Compact Light-Weight CO_2 Capture Technologies for Small-to-Medium-Scale CO_2 Emitters

A techno-economic investigation commissioned by the members of the

Carbon Dioxide Capture and Conversion (CO_2CC) Program

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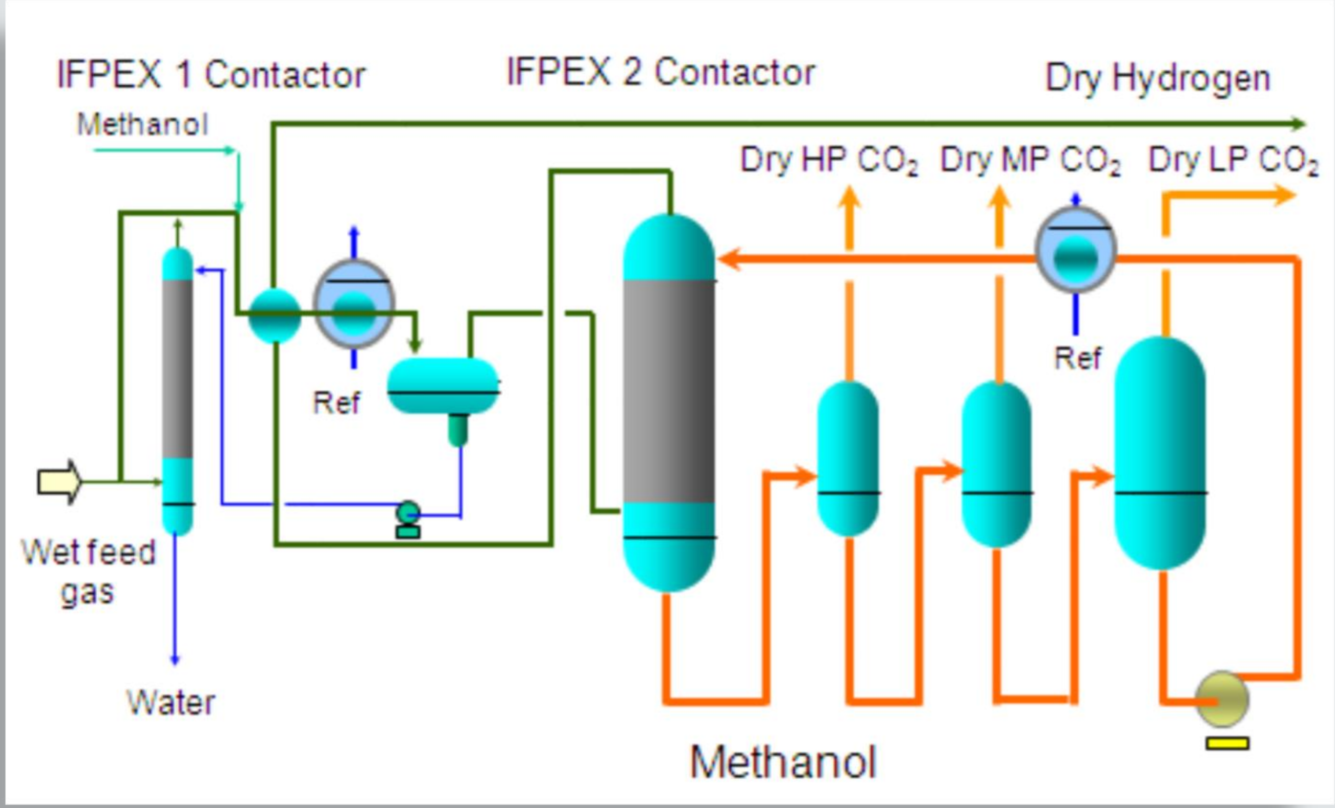
2 SCOPE

- Techniques for reducing the amount of Greenhouse Gas (GHG) from entering the atmosphere are necessary in order to meet national goals of The Intergovernmental Panel on Climate Change (IPCC).
- Carbon Capture, Utilization and Storage (CCUS) technologies are regarded an essential set of tools for removing GHG from point sources although they need much further development and proven scale-up before they can be deployed widely.
- Even smaller point emissions in residential premises, municipal and commercial buildings account for >6% of CO_2 emissions. However, there is a size limit, below which capturing CO_2 is not practicable and different decarbonization approaches are employed (e.g. use of green hydrogen and carbon-neutral fuels).

