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Carbon Capture and Sequestration: A comprehensive Review

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Abstract: More than ever, the fate of anthropogenic CO2 emissions is in our hands. Since the advent of industrialization, there has been an increase in the use of fossil fuels to fulfil rising energy demands. The usage of such fuels results in the release of carbon dioxide (CO2) and other greenhouse gases, which result in increased temperature. Such warming is extremely harmful to life on Earth. The development of technology to counter the climate change and spreading it for widespread adoptions. We need to establish a framework to provide overarching guidance for the well-functioning of technology and mechanism development of Carbon Capture and Storage. Carbon capture and storage (CCS) is widely regarded as a critical approach for achieving the desired CO2 emission reduction. Various elements of CCS, such as state-of-the-art technology for CO2 collection, separation, transport, storage, politics, opportunities, and innovations, are examined and explored in this paper. Carbon capture and storage is the process of capturing and storing carbon dioxide (CO2) before it is discharged into the environment (CCS). The technology can capture high amounts of CO2 produced by fossil fuel combustion in power plants and industrial processes. CO2 is compressed and transferred by pipeline, ship, or road tanker once it has been captured. CO2 can then be piped underground, usually to depths of 1km or more, and stored in depleted oil and gas reservoirs, coalbeds, or deep saline aquifers, depending on the geology. CO2 could also be used to produce commercially marketable products.

With the goal of keeping world average temperatures below 1.5°C (2.7°F) and preventing global average temperature rises of more than 2°C (3.6°F) over pre-industrial levels, CCS model should be our priority to be implemented with the proper economical map.

TABLE OF CONTENTS

I. INTRODUCTION

Climate change is a deliberate issue that we are administering, it has already begun to reflect its effect as melting of ice caps, rise in sea level etc. The concentrations of greenhouse gases (GHGs) in the atmosphere, namely carbon dioxide (CO2), nitrous oxide (NO), methane (CH4), and chlorofluorocarbons (CFCs), have gradually grown over the last century. GHG emissions and concentrations in the atmosphere are growing, there are indicators of fast-rising average surface temperatures, and scientists have discovered diagnostic markers – such as higher high-latitude warming that identify forecasts of this sort of natural disbalance. The global surface temperature increased [0.84- 1.10] °C higher than 1850-19009 d over the twentieth century. Over the 21st century till now, the Global mean sea level has risen about 8–9 inches (21–24 centimetres) since 1880. The rising water level is mostly due to a combination of meltwater from glaciers and ice sheets and the thermal expansion of seawater as it warms.

Precipitation increased by 5 to 10% in the Northern Hemisphere, and droughts became more common in portions of Asia and Africa. In the next century and beyond, global mean surface temperature will climb rapidly. The Intergovernmental Panel on Climate Change (IPCC) will publish its Sixth Assessment Report in late 2021-2022, which provides the best projection of temperature change over the next century i.e. datasets contributed approximately 0.1ºC to the updated estimate of warming in AR6 from AR5 (2014). Global GHG emissions should be cut by 50 to 80 percent by 2050, according to the IPCC, to avoid such a large temperature increase.[16]

Recent studies even indicate that the disruption of ecosystems and extinction of species could be worse than previously believed levels.

2020 has been the first year where wind and solar account for the majority of new global electricity generation capacity, but the fossil fuel industry is still slow to change. Some of the oil majors, in large part due to increasing investor concern about the financial impact of climate risk, are reassessing their strategies. Experts and policymakers are becoming more interested in ‘‘add-on" environmental policies that combine cutting-edge fossil technologies with advanced carbon capture and sequestration technology. If effectively implemented, such solutions could allow for the continued use of fossil energy carriers with minimal (or almost zero) emissions. Even if oil usage is reduced, to meet the carbon budget requirements by 2050 and achieve a net-zero carbon economy, much greater focus needs to be given to carbon capture and storage.

The increase in anthropological CO2 in the atmosphere is linked to climate change, to prevent this chaos there are several proposed solutions like switching to renewable energy (i.e., toward less carbon-intensive energy sources) and using more energy-efficient technologies.

While renewable energy is now widely accepted as the cheapest form of electricity generation, but currently it has not met our energy demand growth hence fossil fuels will still have a significant role. For that to work with climate goals, carbon capture and storage (CCS) technology must be mainstreamed.

