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Various Technologies used in Capturing CO2 and Manufacturing Cost of Microalgae

Govind Yadav
M. Tech Scholar
Department of Energy Technology
Truba Institute of Engineering & Information Technology
Bhopal, Madhya Pradesh, India
er1govindyadav@gmail.com

Prof. Pankaj Badgaiyan
Assistant Professor
Department of Energy Technology
Truba Institute of Engineering & Information Technology
Bhopal, Madhya Pradesh, India

***Abstract*: The main goal of this paper is to investigate a variety of promising techniques for carbon capture from a variety of sources, as well as carbon capture from the atmosphere employing direct air capture (DAC) methods. Afterwards carbon dioxide has been recorded, it is used to grow micro algae. The evaluation is broken down into three sections: direct air capturing with liquid solvent systems, direct air capturing with solid sorbent systems, and microalgae manufacturing costs.**

Keywords: CO_2 Capture, Direct Air Capture process, Temperature swing adsorption (TSA), pressure swing adsorption (PSA), and vacuum swing adsorption (VSA).

I. INTRODUCTION

Post-combustion, pre-combustion, oxyfuel burning, and chemical sequence are four types of carbon capture framework that include CO2 detachment, compressing, and transfer. Various mechanisms (physiochemical solutions, especially amine-relying, adsorption on solid particles, chemical looping sorbents, cryogenic distillation, membranes, hydrate-relying isolation, nanoparticle organic hybrid substances, and ionic liquids) can be used to separate CO2, but only cryogenic distillation, absorption, and adsorbent techniques have been scaled up. The various carbon capture techniques have various technology readiness levels (TRL).

Growing Carbon dioxide levels are affecting irrevocable destruction to climatic condition, and oceanic flora and fauna, and it is therefore critical to limit carbon emissions and mitigate their negative environmental effects. This growing concern has compelled governments all over the world to establish and implement ways to decrease CO2 emissions through the development of clean and green options. Carbon capture and storage (CCS) is a collection of techniques that is presently regarded as among the most viable alternatives for minimizing carbon dioxide emissions throughout the transitional phase from the current fossil-fuel economic system to a sustainable building epoch.

Alternative versions for minimizing total Emissions of co2 are indeed being explored, however carbon capture and storage, or CCS, is the most common way of reducing CO2 emissions from big manufacturing source materials. CCS entails capturing carbon dioxide (CO2) at exhaust emissions, transferring it to a suitable deep, subsurface position, and then storing or trying to bury it. CCS can also refer to the reduction of Atmospheric carbon dioxide (co2, either explicitly or implicitly).

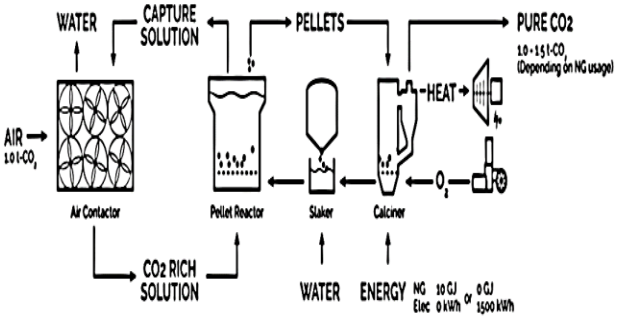

Figure 1 Direct Air Capture process

Direct air capture is the mechanism of capturing co2 from the atmosphere straightforwardly and concentrating it for later use. A chemical, aqueous alkaline solution is utilized to remove CO2 from the concentrated stream [David W. Keith at el. 2018], and the operational sorbents are then stripped with the assistance of heat. Whenever the CO2 is eliminated, it can be preserved for future usages, including microalgae cultivation or even other refinery implementations. CE's Direct Air Capture technique consists of four elements. An air contactor, that is a huge

dimension cooling tower, is the first step in the procedure. Air is drawn into the framework by a large fan and transmits over thin plastic surfaces consisting potassium hydroxide solution. This potassium hydroxide solution binds in a chemical way with CO2 molecules, trapping them in a liquid HCO3 salt solution and eliminating them from the air. This carbonate solution has now been subjected to a series of chemical processes in order to boost the concentration of co2 in compressed and processed form.

