 "Life Cycle Analysis – principles and framework" and ISO 14044 "Life Cycle Analysis – requirements and guidelines". It was developed and tested during the concept phase of the NCD project. The tool and its capabilities have been thoroughly explained in the DNV GL report [1]. A schematic of the spreadsheet model and of the system boundaries are shown below (Figure 2).

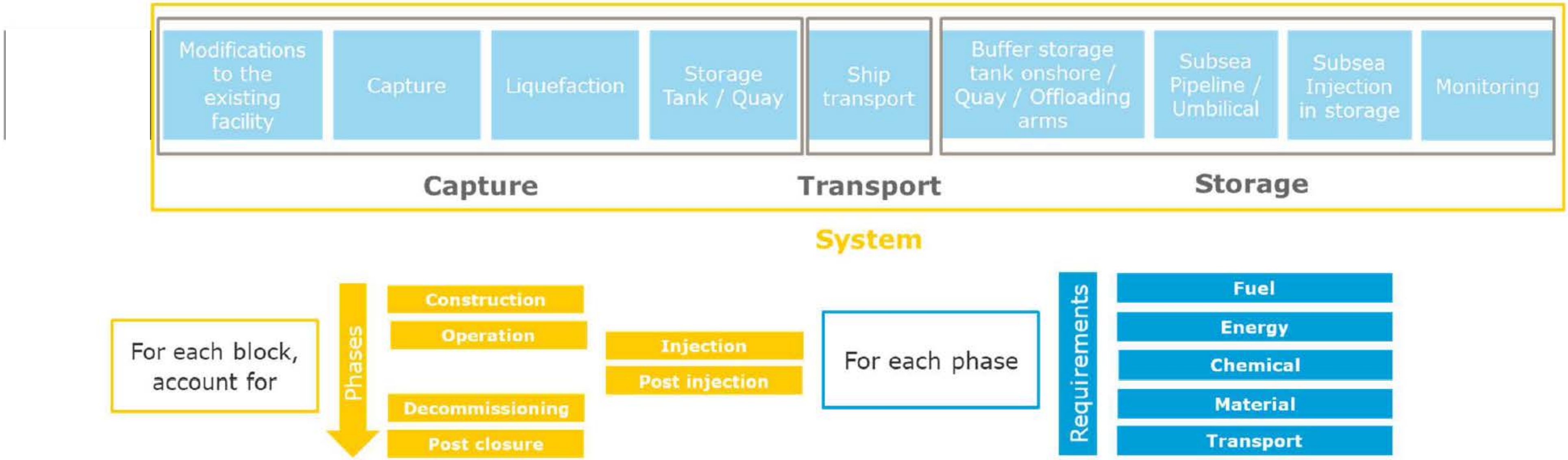

Figure 2: Visualization of the CO_2 footprint system boundaries including the complete system and its building blocks. For each building block, all project phases are included and for each phase CO_2 emissions from the use of fuel, energy, chemicals, materials and transport are included

The tool is equipped to calculate CO_2 equivalents in a 100-year perspective. The functional unit of the system/study is 1 tonne of CO_2 stored.
Emission factors are for the most taken from the GaBi Professional Database or open source data bases. It is assumed 1 $tCO_{2,e}$ emitted in the future is equal to 1 $tCO_{2,e}$ emitted today, which is a conservative approach.

1.1 BACKGROUND

As the purpose of the NCD project is to store CO_2 to mitigate climate change, evaluating the emissions of greenhouse gases per tonne of CO_2 stored is important for the project. The main purpose is to confirm whether it is worthwhile to establish a CO_2 capture value chain and to ensure that more CO_2 is stored than is emitted in the chain over its lifetime.

This fall all FEED study participants have completed input data sheets based on their consumption of fuel, energy, chemicals, materials and transport for all phases of the project; construction, operation and decommissioning. For storage also injection, post injections and post closure survey activities are included. The origin of these data stems from the FEED study work from the three study participants- Norcem, FOV and Northern Lights - and are delivered as part of their FEED study reports [2], [3], [4]. These reports form the basis of the CO_2 footprint calculation results presented in this report.

