LSICC Deliverable 1 - Carbon Capture Technology Overview

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The technology overview of carbon capture can divided into two main categories. Point source carbon capture and direct air capture. The focus of this technology catalogue is the mechanical/chemical processes of capturing CO2, and does not focus on biogenic capture such as forestry and agriculture.

The main outcome is the technology overview table, which can be found as an Excel spread sheet by following this link: https://www.energyplan.eu/wp-content/uploads/2023/06/LSICC-Technology-Overview.xlsx

1 Point source carbon capture

The overview concerns two overall types of point source capture of CO2. One is post-combustion processes, with the other being an oxy-fuel process. Within the post-combustion processes, amine, electro-chemical and enzymatic carbon capture technologies are highlighted. It is not equally simple to find costs for all these types, so the objective is to describe the overall concept and highlight the important energy flows.

The post-combustion types can also be applied to direct air capture principles.

1.1 Post combustion capture

Post combustion carbon capture means that the carbon is captured after combustion processes, e.g., being extracted from the flue gas. Thus, these potential pathways can also be used in direct air capture.

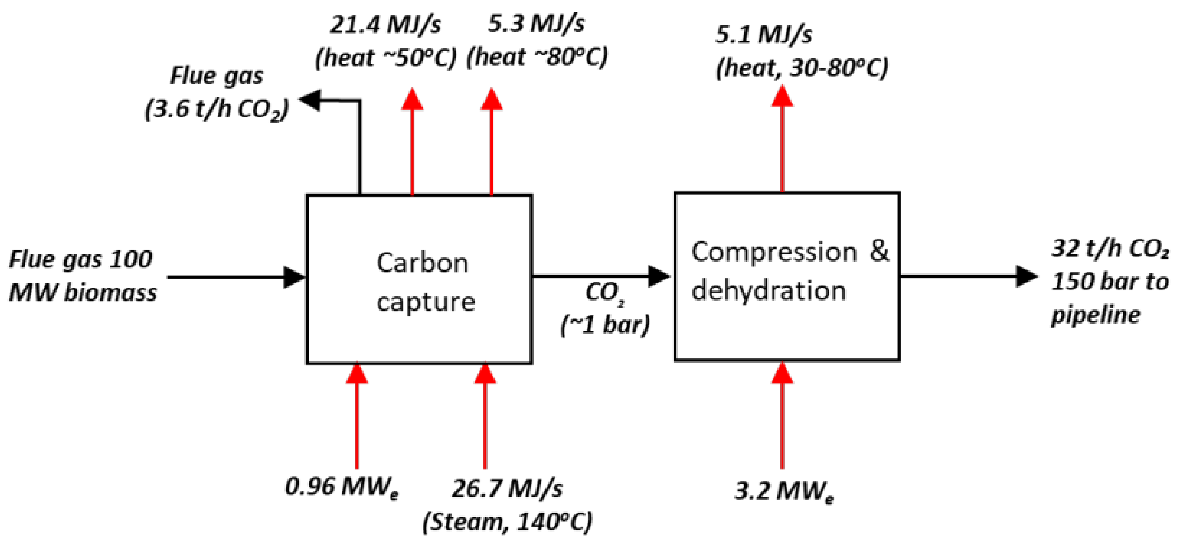
For all these processes compression or liquefaction plant (including dehydration). This ensures either the right conditions for pipeline or road/ship water transport of the CO2.

1.1.1 Amine

Amine carbon capture technology is based on circulation of an amine solvent to both absorb and desorb the CO2 from the flue gas. During the absorption of CO2, the flue gas is maintained cool to keep the most efficient absorption of CO2 from the flue gas. The CO2 rich solvent is then pumped to the desorber, where the CO2 is cleaned from the solvent, ready for transportation, utilisation and storage. To release the CO2 from the solvent, the desorber is heated to around 120-130 degrees. After this release, the solvent is cooled again, ready to work in the absorber [1].

The heat removed can potentially be used in district heating.

The figure below illustrates the overall energy flows.



Energy flows of amine carbon capture, including compression and dehydration. [1]

The amine technology is the most mature CO2 capture method but have concerns regarding energy consumption in the heating and cooling of the solvent. This explains the development in other methods for CO2 capture.

1.1.2 Electrochemical capture

Electrochemical CO2 capture can be applied to a all "types" of CO2. This means the process can be used both in relation to direct air capture and flue gas capture.