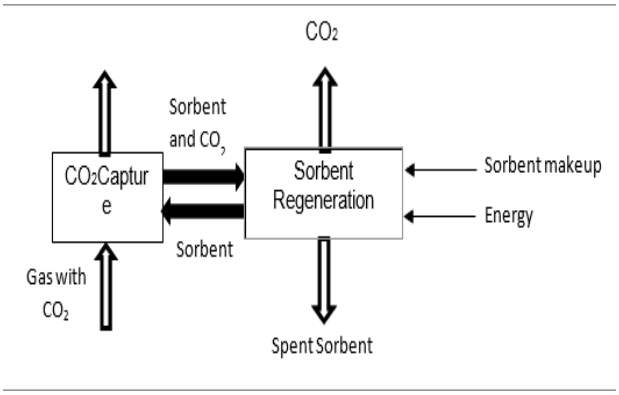

Figure 2 Separation by Solvent/Sorbent

Solvents are chemical combinations that are scientifically made to capture co2 from gases released by industrial sectors. They've been around for decades and are already at the heart of the most well-proven and reach maturity carbon capture innovations. To eliminate CO2, conventional solvents depend on chemical absorption. Those who usually include an amine that reacts to co2 preferentially. Monoethanolamine is the most popular conventional solvent. The figure 2 above shows the process of capturing carbon through solvent.

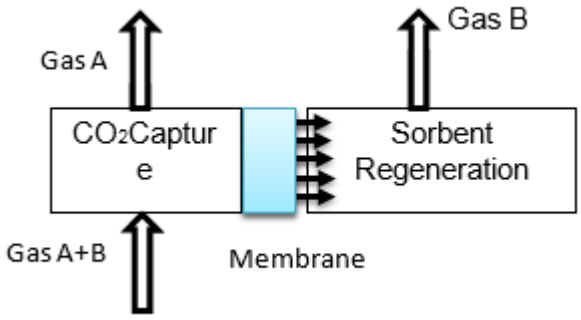

Figure 3 Separation by Membrane.

Membrane technique enables a custom-made substance to preferentially differentiated gases depending on differences in permeability among various gaseous products. Unlike other carbon capture innovations, steady-state procedure is used consistently, with no need for rejuvenation. A partial differential pressure among the upstream (retentate) and downstream (permeate) sides of the membrane generates the driving force for detachment. Feed compression or permeate vacuum trying to pump is necessary in low-pressure inputs, including carbon capture, to offer the differential pressure that needs to drive the procedure.

Membranes are used in real world implementations by ranking up (not scaling up) units as many functionalities as are needed in parallel – for some implementations, this can be large in number. A pre-treatment phase is generally required to eliminate any substances that might affect the membrane. A membrane's average lifespan is 5 to 7 years.

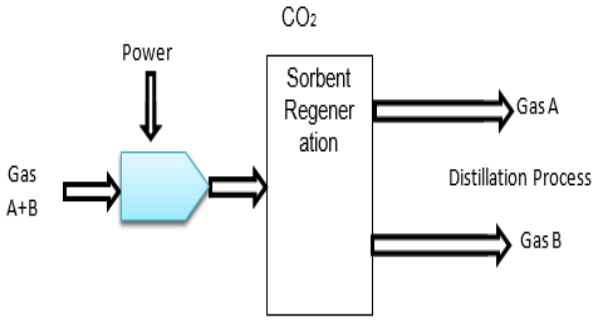

Figure 4 Distillation of Liquefied Gas and Refrigeration Separation.

Cryogenic distillation is a well-known technique for separating gases depending on the various boiling points of Carbon dioxide and the gas elements in the combination. The CO2 is eliminated in the liquid state, and this technique has been employed for natural gas separation. Presently, cryogenic separation is appropriate for differentiating CO2 from a gaseous state with an elevated CO2 concentration (usually more than 50 percent). Since this concentration of Carbon in these streams is comparatively small, and the necessary energy to brought the stream to the subzero temperatures of cryogenic implementation would've been cost prohibitive for the overall process, this method will not be used to remove CO2 from streams including exhaust gas from coal depending or natural gas-fired plants.

II. LITERATURE REVIEW

(Fukuhara et al., 2021) [1] A new catalytic reaction system has been successfully established that integrates DRM-based synthesising gas generation with solid carbon capture. With a maximum rate of 20.3 percent for solid carbon capture, the established reaction system demonstrated the high DRM activity excluding catalyst deterioration. The carbon capturing percentage was improved by using the Fe 3 O 4 wall-type catalyst and controlling the capturing temperature. Carbon deposition from synthesis gas was thought to occur through a reaction process that also involved cementite formation (Fe 3 C). The performance of the carbon gathered diversified relying on

the conditions of capture, such as situation and temperature. Carbon exposed to higher temperatures established CNTs with high crystallinity and elongation, which was also affirmed.