1.2 MANDATE AND GOAL

Gassnova is responsible for the functionality of the CO_2 value chain by adding a holistic view to the input from the different FEED study participants. Calculating the value chain CO_2 footprint is as such one of the corner stones. Gassnova has decided to make the CO_2 footprint calculations a part of the benefit realization reporting of the NCD project. This report presents the results in terms of CO_2 footprint based on the FEED study consumption data for the three main value chains:

- Capture of 400kt CO_2 in Brevik, transport by ship to Naturgassparken, offshore pipeline transport through pipe to Aurora storage site 3000 m below sea level
- Capture of 400kt of CO_2 at Klemetsrud, transport by ship to Naturgassparken, offshore pipeline transport to the same Aurora storage site
- Capture of 800kt of CO_2 in Brevik and at Klemetsrud together, transport by ship to Naturgassparken, offshore pipeline transport and storage at the Aurora site

In addition, all three alternatives above are estimated when utilizing the full capacity of the storage site, 1.5Mt by introducing CO_2 from other sources. The capture from these other sources are not included in the footprint calculations presented in this report.

2 CASES AND MAIN ASSUMPTIONS

To illustrate the span of the possible outcome of chosen value chains Gassnova has calculated the following cases:

- Norcem chain: 25 years capturing 400kt/y at Brevik utilizing the full storage capacity of 1.5Mt/y
- FOV chain: 25 years capturing 400kt/y at Klemetsrud utilizing the full storage capacity of 1.5Mt/y
- Both chains: 25 years capturing 800kt/y CO_2 utilizing the full storage capacity of 1.5Mt/y
- Support period for Norcem chain: 10 years of capture and storage of 400kt/y at Brevik only
- Support period for FOV chain: 10 years of capture and storage of 400kt/y at Klemetsrud only
- Support period for both chains: 10 years of capture and storage of 800kt/y only

- Norcem chain w/BioCCS: 25 years capturing 400kt/y at Brevik utilizing the full storage capacity, 1.5Mt/y and accounting for biological waste in fuel
- FOV chain w/BioCCS: 25 years capturing 400kt/y at Klemetsrud utilizing the full storage capacity, 1.5Mt/y and accounting for biological waste in fuel
- Both chains w/BioCCS: 25 years capturing 800kt/y, utilizing the full storage capacity, 1.5Mt/y and accounting for biological waste in fuel

Other cases and possibilities will most probably fall between these extreme points of capture, transport and storage scenarios.
For single capture site value chains only one ship for transport is required while for two capture site value chains two ships are included.
All storage alternatives are based on only one well.
All electricity consumed is based on the Norwegian electricity mix extracted from the GaBi professional database, 29 g/kWh. For comparison the value disclosed by NVE for 2018, is somewhat lower, approximately 19 g/kWh [5].

3 RESULTS

Results are presented on an aggregated level in table 1 below, i.e. the total CO_2 footprint number for each individual value chain as listed above.

Table 1: Results of value chain cases calculated and given as tonne of CO_2 equivalent emitted per tonne of CO_2 stored

	Norcem Chain	FOV Chain	Norcem+ FOV Chain
25 years capture + storage 1.5 Mt storage capacity used	**0.047**	**0.103**	**0.077**
10 years capture + storage Only 400/400/800 kt stored	**0.087**	**0.14**	**0.10**
25 years capture + storage 1.5 Mt storage cap. used, BioCCS incl. *	**-0.053**	**-0.397**	**-0.223**

*) negative numbers indicate CO_2 is extracted from atmosphere

See chapter 3.2 for explanation and discussion of the results and chapter 3.3 for a discussion on uncertainties in the input data and calculations.

All calculations are documented in separate spreadsheet files stored in Sharepoint [6].