IFPEXOL Process for CO_2 capture from HP synthesis gas



The following slides depict some key take-aways from this recently completed report.

3

OVERVIEW

Different Size Emitters and CHP Units

- 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 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 the district level, although there are a few projects in existence which are looking to do so.
- Downscaling of CCS for these types of emitters is a big challenge, although CO2 utilization projects 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).

This report evaluates CO_2 emission profiles in the energy and industrial sectors for small to medium emitters, and a range of capture processes including both mature and emerging technologies.

Downscaling Progress

- **To date, the focus of carbon capture developments has been on large scale energy plants.**
- **Some commercial solvent capture systems may have more scope to downscale than others.**

CURRENT FOCUS LIMITATIONS

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.

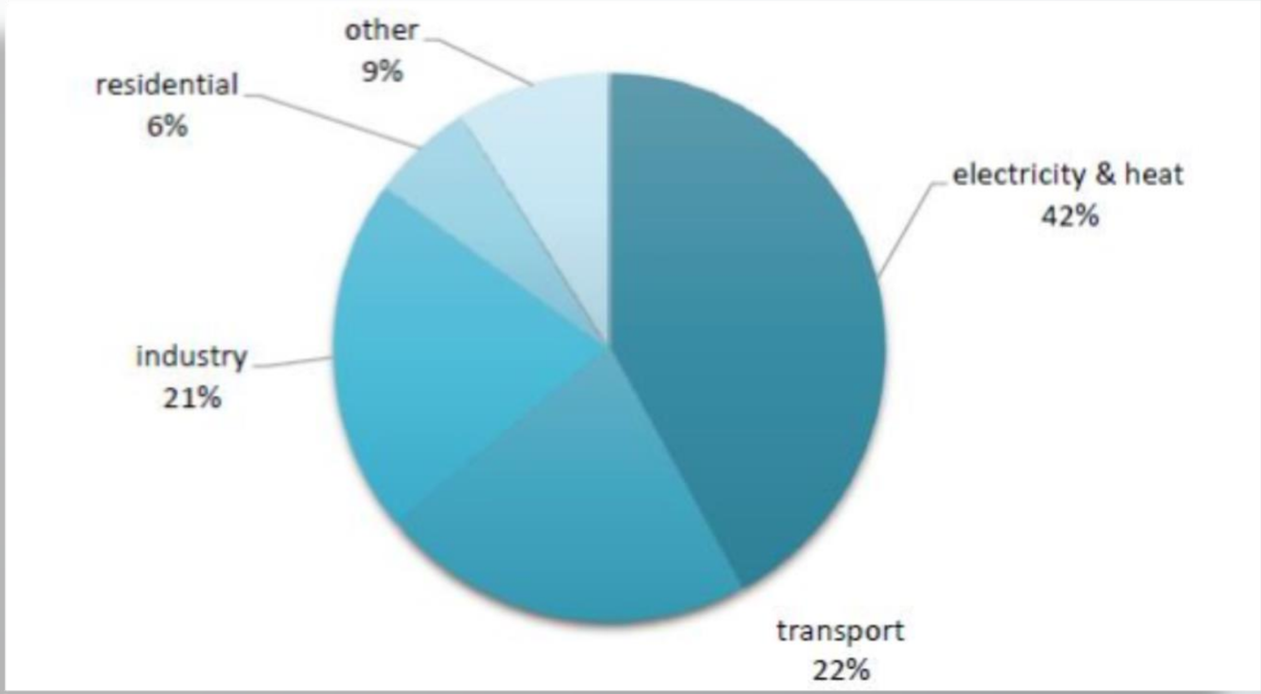
SCOPE OF SOLVENT CAPTURE SYSTEMS

There is also the possibility 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. Nonetheless, developments in commercial processes which would enable small-to-medium scale operations are underway.