(Roussanaly et al., 2021) [2] With growing interest in carbon capture and storage (CCS) to help sector help Mitigate climate change, a greater interpretation of expenses is needed to help decision-makers and guide research to boost the effectiveness and lowering the price of encouraging additional choices. Whereas many researchers have examined into the techno-economic achievement of CCS implemented to industrial sites, there have been big variation in estimated costs. Whereas this was somewhat due to changes in the cases examined and the capture techniques chosen, a large part of that is due to facets of expense evaluation tools and presumptions.

(Gambhir & Tavoni, 2019) [3] Researchers are highly likely to need ways to remove substantial CO2 from the atmosphere due to the limited amount of CO2 that can be released into the atmosphere before exceeding the 1.5C–2C goal of the Paris Agreement on climate change. Direct air carbon capture and sequestration (DACCS) is evolving as a potentially significant synthetic CO2 elimination technology, in additament to the biological strategic options to dating site, including afforestation and bioenergy with CO2 capture. The authors explain how DACCS works in this article, focusing on two major processes that have been scaled up to large-scale pilot plants. They talk about cost estimates, operations and maintenance energy requirements, as well as environmental and ethical concerns.

(Mulyasari et al., 2021) [4] The CCUS Gundih Pilot Project's implementation of CCUS advanced technologies in Blora will be guided by the interaction and engagement methodologies introduced in this study. The above techniques include best practises for dealing with multiple social aspects of CCUS implementation on the project site. Its goal is to be a useful and informative tool in the planning and installation of the pilot project's public engagement strategic plan. Recognizing public perceptions of the CCUS project as well as how to engage and interact with local residents at the project site are critical to the technology's effective execution. The CCUS life cycle proposal is divided into several steps, each with a various level of evolvement and participation from stake - holders. Thus it is essential to understand how to manoeuvre this procedure while engaging with customers.

(Magnanelli et al., 2021) [5] Various cases for integrating a CO2 capture plant in a WtE plant have been explored in this research. As a research investigation, the grate-fired WtE plant in Kristiansand, Norway, which produces all heat and electricity, was utilized. Throughout a benchmark year, an amine depending absorption plant was developed to extract Carbon dioxide as from flue gas released into the atmosphere by the WtE plant. The heat necessity of the capture plant was identified in relation to 27.2 percent of the negligible thermal capacity of the WtE plant whenever the two plants were viewed in isolation. Steam retrieval from the boiler drum and from the turbine had various impacts on heat and power manufacturing whenever the two plants have been combined.

(Ohenoja et al., 2020) [6] The goal of this research was to figure out how FBC wood-peat fly ashes self-harden and carbonate at the same time. The ambient and Carbon dioxide culturing circumstances at atmospheric pressure as well as room temp were especially in comparison for three distinct FBC fly ashes having varying CaO content material. FBC fly ashes from peat as well as wood can be used to encapsulate and mineralize CO2 throughout self-hardening responses, according to the findings. CO2 curing has the potential to increase the strength of self-hardened fly ashes besides up to 75%. Different fly ashes (FA1 and FA3) showed enhanced strength, but each fly ash sample (FA2) revealed a reduction in strength, most likely due to lowered ettringite creation.

III. METHODOLOGY

The current work is divided into three sections: direct air capturing employing liquid solvent systems, direct air capturing employing solid sorbent systems, and microalgae cost of production assessment. Alkaline solutions including NaOH and KOH are now employed liquid sorbents in a typical DAC system. Acidic gases including CO2 are managed to capture when ambient air is managed to pass thru a base (in this case, a NaOH alkaline solution). CaCO3 is precipitated by mixing an alkaline solution containing CO2 with a Ca(OH)2 solution. Water is started pressing out of precipitated Calcium Carbonate $CaCO_3$. To differentiate gaseous CO2 and solid CaO, the precipitation is heated to around 800°C. By water intake, completely separate CaO can be converted to Ca(OH)2. Ambient CO2 is managed to capture in a strong-base ion interchange resin for the solid adsorbents. Ion-exchange resin is used in the filter of DAC techniques that use solid adsorbents. The resin's adaptability allows for a wide range of filter forms. A fan or blower creates air circulation into the filter. To generate 100t of microalgae biomass, massive quantities of nutrients are necessary, including up to 200 t of CO2, 10 t of N, and 1 t of P, according to the Expenses assessment of microalgae generation.