3.1 ILLUSTRATION OF RESULTS

Results are presented as graphs showing first the importance of the different phases of the individual projects in figure 3, the phases being construction, operation, and decommissioning for capture and transport and added also post-injection and post-closure for the storage facility. Then, in figure 4 the primary contributors to the total CO_2 footprint of the 6 first cases as described in chapter 2 are illustrated.

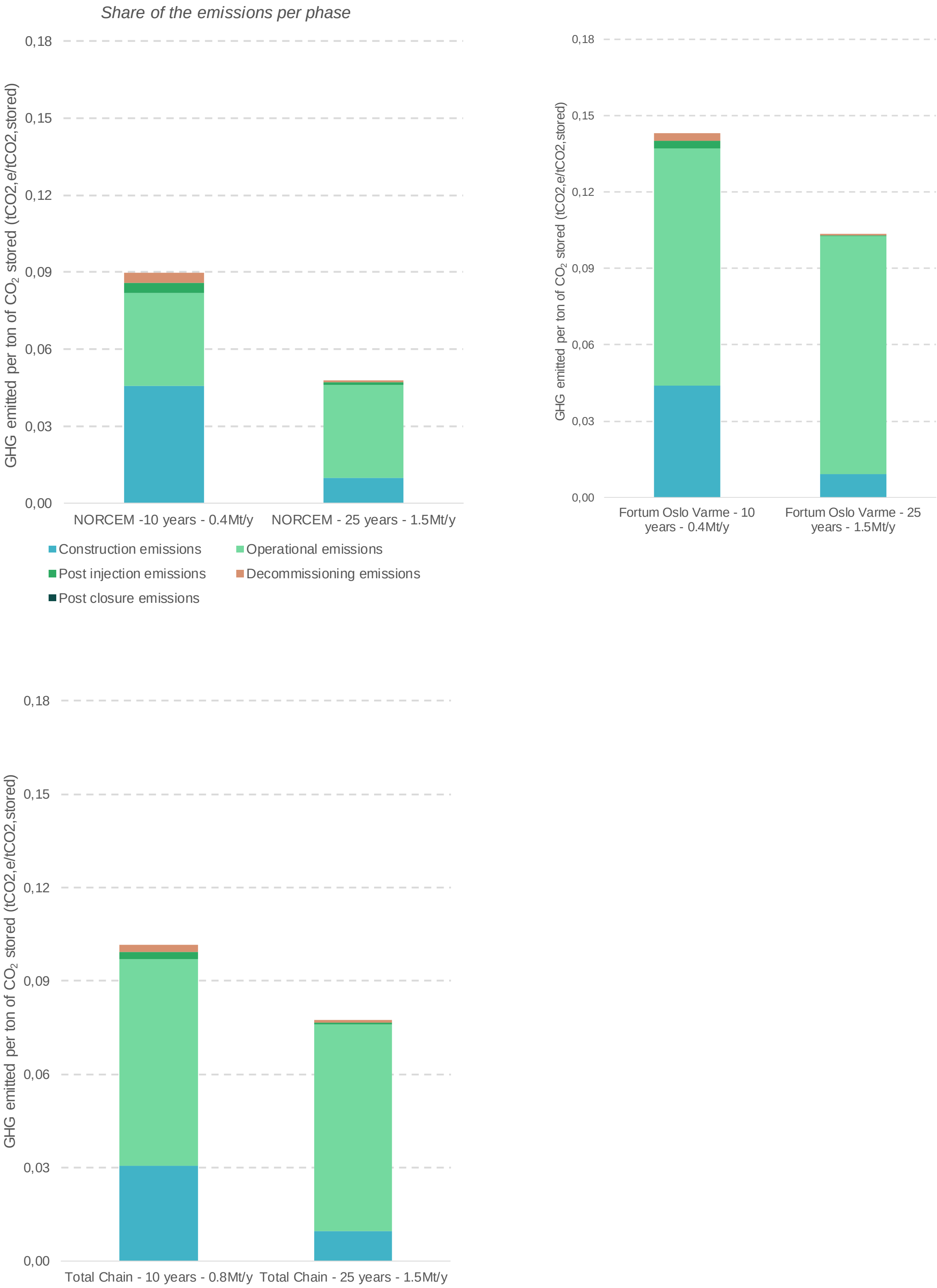

Figure 3: Graphs illustrating the importance of the individual phases of the projects studied, i.e. construction, operation and decommissioning, Norcem upper left, FOV upper right and both chains combined underneath. For storage also post-injection and post-closure activities are included. Legend is the same for all graphs as given below the upper left graph.