CO_2 Emissions by Sector

- Industrial emitters are the second-largest stationary CO_2 emitting sector.
- Depending on whether indirect emissions are re-allocated to the sector, industrial emissions account for 20-40% of the 32 Gt-CO_2/yr of global CO_2 emissions.
- They are projected to grow further and more than double in size until 2050 compared to 2010.
- Power plants are generally larger point sources compared to industrial facilities. Half the emissions in the power sector are emitted by facilities with more than 5 Mt-CO_2/yr individual emissions.
- In the industrial sector there are only 8 facilities with individual emissions this high.

GLOBAL DIRECT CO_2 EMISSIONS BY SECTOR

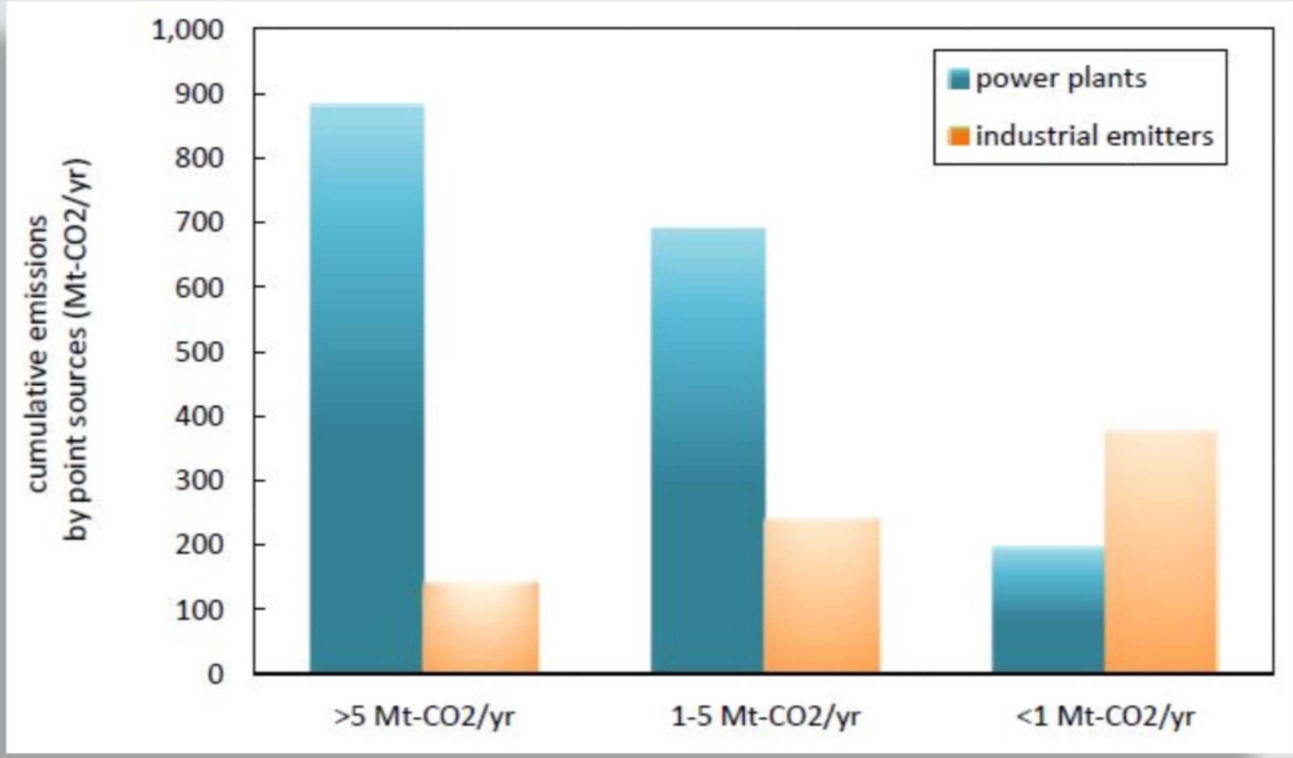


It is worth investigating both the energy sector as well as the industrial sector when considering medium to small CO2 emitters.

