Carbon capture and utilization

HIGHLIGHTS

Processes and technology status – Carbon dioxide (CO_2) capture, storage, and utilization (CCS and CCU) are effective technologies for CO_2 fixation [1]. CCU is about the reusing of the captured CO_2 by utilizing it directly or as a feedstock for the production of valuable products [2].

Cost - The cost of CCS/CCU depends mainly on the CO_2 source and purity. The scale of CO_2, the implemented capturing technology, and CO_2 taxes are significant factors of CCS/CCU costs [3]. The specific capital costs per ton of captured CO_2 by 2025 are estimated to be 20-40 $€_{2013}$ [4].

Potential and barriers – CCS/CCU technologies are at a good advanced status concerning its design and optimization at a significant rate over the past years and are a potential solution to the problems of greenhouse-gas emissions [3]. The most threatening risks are the high costs and a lack of supporting regulation [5].

Carbon capture and utilization – Carbon capture, storage, and utilization or separation (CCS/U) aim to reduce global anthropogenic CO_2 emissions to tackle climate change by capturing carbon at the emission source and preventing its entry into the atmosphere. In parallel, some studies deal with the capturing of CO_2 from the ambient air [3].

Process overview – CO_2 capture is accomplished by employing several methods like the use of membranes, chemical looping, cryogenic distillation, etc. [3]. The collected CO_2 can be stored in geological sites or can be utilized for enhanced oil recovery or in chemical industries. The CO_2 utilization techniques are young and significant research is needed to make these processes economically viable [7].

Carbon capture technologies and methods – Different capture and separation technologies via several methodologies exist, and their costs depend on the CO_2 amount, CO_2 partial pressure, and the concentrations of contaminations such as N_2 [5], [8].

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Capture technologies are typically categorized as pre-combustion, oxy-fuel combustion, and post-combustion processes [5]. Figure 1 depicts a schematic overview of the different CO_2 capture categories [5]. Among CCS technologies, post-combustion is the most mature alternative to capture CO_2 and finds use to retrofit existing carbon emissions [9]. Post- and pre-combustion captures rely on methodologies that can separate CO_2 from the mixed stream, via i) Solvent scrubbing, ii) Solid adsorbent, iii) Adsorption, iv) Membrane, v) Cryogenic distillation [3].

Carbon utilization pathways - CO_2 utilization is the process of using emitted carbon dioxide (CO_2) as a raw material or as a catalyst for new products. Possible carbon utilization pathways include the usage of CO_2 in the manufacturing of fertilizers, urea, methanol, oil and gas recovery in addition to water desalination projects and electrochemical conversion to certain chemicals [3].

Conversion of CO_2 to synthetic fuels was identified as a promising pathway to scaling up the carbon capture technologies, as the valuable products would offset the carbon capture and conversion costs [6]. Other ways of reducing carbon emissions include negative emission techniques, renewable resources, and direct air capture techniques. CO_2 utilization is possible via both direct and indirect pathways [3]. As figure 2 depicts, methanol is the most prevalent product of CO_2 conversion as reported in the literature set, followed by CO_2-based chemicals and fuels [2].

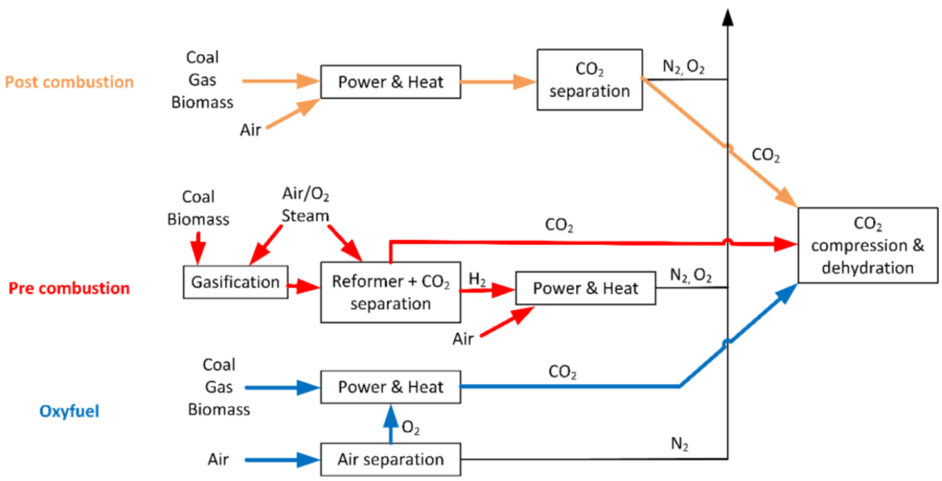

Figure 1: Overview of CO_2 capture technologies [5].

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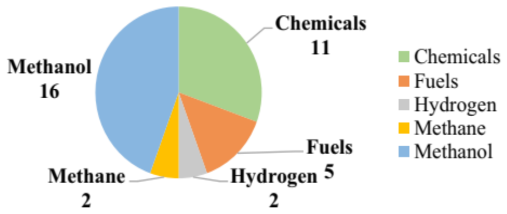

Figure 2. CO_2-derived product categories addressed in the literature set [2]

Moreover, green methanol production, based on intermittent renewable energy sources, requires a more flexible operation mode and close integration with other sections, such as the electrical grid and electrolysis processes [10].

CCS and CCU in Belgium – ArcelorMittal Belgium has started the construction of two new groundbreaking facilities at the Ghent site to reduce carbon emissions. The two installations represent a total investment of 160 million euros and will avoid approximately 400,000 tons of CO_2 emissions per year in the first phase [11].

