Compact light-weight CO2 capture technologies for small to medium-scale CO2 emitters

There is a significant challenge and opportunity for applying CO2 capture technologies to smaller emitters says a techno-economic investigation from The Catalyst Group Resources. However greater understanding is needed of the different CO2 point sources across all sectors and the different strategies needed for tackling them based on individual profiles.

While there are a smaller number of very large emitters, e.g. large-scale coal and gas-fired power plants, there are also a wide range of smaller energy plants and industrial emitters, for instance in chemicals, pulp and paper, refining and heavy industrial manufacturing. To date, the focus of carbon capture developments has been on large scale energy plants and systems developed for those emitters have varying potential for downsizing.

In terms of size, large emitters in the energy sector such as coal and gas fired power stations typically fall into the size of 1-5 GW. Associated CO2 emissions are in the order of 5-25 million tons CO2/y. Small-to-medium emitters fall approximately in the range of 50-750 MW and emit typically 1-5 million tCO2/yr. Globally these number in the order of 100,000s. These include smaller coal and gas energy plants, industrial emitters and some larger municipal plants e.g. waste to energy (WTE).

Combined Heat and Power (CHP) units located in industrial manufacturing plants also form part of those sectors profiles. In those schemes, there is potential to combine flue gas streams to go to one central capture plant. More challenging are lone CHP plants serving the needs of communities at district level, although there are a few projects in existence which are looking to do so.

Collectively industrial emitters account for around 20% of annual CO2 emissions. Even smaller point emissions in residential premises, municipal and commercial buildings account for >6% of CO2 emissions. However, there is a size limit below which capturing CO2 is not practicable and different decarbonisation approaches are employed (e.g. use of green hydrogen and carbon-neutral fuels).

Unlike the energy sector, a range of industrial emission sources do not have low-emission alternatives (i.e. renewable energy) and tend to have multiple CO2 emission sources through the plant.

Downscaling of CCS for these types of emitters is a big challenge, although CO2 utilisation projects for instance for sustainable concrete production have relatively small CO2 recovery systems as part of the flowsheet. Near term, more obvious targets include sectors under pressure to reduce their carbon footprint e.g. cement and steel, oil refineries and some of the more energy intensive chemical sectors e.g. hydrogen and ammonia.

The vastly heterogenous characteristics of GHG sources across all these sectors, not just in terms of size, but also flue gas composition, accessibility and opportunities to build a surrounding CCUS infrastructure at specific site locations means a complex range of solutions are necessary.

A tailored solution for different industry sectors

Given the multitude of technologies evaluated, and the range of stationary emission sources discussed, the report aims to best match those sources with appropriate capture technologies:

- For dilute CO2 sources (< 20 %mol CO2) at high or low-pressure, and low-pressure sources up to 40 %mol, currently the only feasible technology that is currently available is amine absorption.

- With further development, the C-Capture process, and Inventys' VeloxoThermprocess may become viable commercial alternatives within a decade.

- For high concentration CO2 sources (≥ 30 %mol) at either high or low pressure, cryogenic capture and adsorption-based capture become viable.

- If excess refrigeration were available at a site, cryogenic capture, or physical absorption processes such as Rectisol, may become feasible alternatives based on a site-specific techno-economic analysis/FEED study.

- For oxy-fuel combustion, or oxygen generation in general, large scale O2 production (> 500 tpdO2) is currently most feasible by cryogenic distillation.

- Membrane-based technologies, and chemical looping technologies, are the furthest from commercialization.

- It is unlikely for chemical looping technologies to achieve commercialization, at least in the short-term, due to process complexity.

Downsizing of CO2 capture systems designed for larger emitters can pose a big challenge. Some commercial solvent capture systems may have more scope to downscale than others.

There are various limitations to applying these methods at small-to-medium scale, namely the trade-off between capital and operating costs (CAPEX and OPEX) in the case of solvent approaches e.g. monoethanolamine (MEA). A high CAPEX translates to a higher penalty on process operating cost at small scale. Therefore, the comparatively high operating costs for MEA could not be justified when capital costs were also higher per tonne of acid gas capture.

A further possibility is to use membrane systems. Membranes have already been applied for a range of gas separations at the industrial scale, but the issues of fouling need to be overcome before they could be applied at scale for CO2 capture. Developments in commercial processes which would enable small-to-medium scale operations are discussed in the full report.

The report contains a full sectoral analysis including:

- Energy
- Iron and steel
- Cement
- Pulp and paper
- Refineries
- Ethylene production
- Ethylene oxide production
- Hydrogen production
- Ammonia production
- Natural gas processing
- Ethanol production

Technology overview

Considering the power sector is the largest CO2 emitter, the majority of research and development efforts have been directed towards this area, i.e. post-combustion capture, which involves the separation of CO2 from exhaust gases (flue gases). The advantage of post-combustion capture is that it is retrofittable to a range of processes considering its 'end-of-pipe' nature. A challenge in this area though are whether provisions have been made regarding process expansion.