Profile of Small-to-Medium CO_2 Emitting Installations

- There is great variety of CO_2 sources of small to medium size.
- There is a spread of the sizes of CO_2 emitters in every industry.
- Industrial CO_2 sources are smaller on average and hence of interest when examining small/medium sources.
- However, there are still many coal- and gas-fired power plants that are in the same size range as industrial sources.

US CO_2 emissions by point sources by size



Focus on Sectors – 1 of 2

ENERGY SECTOR

The power sector is the single largest CO_2 emitter world-wide. 37% of power is generated by coal, 30% by natural gas and 1% by oil. The remaining amount is generated by nuclear power plants and renewables, i.e., almost carbon-neutral power generation technologies.

40% of energy consumption is attributed to heat, causing 25% of CO_2 emissions. Most of the domestic heating, around 80% of homes, is carried out using natural gas, the remainder is made up by electricity, oil, and biomass

IRON AND STEEL

The iron and steel industry globally accounts for 31% of all industrial CO_2 emissions (IEA, 2011). In recent history there have been substantial improvements concerning the efficiency of the plants, hence today iron and steel is considered a modernized industry. That leaves little room for process optimization and CO_2 emissions reduction through efficiency gains. This means carbon capture and sequestration (CCS) potentially offers the first choice in mitigating the emissions. The plants currently being operated are mostly recently built plants, which makes retrofit CCS installations attractive.

COMBINED HEAT AND POWER

Combined heat and power (CHP) plants generally achieve a higher efficiency than power plants by utilizing heat which would otherwise be waste heat.

CHP plants are used in cement plants, refineries, chemical plants and other industrial facilities to provide utilities such as power and steam.

CHP plants are also used to provide power and heat for residential areas. Around half of global heating demand supplied by district heating is provided by recycled heat, fossil CHP plants and industries. A small percentage is provided by waste and biomass CHP plants.

CHP plants, even without CCS, have the potential of mitigating a limited amount CO_2 emissions by removing the need for additional heating systems.

Focus on Sectors – 2 of 2

CEMENT

The cement industry accounts for 30-35% of global industrial CO_2 emissions. The same manufacturing process is used throughout the industry with only minor variations. Historic improvements through increase in efficiency, use of waste heat instead of high carbon heat sources, and increasing ratio of additives have lowered the industry's carbon footprint but have now reached a limit. Meanwhile, the production volume in the cement industry is increasing.

PULP AND PAPER

Pulp and paper production is a small industry and contributes only 2% or 252 million t-CO_2 /yr to global industrial CO_2 emissions. For this reason, it is often neglected in studies. Plants tend to be close to the resource sources, i.e., forests, which tend to be in remote locations. The CO_2 sources are widely dispersed and not close to industrial clusters, complicating CCS efforts.

REFINERIES

Refineries account for 800 million t-CO_2/yr globally, equivalent to 10% of industrial CO_2 emissions (IEA, 2017). In refineries crude oil is distilled to produce fuels and a variety of petrochemical feedstocks for other products.

CHEMICAL INDUSTRY

The output of fractionated distillation of natural gas and other feedstocks, i.e. ethane, propane or heavier hydrocarbons, is used to produce ethylene, among other chemicals. Around 95 million t-CO_2/yr can be attributed to ethylene production