The initial circumstance for the DAC procedure with a liquid suitable solvent is used in this study, as seen in Figure 5. The contractor and regenerator are the two foundational units in this model. A chemical reaction involving aqueous potassium hydroxide solution (KOH) and CO2 is carried out in the air contractor unit. Potassium carbonate as well as water will be formed H2O. This K2CO3 remedy is sent to the causticiser. K2CO3 is reacted having calcium hydroxide (Ca(OH)2) once

more in this segment. This reaction that produces calcium carbonate (CaCO3), that also is sent to the calcifactor and filter press, in which the water is eliminated and the sludge is sent to the calciner.

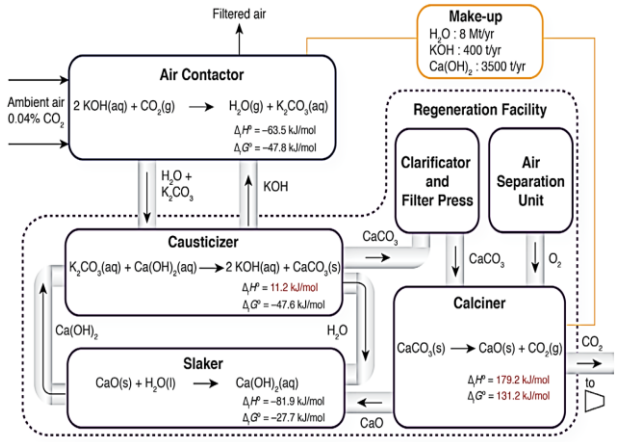

Figure 5 Process of the liquid solvent-based direct air capture system

Calcium carbonate is heated including natural gas in the existence of oxygen at around 900°C in this unit, producing calcium oxide (CaO) and Carbon dioxide . The Carbon dioxide that is produced can either be compressed or transferred.

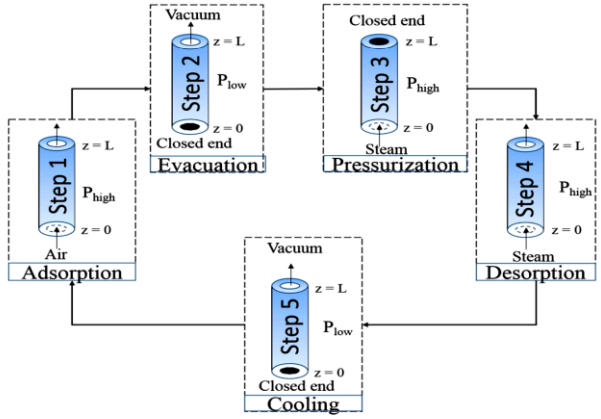

Figure 6 Process description for Solid Sorbent Systems [A. Sinha 2016]

As seen in the diagram, the complete situation of employing solid sorbent to capture Carbon dioxide employing the direct air capturing methodology is split into 5 stages. Adsorption is the first step, followed by evacuation, pressurisation, desorption, and cooling. At environmental circumstances, air moves through the channel during the adsorption step (298 K, 1 atm and 25 percent relative humidity). Throughout that step, the adsorbent film begins to adsorb Carbon dioxide, and condensed water is evaporated from the channel area at the beginning of the stage in cyclic steady state.

At the finish of the adsorption process in the step, the channel is evacuated and pack with air (consisting O2). At extremely high temperatures, the amine organizations in the MOFs necessitate this step. The third stage is to pressurize the channel to 1 atm to avoid any air (O2) back - flow out from channel's tail end. The back end of the channel is closed, and saturated steam at 1 atm is passed thru the end till the a whole channel is pressurized. The third phase is desorption, which involves opening the back end of the channel and feeding saturated steam at 1 atm from front finish. The temperature of the adsorbent rises as water vapor condenses on its exterior. As a result of the temperature swing, CO2 is absorbed throughout this step. The system is then cooled to 348 K in the final stage of the cycle. Since this system is at 373 K at the end of the desorption stage, this phase is necessary. This puts the adsorbent at danger of oxidative degeneration of amine groups.