The other capture technology being considered for the power sector is oxy-fuel combustion. Oxy-fuel combustion involves combustion of the fuel in an O2/CO2 atmosphere such that a CO2 rich flue gas is produced, requiring little further processing. Consequently, development around oxy-fuel combustion technologies are concerned about the economical production of O2 at large scales, as the traditional technology (cryogenic distillation) is energy intensive.

Regarding the heat sector, a range of alternatives are being proposed for its decarbonisation. They predominantly include green hydrogen, electrification, and carbon negative fuel sources. Green hydrogen involves producing H2 at plants with integrated CCS and distributing the produced H2 in existing natural gas networks for combustion.

Electrification would allow heat to be generated using heat pumps or direct heating using electricity produced from low-carbon electricity sources, however, the success of this is reliant on the development of local electricity grids to tolerate the increased demand. Carbon negative fuel sources such as biogas or biomass are also an alternative, as the combustion of said fuel would result in low-carbon or carbon-neutral heating.

Combined heat and power (CHP) plants in various forms contribute approximately half of global heating demand for district heating. In addition, the majority of industrial facilities have on-site CHP plants to meet their utility requirements – many thousands globally. These may present a number of CCS opportunities, however, retrofitting CCS to these plants will reduce the energy available for end-use.

The production of steel, cement, ethylene oxide, hydrogen (and ammonia), and ethanol, all have steps where the production of CO2 is unavoidable due to the process chemistry. Most of these emission sources can be considered for post-combustion capture, as the CO2 is generated from the combustion of a carbonaceous fuel with air, and in the case of clinker production in the cement process, the calcination of the lime further enriches the CO2 content in the flue gas.

In specific cases such as H2 separation from syngas in hydrogen production, where a CO2/CO/H2 separation takes place, it is considered pre-combustion capture. The term pre-combustion capture originated from the concept that H2 could be used a fuel source, the combustion of which would produce H2O. Syngas is produced by the reforming of natural gas, or gasification of other carbonaceous material (coal, oil, biomass), from which the CO2 is separated prior to combustion of the fuel.

Commercial progress

There are a range of technology alternatives for the main CO2 methods, post-combustion capture, pre-combustion capture, and oxy-fuel combustion that are at various stages of commercial development. There are some