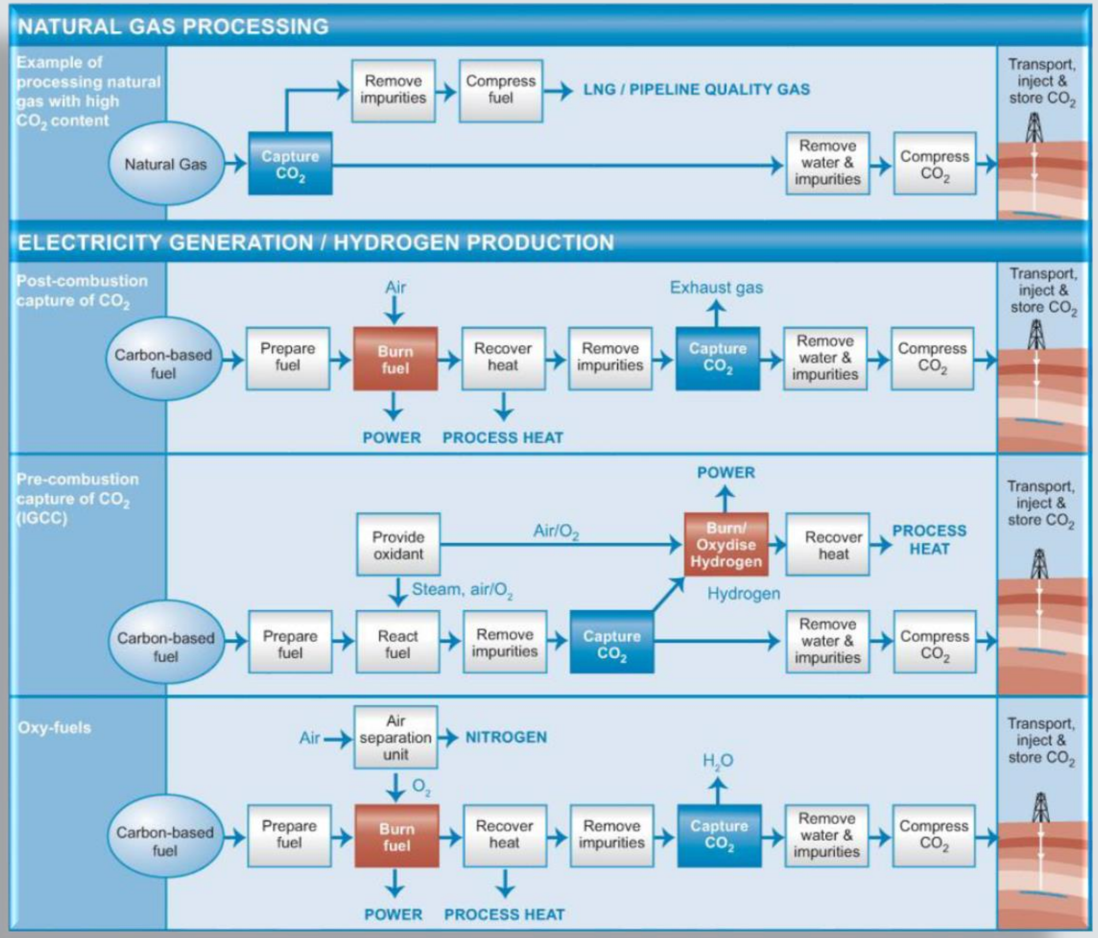
Capture Technologies for Compact Lightweight CO_2 Sources

CAPTURE METHODS OVERVIEW

Carbon capture technologies have been traditionally grouped in to 4 main categories:

- Acid gas removal from natural gas
- Post-combustion capture from the combustion of carbonaceous fuels
- Pre-combustion capture to produce hydrogen
- Oxy-fuel technologies to produce O_2.

Main Processes for CO_2 Capture



A more recent addition to this has been direct air capture (DAC), where CO_2 is removed from ambient air.

Combustion Methods: Overview

POST-COMBUSTION CAPTURE

Post-combustion capture, as the name implies, is a CO_2 separation that takes place following the combustion of a carbon-based fuel. More generally, it can be considered as the separation of CO_2 from air gases. It has been traditionally considered for large point source emissions, such as power stations. However, there are also opportunities in industrial capture where this technology is applicable; cement, power and heat, and pulp and paper.