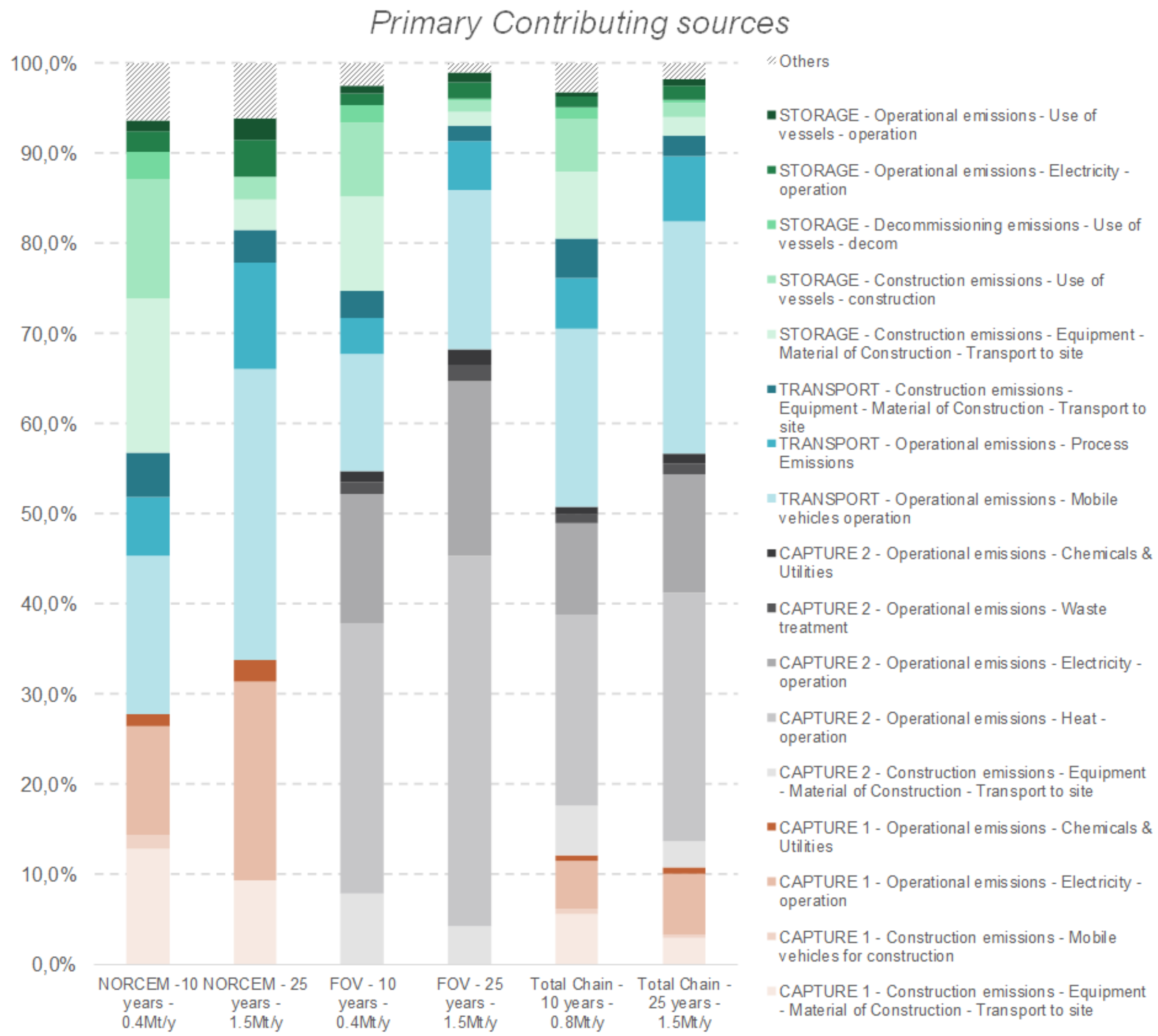

Figure 4: Relative comparison of primary contributing blocks in the whole value chain for the 6 different cases calculated, where Capture 1 is Norcem, Capture 2 is FOV and Total chain is both of them combined

3.2 DISCUSSION/EXPLANATION OF RESULTS

Generally, the NCD project is very low in CO_2 footprint compared to projects studied elsewhere [7] mainly due to the capture projects utilizing available waste heat or steam from own plants subject to capture, Norwegian electricity mix being very low in CO_2 footprint and a high focus on using low footprint energy and fuel alternatives wherever possible. An average value for the carbon efficiency for a number of projects in Europe has proved to be around 85% compared to the two Norwegian value chains studied here with a carbon efficiency of approximately 95% and 90% for Norcem and FOV respectively. Note that carbon efficiency is the inverse of CO_2 footprint.

The results are showing the Norcem value chain is the best case in terms of low CO_2 footprint (see figure 3). This is mainly due to the chosen energy supply utilizing available waste heat from the flue gases. CO_2 capture with a post-combustion amine process is high in energy demand and to have waste heat available is absolutely an advantage: the operational emissions from heat generation in the FOV case account for around 30% of the chain emissions where it is not an item of emissions for Norcem (see figure 4 for comparison).