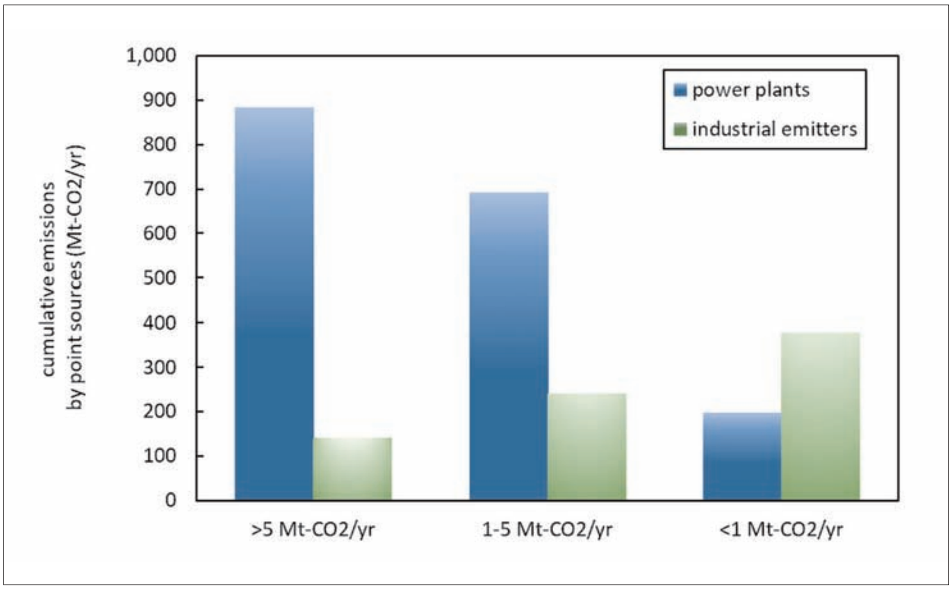

Figure 1 - US Emissions by point sources by size. Source: EPA, 2018

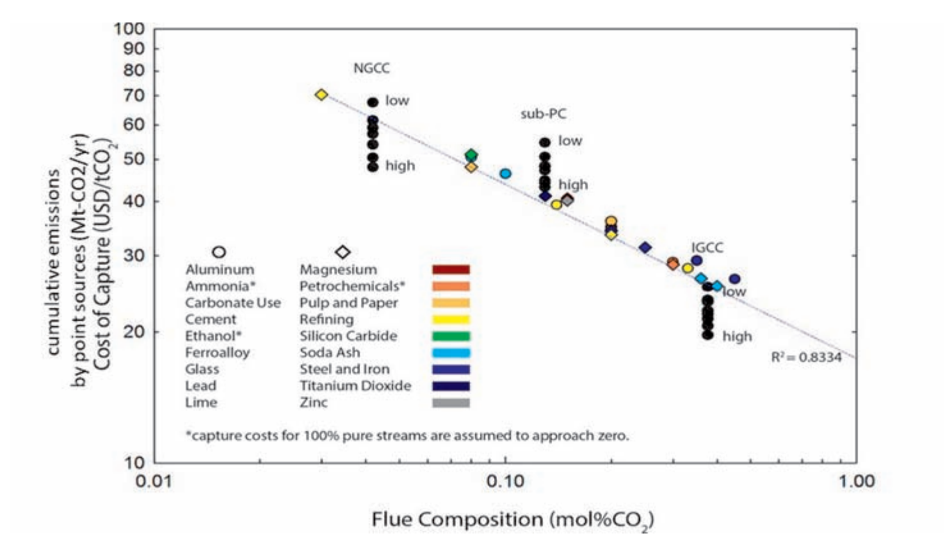

Figure 2 - Prediction of capture costs from a range of industrial sources (coloured symbols), and power generation (black circles) for low and high flow rates (Psarras et al., 2017)

technologies which seem promising and may become viable in the medium term if further development funding can be secured.

The C-Capture post-combustion capture process based on non-amine absorbents has advantages in terms of corrosivity, degradation, and regeneration energy. Inventys' VeloxoTherm technology has seen promising developments in making temperature swing adsorption (TSA) accessible to CO2 capture by reducing process cycle times from hours to minutes, resulting in significant process intensification.

Some technologies have shown progress; however, their future is uncertain. The Air Liquide hollow fibre membrane (HFM) cryogenic process, and the MTR Polaris process for post-combustion capture have seen reasonable development, with the MTR process being scaled up to 20 tpdCO2. The main concern about membrane processes is that CO2 product purities are low, requiring further processing for most CCUS applications inhibiting commercialisation.

Air Products' Ion Transport Membrane (ITM) process for low-cost O2 production did experience reasonable development and is the closest to commercialisation. However, due to the high process temperatures required, it is not a viable integration option for most processes which is key to minimising energy consumption. Development by Air Products appears to be discontinued.

Another CO2 capture method which has been proposed more recently is direct air capture (DAC). As the name implies, CO2 is captured from the ambient air, resulting in net negative emissions. There are three main competitors for DAC technology, Carbon Engineering, Climeworks, and Global Thermostat. Carbon Engineering proposes a chemical absorption process, and the latter two operate adsorption-based processes.

Although a range of carbon capture technologies are being proposed and have been investigated, the majority of them are still in the early stages of development. The Aker Solutions Just Catch system is an immediately viable option for post-combustion capture at scales up to 0.1 MM tCO2/yr.

Air Liquide's CryoCAP™ process, and packed-bed pressure swing adsorption (PSA) processes offered by the traditional vendors are viable options for pre-combustion capture applications. Air Liquide also offers a CryoCAP™ Steel which is an alternative post-combustion capture technology for steel and cement processes.

Due to the costs associated with O2 production at the scales required for oxy-fuel combustion, combined with limited developments in this area, it is unlikely that oxy-fuel combustion will become a commercially viable CCUS alternative.

Chemical looping processes could be considered as still being in their infancy. There are a range of issues regarding adsorbent life, and process configurations are generally complex. In conjunction with the requirements for high-grade heat and oxygen, it is unlikely that these processes will achieve commercialisation.

Membrane-based separation processes are also unlikely to achieve commercialisation for post-combustion capture applications; however, offerings from Air Liquide and MTR may be feasible for pre-combustion capture applications. There are also a range of instances where membranes from a range of vendors are already being applied for high-pressure CO2/CH4 separations.

Although DAC has a number of concerns from an overall feasibility perspective, it does have the advantage of having high public acceptance. Although it may not be the most sound alternative from a techno-economic perspective, it may experience deployment due to this factor alone.

In the next issue

This is the second in a series of articles summarising key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program.

The next issue will feature "Advances in Direct Air Capture of CO2". Don't miss "Technical and Commercial Progress Towards Viable CO2 Storage" which featured in the previous issue.

References

EPA (2018) EPA Facility Level GHG Emissions Data 2017.

Psarras, P. C. et al. (2017) 'Carbon Capture and Utilization in the Industrial Sector', Environmental Science & Technology, 51(19), pp. 11440–11449. doi: 10.1021/acs.est.7b01723.

More information

More information about this and other services of the CO2CC Program can be found at:

www.catalystgrp.com/php/tcgr_co2cc.php