PRE-COMBUSTION CAPTURE

Pre-combustion capture is concerned with removing the carbon source from the fuel prior to combustion. In its traditional implementation, it is applied to integrated gasification combined cycle (IGCC) power plants where a carbonaceous fuel is first gasified to produce syngas, a mixture of CO_2, CO, H_2 and H_2O. The CO and H_2O are then further reacted to maximize the production of CO_2 and H_2. The CO_2 and unreacted CO are then separated, leaving the H_2 to be combusted, resulting in a flue gas of air and water.

Combustion Methods: Overview (cont'd)

OXY-FUEL COMBUSTION

Oxy-fuel combustion involves the combustion of carbonaceous in oxygen rather than air. This then results in a flue gas which is > 95 %mol CO_2 and can be sequestered or utilized with minor processing. Although an agreeable concept, the production of O_2 can be energy intensive depending on the scale. The current commercial methods of O_2 production are via adsorption, or cryogenic distillation.

DIRECT AIR CAPTURE (DAC)

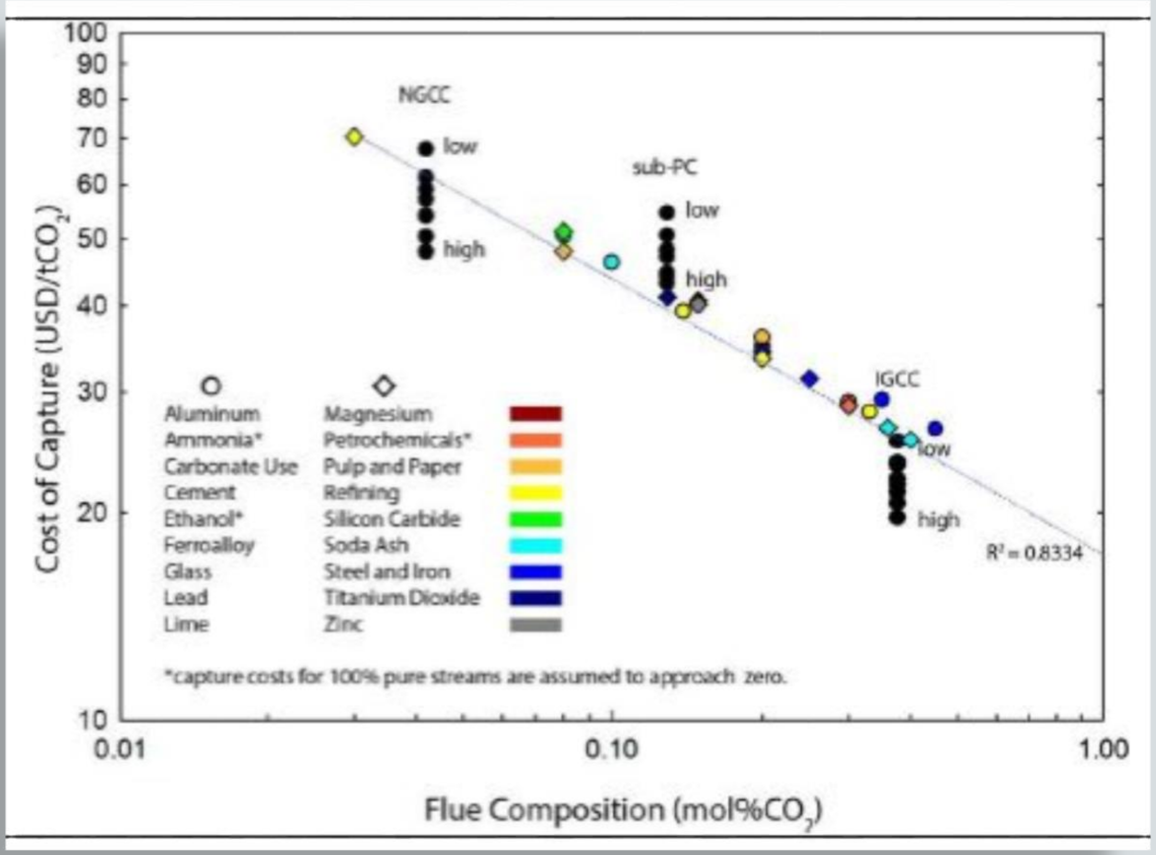
Direct air capture (DAC) is a relatively new CO_2 capture strategy for the purposes of greenhouse gas emissions reduction. It was first proposed around the mid-2000s with commercial activity initiated in 2009 by Carbon Engineering. As the name suggests, DAC involves the removal of CO_2 from ambient air. The primary challenge associated with direct-air capture is the dilute feed, ≈ 410 ppm CO_2, or 0.041 %mol. This precludes many of the carbon capture technologies previously discussed.