At Klemetsrud steam is supplied from the boilers in the waste incinerators but to replace the heat consumed by the capture process and to be able to deliver the same heat to the district heating, large heat pumps with a considerable power demand will have to be installed. Steam is supplied from the plant and only the CO_2 not captured, based on 95% capture rate and 95% availability, is allocated to the steam supply. Even though, the largest contributor to the footprint of FOV chain is the heat supply during operation, see figure 4.

Other dominating contributors to the CO_2 footprint in the value chains are the consumption of fuel, i.e. natural gas, for the ship engines and the methane emission and leakage during ship transport. From figure 3 and 4, it can be seen that the construction phase is less important compared to the operation phase but tend to get more visible for the 10 years case compared to the 25 years case. In Norcem case it represents 40% of the emissions.

The BioCCS cases in table 1 reflect the fact that the waste incinerated at Klemetsrud contains 50% biological waste and by capturing CO_2 at Klemetsrud for each tonne of CO_2 captured and stored almost 0.40 $tCO_{2,e}$ from the biological cycle is extracted from the atmosphere. This is to a lesser extent the case at Norcem where a smaller portion (approx. 10%) of the fuel used in the process is of biological origin. This implies at Norcem just above 0.050 $tCO_{2,e}$ from the biological cycle is removed from the atmosphere for each tonne of CO_2 captured and stored. For the time being there is no way to report and get credit for biogenic CO_2 in the ETS-system but this may find a solution in the future.