Moreover, The Power to Methanol project in Antwerp will produce methanol from captured CO_2 combined with hydrogen that has been sustainably generated from renewable electricity [12].

Investment and production costs – CO_2 is not available cost-free and requires financial investments for capturing, purification, and transportation depending on the site location. Some studies state that the capture cost amounts to 70-80% of the total cost of a full CCS system [5]. The most important drivers of CCS cost are the economics of scale, partial pressure of CO_2, energy costs, and technology innovation. By increasing the storage size and the CO_2 patricidal pressure, CCS costs decrease [13]. Overall, high purity sources include ethylene oxide (EO) and ammonia plants. For example, the potential of CCS in the EO plants in the Dutch industry is abating ~0.1 Mt_{CO2} at an abatement cost of ~25 €$_{2013}$/t_{CO2} [4]. Prefabricated, modular carbon capture technology can reduce capital and operational costs by up to 75% and 50%, respectively [14]. In general, CCS costs may vary widely on a case-by-case basis [15]. Costs in natural gas processing, fertilizer, and bio-ethanol have a relatively narrow band of variance across all countries, with a range of 17.7 – 23.9 €$_{2017}$[1] per ton of avoided CO_2. Details of CCSU costs are available in the table 1.

Energy requirements – The physical solvent-based processes require less energy compared to the chemical absorption processes. Energy demands of physical

[1] 20 \$$_{2017}$ to 27 \$$_{2017}$, 1 €$_{2017}$ = 1.13 \$$_{2017}$ [20]

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solvent-based processes range between 160 and 180 kWh per ton CO_2 recovered.

For the production of chemicals, the CO_2 reacts with organic compounds to form carbonates/carbamates via the carboxylation process. Although the conventional processes are broadly used the CO_2 reaction with organic substances gives better fixation with fewer energy requirements [7].

Potential for CCS deployment –

World-wide the highest potential and market size for CO_2 utilization are in the chemical and oil industry, with the Enhanced Oil/Gas Recovery (EOR/EGR) and to have the greatest potential for non-captive demand, the urea production, the polymer processing as well as in fuel and chemical synthesis such as renewable methanol, formic acid. It is also important that the cement sector has a great uptake potential whereas in the food sector, also a medium potential exists (e.g. carbonation, packaging, and horticulture) [16]. Currently, there are eighteen large-scale facilities in operation in the world, five under construction, and twenty in various stages of development [17].

Recent innovations on CCS/CCU

The recent innovation on carbon capture is the modular CycloneCC which works with patented APBS solvents[2] to achieve a 50% operating cost reduction [19]. CycloneCC is based on a novel process technology called rotating packed beds (RPBs) as shown in figure 3. The flue gas is introduced to the RPB from the outer edge of the packing and exits at the inner edge where the solvent enters. Therefore, the gas and the liquid contact each other in a counter-current fashion. The flue gas is absorbed by the solvent and the CO_2 present selectively reacts with the active components in the solvent thereby temporarily locking the CO_2 within the solvent [19]. The mission of CycloneCC is to achieve 25.8 €$_{2021}$ [3] cost of carbon capture especially for the hard-to-abate industries [19].

[2] APBS-CDRMax® is a commercially-available CO_2 capture solvent used for industrial flue gases or off-gases with CO_2 concentrations ranging from 3-25% by volume.

[3] 30 $\$_{2021}$; 1 $\$_{2021, Oct.}$= 0.86 EUR$_{2021, Oct.}$ (average)

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Figure 3. CycloneCC unit structure

Moreover, CycloneCC technology offers a smaller size which is 10 times smaller than the conventional CO_2 capturing unit. When commercialized, industrial companies and customers will be able to install these units in less than 8 weeks highly improving their operational profile and any downtime our customers may face [19].

Table 1. Summary table of CCS costs

Plant	Cost *
EO	25 €$_{2013}$/t$_{CO2}$
Natural gas and bio-ethanol processing,	17.7 – 23.9 €$_{2017}$/t$_{CO2}$
Cement	92 – 171.7 €$_{2017}$//t$_{CO2}$
Iron and steel	62.8 - 105.3 €$_{2017}$/t$_{CO2}$
Coal-fired power plants	34 - 68 €$_{2018}$/t$_{CO2}$
Direct Air Capture	200 - 1000 €$_{2018}$/t$_{CO2}$
Large CO_2 exhaust sources	18 - 90 €$_{2015}$/t$_{CO2}$
High purity CO_2 sources	5.4 – 10.8 €$_{2015}$/t$_{CO2}$
Price of green hydrogen	2.6 - 3.8 €$_{2018}$/kg$_{H2}$
Coal-based CO_2 catalytic hydrogenation	2500-3300 €$_{2020}$/t$_{Produced\ petrochemicals}$
CO_2 transport and storage	10 €$_{2017}$/t$_{CO2}$**
Offshore transport and storage	14.2 - 32.7 €$_{2017}$/t$_{CO2}$
CO_2 storage costs in liquid form	4.46 - 13.86 €$_{2018}$/t$_{CO2}$
Truck transportation of the CO_2	0.22 €$_{2018}$/t$_{CO2}$ per km

* Costs depend on the type of capturing. For example, the pre-combustion route could offer a cheaper cost than that of post-combustion and oxy-fuel combustion routes by 38–45 and 21–24%, respectively (in theory).

** Increasing the annual transport flow rate from 0.5 to 5 Mt$_{CO2}$/y would reduce average transport cost more than three times, from over 20 €$_{2017}$/t$_{CO2}$ to around 6 €$_{2017}$/t$_{CO2}$. Moreover, the cost of CO_2 storage contributes relatively small amounts to overall project costs.

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