COMMERCIAL PROGRESS

Commercial progress has been made in the areas of oxy-fuel combustion with the Air Products Ion Transport Membrane (ITM) process for the more economical production of O_2 using inorganic membranes. However, given the withdrawal of research funding, progress has halted.

The remainder of novel progress has been made in the area of direct air capture. This was an area that was not receiving significant attention even two years ago; however, there are now three companies vying to commercial their technology.

Prediction of capture costs from a range of industrial sources (colored symbols), and power generation (black circles) for low and high flow rates



13

OUTLOOK

OVERALL PROGRESS AND REMAINING HURDLES

Each 'sector' in carbon capture has seen varying levels of progress.

Given the multitude of technologies evaluated, and the range of stationary emission sources discussed, this techno-economic investigation aims to best match those sources with appropriate capture technologies.

For dilute CO_2 sources (< 20 %mol CO_2) 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' VeloxoTherm process may become viable commercial alternatives within a decade.

For high concentration CO_2 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 technoeconomic analysis/FEED study.

For oxy-fuel combustion, or oxygen generation in general, large scale O_2 production (> 500 tpdO_2) 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.

Developments in the membrane area are less likely to achieve commercialization for post-combustion capture applications; whereas they are more likely to achieve success in pre-combustion capture applications.

Carbon Dioxide Capture and Conversion ((CO_2CC)) Program

The **Carbon Dioxide Capture and Conversion (CO_2CC) Program** is a membership-directed consortium, launched in January 2010, whose members are involved in developing, monitoring and utilizing the "State-of-the-Art" in technological progress and commercial implementation of carbon dioxide capture and conversion.

The program's objective is to document and assess technically and commercially viable options for the capture/clean-up/utilization of CO_2 and its mitigation via energy efficiency gains which meaningfully address the challenges posed by CO_2 life-cycle and overall sustainability issues. Included in the program's scope are:

- CO_2 capture and/or separation
- CO_2 concentration, purification and/or other post-treatment
- CO_2 utilization/conversion (e.g., CO_2 as a feedstock) for use as a fuel or intermediate, including enhanced oil recovery (EOR)
- Energy requirements (and other costs), including energy efficiency
- Industrial process improvements and energy saving initiatives which mitigate CO_2 production
- Bottom-line financial (income) impacts resulting from CO_2 reduction programs
- Life-cycle considerations and sustainability of CO_2 applications
- GHG/CO_2 regulation and "cap and trade" developments

By the direction of the member companies (through balloting and other interactive means) and operated by TCGR, the program delivers weekly monitoring communications via email (**CO_2CC Communiqués**), three techno-economic reports (highly referenced and peer reviewed) and scheduled meetings of members (either in-person or via webinar).

In addition to the program deliverables, TCGR works with members to identify and foster competitive advantage and opportunity.

Access to Deliverables is Exclusive to Members

Contact & More Information

More information about this and other services of the **CO_2CC Program** can be seen at http://www.catalystgrp.com/php/tcgr_co2cc.php.

Call +1-215-628-4447 or e-mail Chris Dziedziak cdziedziak@catalystgrp.com, and we'll be happy to discuss these and other interesting membership benefits.

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