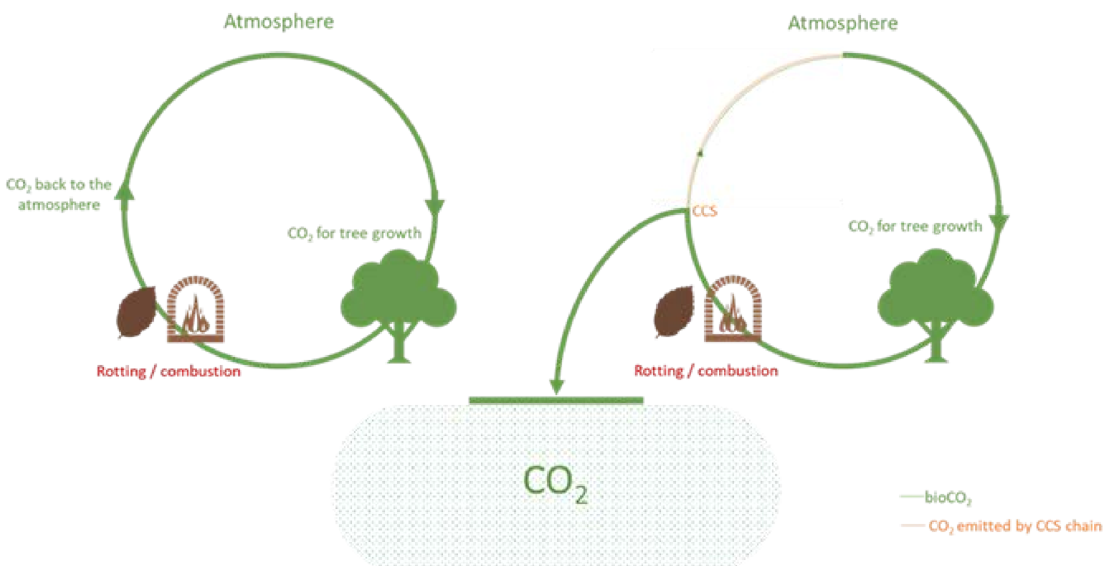

Figure 5: The effect of capturing biogenic CO_2

Figure 5 above illustrates how the balance can get negative, when part of the CO_2 that is stored is from biological origin. Storing the CO_2 has some CO_2 emissions that come with the process to put in place and it is true that the CO_2 has already been removed from the atmosphere in the carbon balance from the tree or other bio-based material but here the trick is that we are not sending it back to the atmosphere by burning it and by that we are breaking the carbon cycle connected to this tree/biomaterial.

The balance is unbalanced and by not emitting anymore this CO_2 to the atmosphere, we are removing it. Storing it means that some CO_2 coming from elsewhere will replace the CO_2 from the tree in the carbon balance of this tree. This is the whole concept of BioCCS.

Another studied case just focused on the transport and storage part of the chain. This part account for 0.035 $tCO_{2,e}/tCO_{2,stored}$ when considering the total chain scenario over 25 years if limiting the storage capacity to Norcem and Fortum captured CO_2 (800ktCO_2/y). If, an additional emitter such as Preem, an oil refinery on the Swedish west-coast near Gothenburg, could capture 700 kt CO_2 and by that utilize the full storage infrastructure of 1,5 Mt, taking into account an additional ship and the corresponding distance from Preem to the storage site, then the carbon footprint decreases of 10%: 0.032 $tCO_{2,e}/tCO_{2,stored}$.

3.3 DISCUSSION OF UNCERTAINTIES

Confidence levels in activity data (consumption data provided by the different stakeholders in the chain) were completed by the different data providers. The different levels are defined as follows:

- High confidence: Data from design documents
- Moderate confidence: Data deduced from the design documents
- Low confidence: Estimates based on expert judgement

Considering the level of definition of the project (FEED) and the fact that it is first of a kind plant constructions and operations, the confidence level of some of the activity data are on the low to moderate side especially for the clearing and use of mobile vehicles for construction, and the decommissioning activities. For material use and operation, this is as good as it can get at this stage of the project. As for economic studies, contingencies were applied, particularly on the material consumption. This is done to cater for material losses during fabrication, transport and construction and reflects the use of contingency also associated with CAPEX estimation. For all calculated cases, a 15% contingency on all materials spent during construction was added. The two capture sites had a somewhat different approach to cost estimation contingency where Norcem used 15% and FOV used 3-5%. Reducing to 5% contingency on material consumption did not have a visible impact on the total footprint calculation mainly due to construction generally being less important than operation in these calculations.

As far as emission factors are concerned, the different confidence levels are the following ones:

- High confidence: data found in verified databases, widely accepted data
- Moderate confidence: data from peer reviewed papers or expert judgement, high to moderate degree of consensus
- Low confidence: data from grey literature, moderate to low (or unknown) degree of consensus

Most of the emission factors and generic consumption data (e.g. fuel consumption of a truck) are taken from established databases and are on a higher confidence level than the activity data. This is illustrated in the table below.