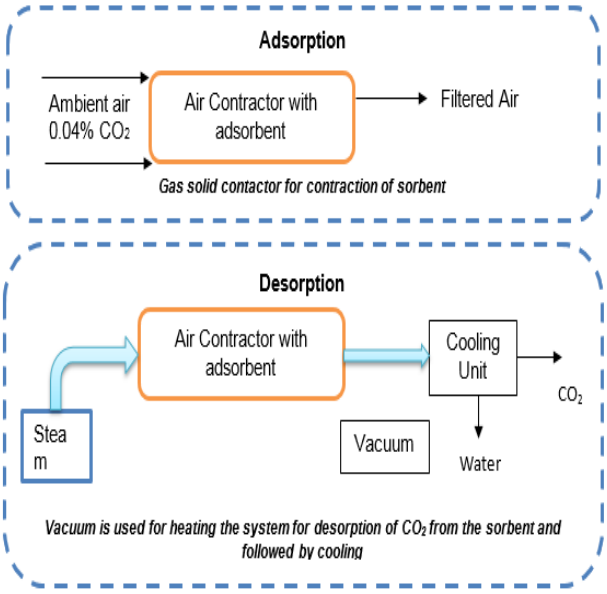

Figure 7 Schematic diagram sorbent based direct air capture process

Figure 7 depicts the major stages of this process, that are adsorption and desorption. The air is circulated thru an air contractor with a solid sorbent that adsorbs Carbon dioxide directly from the air in this framework. The CO2 engrossed adsorbent is then subjected to heat vacuum, resulting in the release of Carbon dioxide from the adsorbent, as well as the procedures is then restarted by cooling the sorbent quite far.

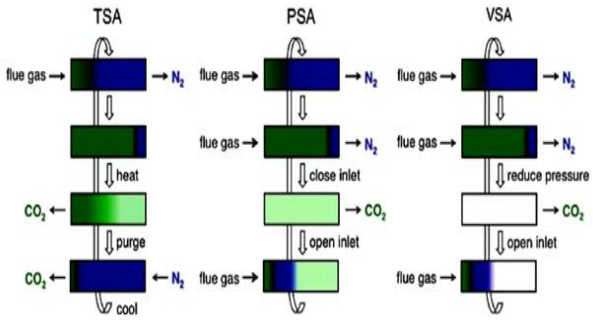

Figure 8 Schematic diagrams of TSA, PSA, and VSA processes for regenerating solid adsorbent

Temperature swing adsorption (TSA), pressure swing adsorption (PSA), and vacuum swing adsorption (VSA) are the three types of CO2 capture processes as can be seen in figure 8. In TSA, adsorbents are employed in a huge column, as well as the amount of Carbon dioxide desorbed increases as the temperature rises, whereas in another two, Carbon dioxide is desorbed by lowering the pressure needed. PSA loop is anticipated to be more effective in the gas stream.

IV. RESULT AND DISCUSSIONS

The main goal of this research is to look into various emerging techniques for carbon capture out from numerous sources, as well as carbon capture from the atmosphere using direct air capture (DAC) techniques. It is employed for micro algae cultivation after Carbon dioxide has been captured. The result assessment is divided into three areas: direct air capturing utilizing liquid solvent systems, direct air capturing employing solid sorbent systems, as well as microalgae cost of production assessment.

The technique for liquid solvent depending direct air capture is the first circumstance. As an consequence, a financial analysis is carried out, which is mentioned further below. The least work of catching 75% of the CO2 at 98 percent purity, as per the IPCC and evaluations of the risks and revenues of direct air capture, is presuming a preliminary atmospheric concentration of Carbon dioxide of 400 ppm at 25°C.