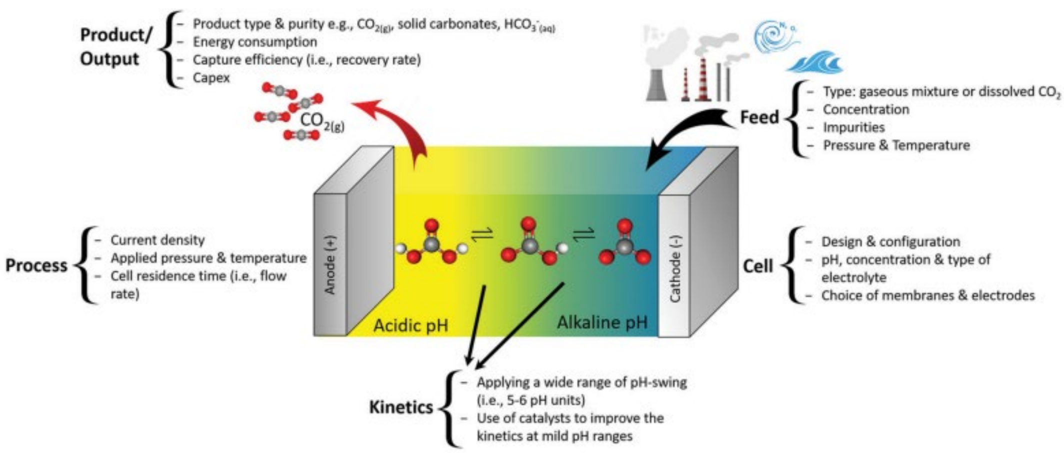
Electrochemical capture technologies primarily rely on the concept "pH-swing". CO2 is captured and released by shifting the pH value of the working fluid, thus shifting between the fluid being basic and acidic. This can be achieved since the pH level impacts CO2 hydration and dehydration of the working fluid.

To achieve the pH swing different electrochemical processes can be applied, depending on the specific technology. This includes electrolysis, bipolar membrane electrodialysis, reversible redox reactions for instance. To run these processes, electrical energy is required, but there are potentially lower energy requirements than for the amine process. Heat is not necessarily required but can be beneficial for some processes. [2]

However, costs are currently quite high, so technology development is required.

Certain electrochemical processes have shown potential of achieving an energy consumption of 100 kJ/mol of CO2, which corresponds to 0.63 MWh/ton of CO2 [2]. The amine processes currently have an electricity input of 0.03 MWh/ton and a heat input of 0.83 MWh/ton [1].

The figure below shows the overall concept of electrochemical CO2 capture.



Overall process concept of electrochemical CO2 capture. [2]

1.1.3 Enzymatic capture

The concept of enzymatic carbon capture is to use carbonic anhydrase instead of chemicals present in for instance the amine process or the electrochemical process. The advantage of the process is a potential lower heat demand, with the concept working on 80 degrees instead of the 120-130 degrees in the amine process[3].

The process with enzymatic capture is quite like the amine carbon capture[3]. Based on [3] energy consumptions can be reduced by up to 40% compared to an amine- carbon capture.

[4] Investigates the use of carbonic anhydrase and finds a lower energy use as well as a cost reduction from 68.3 USD/t CO2 in the amine case, to 38.5 USD/t CO2 in the enzymatic carbon capture process. This is due to lower costs both in terms of investments, as well as operation and maintenance. Furthermore, it is also less energy intensive. [4] identifies a reduction from 0.35 MWh/t in the amine process to 0.20 MWh/t in the enzymatic capture process. This is approximately 40%, similar to the result found in [3]

1.2 Oxy fuel combustion

Oxy fuel refers to changing the combustion process of a power station/boiler. Conventional boilers use atmospheric air with high Nitrogen contents. The oxy fuel combustion remove nitrogen before combustion. This ensures a flue gas consisting mostly of water vapor and carbon dioxide, thus removing the need for post combustion separation. [1]

Due to this technology being based on combustion processes, oxy fuel combustion only is relevant as a point source technology.

To save the post combustion carbon capture, other investments must be made in the air separation unit, and the CO2 purification unit. Both these are also expensive. Thus, the potential of oxy fuel combustion might exist in combination with electrolysis in a future 100% renewable energy system, where oxygen is a waste product from hydrogen production in electrolysis.[1]

2 Direct air capture

Direct air capture focuses on the concept of removing CO_2 by capturing ambient air at any point, instead of cleaning flue gas.

The CO_2 content in ambient air is quite low, approximately 200-300 times lower than typical flue gas[1], the technology requires large volumes of air to capture significant amounts of CO_2.

There are several ways of approaching DAC, ranging biogenic to energy based solutions. These are all described in detail in [5].

About the energy system, the main consequence of direct air capture are the high investment costs, since the units are quite large and the energy requirement to capture the amount of ambient air needed.

The current, most mature technologies, rely on a low temperature absorption, by adsorbing CO_2 from the air, for instance by using electrical energy. To desorb the CO_2 from the filter material, higher temperatures will be applied. The filter will be heated to around 85-100 degrees. [1] Another option is high temperature liquid absorption developed by Carbon Engineering. This stores the CO_2 through a calcination process requiring 600-900 degrees [1,6]. To reach these temperatures, the burning of natural gas is required. Thus, further CO_2 capture is needed to completely achieve CO_2 neutrality in the case of high temperature absorption.

3 Summary

The economic and technical sheets can be found in the link in the introduction.

To further model carbon capture, the work here indicates the following model improvements required:

1) Carbon capture balances, to be depending on the operation of point sources.
2) Synergies with both heat input and heat output, as the technologies require heating.
3) Potentially a natural gas demand for certain types of DAC.
4) Oxy fuel modelling should be linked to electrolysis and oxygen outputs, to ensure synergies between different types of modelling.
5) Potentials for combination of DAC and point source capture to ensure stable CO_2 capture loads potentially required for CCU.