Table 1: Confidence level of data used for the carbon footprint (green: high - orange: moderate - red: low)

Phase	Item	Activity Data – Confidence level				Emission Factors – Confidence level
		Capture 1	Capture 2	Transport	Storage	
Construction	Preparation of the site / Clearing					
	Buildings / Roads Construction					

	Equipment - Material of Construction - Transport to site					
	Mobile vehicles for construction					
	Chemicals and Utilities - construction					
	Use of vessels - construction					
Operation	Chemicals & Utilities					
	Electricity - operation					
	Heat - operation					
	Mobile vehicles operation					
	Process Emissions					
	Waste treatment					
	Use of vessels - operation					
Post injection	Use of vessels - post inj					
Decommissioning	Clearing - decom			Ship to be reused after operation		
	Mobile vehicles					
	Waste disposal					
	Use of vessels - decom					

This table reflects that there are still some uncertainties in the input data and as such some uncertainties around the carbon footprint of the project. These uncertainties have been reduced as much as possible. Operation is the main contributor to the footprint followed by construction. Most data in these phases have a moderate to high confidence as reflected in the table. The carbon footprint results will thus not change much with a reducing uncertainty.

4 CONCLUSION

The CO_2 footprint of the NCD project has been studied. Several alternatives considering single or combined capture sites value chains with partial or full storage capacity used and different project durations were calculated.

Generally, the NCD project is very low in CO_2 footprint mainly due to:

- the capture projects utilizing available waste heat or steam from own plants subject to capture,
- Norwegian electricity mix having a very low CO_2 footprint and,

- a high focus on using energy and fuel alternatives with a low CO_2 footprint wherever possible.

Results show the Norcem value chain has a footprint approximately half the footprint of the FOV value chain. It is however, important to keep in mind that all value chains studied in the NCD project has a low CO2 footprint due to the bullet points listed above. . It is also worthwhile to mention that the footprint of the studied value chains will decrease even more when CCS is introduced in production facilities for the steel, concrete, chemicals and energy consumed to establish the CCS value chains.
If capture and storage of CO_2 from biological origin is included in the calculation it is seen that the FOV case is more favorable as it will extract almost 0.4 $tCO_{2,e}$/t CO_2 stored from the atmosphere compared to 0.05 $tCO_{2,e}$/t CO_2 stored for the Norcem case.

For Norcem the footprint will almost double if transport and storage infrastructure are only utilized for an assumed support period of 10 years compared to operating the value chain for the designed facility lifetime of 25 years. For FOV the relative increase is only 40% due to footprint from operation being higher than from construction.

The calculated footprint of the different value chain alternatives will be included in Gassnova's DG3 report and form part of the evaluation of the different capture projects and the full value chains.

5 REFERENCES

[1] DNV GL report: Carbon footprint of CCS value chain – Case Study, report no 2018-0687, rev. A, document no 185109, Bærum, 2018-08-19 (Gassnova doc no 18/164-3)
[2] Norcem DG3 report
[3] FOV DG3 report
[4] NL DG3 report
[5] https://www.nve.no/energy-market-and-regulation/retail-market/electricity-disclosure-2018/
[6] Link to Sharepoint result files https://ekstra.gassnova.no/CCS%20K-FEED%20studie/Documents/Forms/AllItems.aspx?RootFolder=%2FCCS%20K%2DFEED%20studie%2FDocuments%2F7%20Samordning%20%28OJA%29%2F7%2E7%20HMS%20og%20myndighetskontakt%2FKlimafotavtrykk%2FFeed%20Final
[7] Cuellar-Franca, R.M., A. Azapagic (2015). Carbon capture, storage and utilization technologies: A critical analysis and comparison of their life cycle environmental impacts / Journal of CO2 utilization 9, (2015) 82-10288