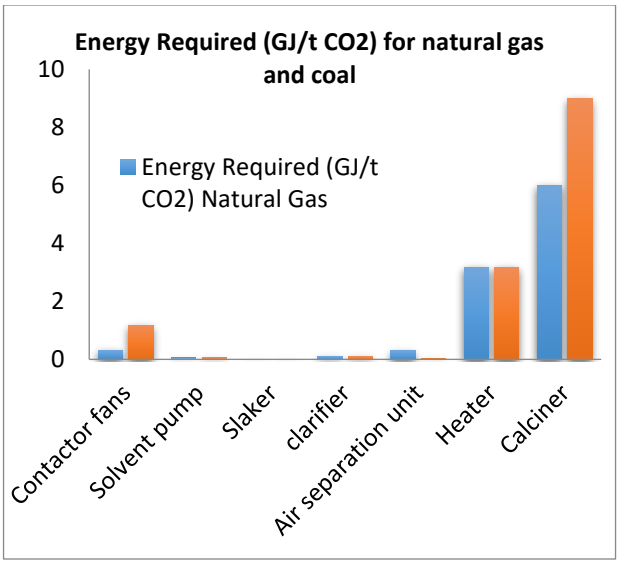

Figure 9 Energy Required (GJ/t CO2) for natural gas and coal

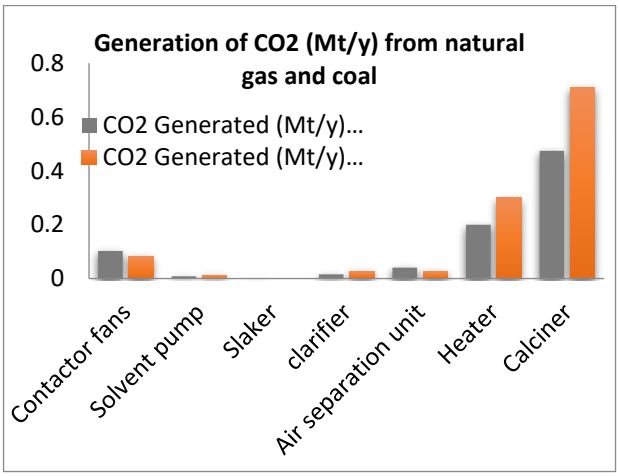

Figure 10 Generation of CO2 (Mt/y) from natural gas and coal

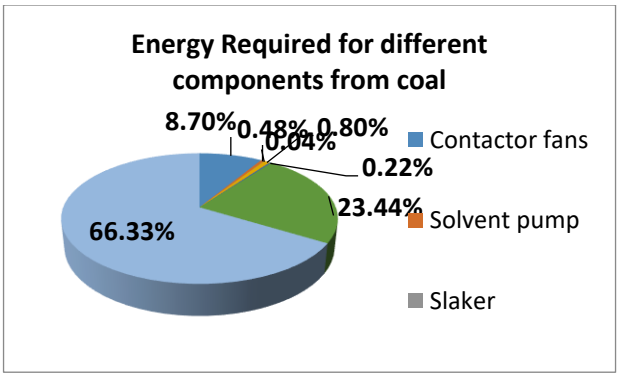

Figure 11 Energy Requirements for a liquid solvent DAC system from coal

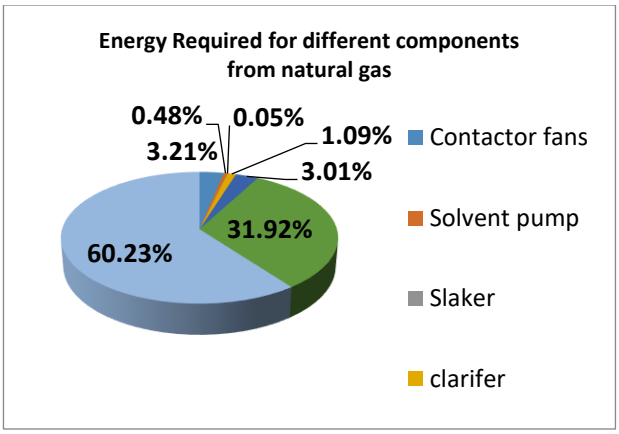

Figure 12 Energy Requirements for a liquid solvent DAC system from natural gas

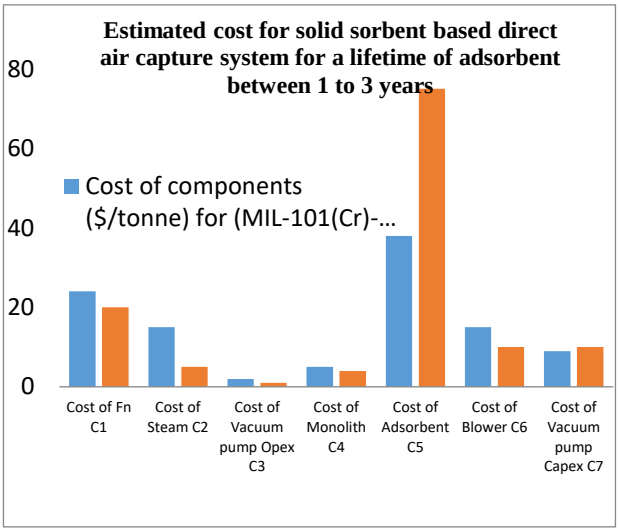

Figure 13 Estimated cost for solid sorbent based direct air capture system for a lifetime of adsorbent between 1 to 3 years.

It was found that the total cost for MIL-101(Cr)-PEI-800 is $75-140/tCO2 captured for a lifetime of adsorbent between 1 to 3 years and for mmenMg2(dobpdc) is $60-190/tCO2 captured for same lifetime.

quantities of nutrient content are processed to create microalgae on a massive scale. To generate 100t of microalgae biomass, approximately to 200t of Carbon dioxide, 10t of N, and 01t of P are necessary. Close to 1kg of microalgae biomass can be generated per cubic metre of sewage, relying on the mean content of C, N, and P in sewage.

The biomass cost of manufacture of $5/kg when utilising clean water, fertilisers, and CO2 as nutrients sources, as per F.G. Acién at el. 2016, while the microalgae biomass manufacturing expense is $3/kg when employing thin-layer cascade reactors. These figures are close to the $5/kg figure determined for large-scale shuttered tubes photobioreactors.

Table 1 Capital Costs (CAPEX) estimation for a Liquid Solvent DAC

Main components	Cost ($M) per Mt/y CO2 removal	Reference
Contactor array	210–420	Holmes and Keith 2018
Slaker, causticizer, clarifcator	130–195	Socolow et al. 2013
Air separation unit	65-100	Rubin et al., 2007
calciner Oxy-fired	270–540	Socolow et al, 2013
Total cost	**675-1255**	

Table 2 Operating cost (OPEX) includes maintenance, labour, waste removal and makeup cost, electricity and fuel cost

OPEX	Cost ($M/y)		Remark
Maintenance	18-33		0.03 of total capital requirement
Labour	6-10		0.30 of maintenance cost
waste removal and Makeup	5-7		Lower bound: $500/t KOH, $250/t Ca(OH)2, $0.30/t H2O, $260/t waste disposal Upper bound: 1.5 factors for make-up OPEX.
Electricity	12-28		calculated from electrical requirements reported in
Natural gas and coal	25-35	18-25	calculated from low and high thermal requirements, assume NG cost of $3.25/GJ & coal cost of $2.33/GJ
OPEX total for natural gas	**66-113**		

OPEX total for coal	**59-103**

V. CONCLUSION

The main goal of this research is to look into various emerging technologies for carbon capture from multiple resources, as well as carbon capture from the atmosphere using direct air capture (DAC) technology. It is used for micro algae cultivation after CO2 has been captured. The result assessment is divided into three sections: direct air capturing utilizing liquid various solvents, direct air capturing employing solid sorbent systems, and microalgae operating cost assessment. From this research, the following conclusions were made.

Energy demands for a liquid solvent DAC system from natural gas are more than 92 percent ingested by the calciner and heating element, with the residual 8% expended by other elements including the contractor, solvent pump, slaker, clarifer, and air separation unit, whereas energy demands for caol are about 89.77 percent ingested by the calciner and heating element, that's less than natural gas, and the residual 10.23 percent served by other elements including the contractor, solvent pump, slaker,The overall energy usage per tonne of CO2 is 1527 kWh.

Carbon Capture utilizing a Liquid Solvent in a DAC system will indeed cost $147-264 per tonne of CO2 for natural gas and $140-254 per tonne of CO2 for coal.

Carbon Capture employing solid Solvent in DAC system costs $75-140/tCO2 captured for MIL-101(Cr)-PEI-800 and $60-190/tCO2 managed to capture for mmenMg2(dobpdc).

Microalgae costs of production $5.9/kg with a 30,000-tonne-per-year capacity.

For microalgae cultivation, the demand for Co2 is double the the capacity per tonne of microalgae biomass. 2 tonnes of CO2 are estimated to produce tonne of microalgae. So, if 1 tonne of CO2 is produced per day and utilised generate microalgae, only 0.5 tonne of microalgae can be generated per day.

The expense of carbon capture employing solid solvent for mmenMg2(dobpdc) has been found to be the cheapest, ranging between $60 and 190/tCO2, while the cost of microalgae cultivation is $5900/tonne. As a result, the overall cost (carbon capture + microalgae production) is $5960-$6090 per tonne.

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