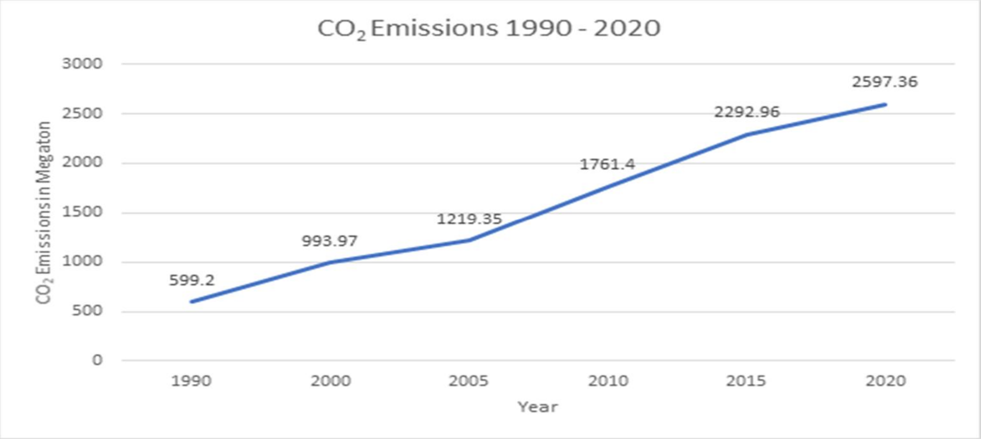
II. SOURCES OF CO_2

There are both natural and human sources of carbon dioxide emissions. Natural sources include decomposition, ocean release and respiration. Human sources come from activities like cement production, deforestation as well as the burning of fossil fuels like coal, oil and natural gas.

Due to human activities, the atmospheric concentration of carbon dioxide has been rising extensively since the Industrial Revolution and has now reached dangerous levels not seen in the last 3 million years. Human sources of carbon dioxide emissions are much smaller than natural emissions but they have upset the natural balance that existed for many thousands of years before the influence of humans.

This is because natural sinks remove around the same quantity of carbon dioxide from the atmosphere than are produced by natural sources. This had kept carbon dioxide levels balanced and in a safe range. But human sources of emissions have upset the natural balance by adding extra carbon dioxide to the atmosphere without removing any.

Carbon dioxide emissions from fossil fuel and industrial purposes in India totalled 2,597 megatons in 2019. Since 1990, carbon dioxide emissions from fossil fuel and industrial purposes in India have increased by more than 300 percent. This growth was driven by increased coal use in India. [5]



Indian CO2 Emissions (1990-2020) [5]

A. Electricity

India is the world's third-largest producer and third-largest consumer of electricity. The national electric grid in India has an installed capacity of 383.37 GW as of 31 May 2021. Renewable power plants, which also include large hydroelectric plants, constitute 37% of India's total installed capacity. During the financial year (FY) 2019-20, the gross electricity generated by utilities in India was 1,383.5 TWh and therefore the total electricity generation (utilities and non-utilities) within the country was 1,598 TWh. The gross electricity consumption in FY 2019 was 1,208 kWh per capita.[5]

India's electricity sector is dominated by fossil fuels, especially coal, which during the 2018-19 financial year produced about three-quarters of the country's electricity. The government is making efforts to extend investment in renewable energy. The government's National Electricity Plan of 2018 states that the country doesn't need more non-renewable power plants within the utility sector until 2027, with the commissioning of 50,025 MW coal-based power plants under construction and therefore the addition of 275,000 MW total renewable power capacity after the retirement of nearly 48,000 MW old coal-fired plants. It's expected that non-fossil fuels generation contribution is probably going to be around 44.7% of the entire gross electricity generation by the year 2029-30.

1) *Coal:* India's electricity sector consumes about 72% of the coal produced within the country. India consumed 622.22 million tonnes of coal for utility power generation during 2019-20 which is a smaller amount by 1% compared to 628.94 million tons during 2018-19. However, coal imports for utility power generation increased by 12.3% during the year 2019-20 at 69.22 million tons from 61.66 million tons during 2018-19. The Centre for Science and Environment has assessed the Indian coal-based power sector together of the foremost resource-wasteful and polluting sectors globally thanks to the high ash content in India's coal.[5] With the expected rebound within the demand for coal to satisfy the rising electricity requirement, CO2 (CO2) emissions within the country in 2021 are going to be 1.4%, or 30 million tonnes (MT), above the amount recorded in 2019, the International Energy Agency (IEA) said during a recent report. The expected rise in coal-fired electricity generation in 2021 is probably going to be 3 times greater than the rise in generation from renewables, the agency said, adding that “coal demand is predicted to extend by almost 9%, contributing the foremost to rebounding demand, as electricity demand recovers”. In their Intended Nationally Determined Contribution (INDC), countries have agreed to reduce the carbon intensity of their GDP by 33 percent to 35 percent by 2030, compared to 2005 levels, as part of the Paris global climate change COP21 agreement. “CO2 emissions in India are now broadly on par with emissions within the European Union at 2.35 gigatons (billion tonnes), although they continue to be two-thirds lower on a per capita basis and 60% below the worldwide average,” the IEA noted. Emissions had dropped in 2020 as an impact of the countrywide lockdown to regulate the coronavirus pandemic and economic recovery in India in 2021 is about to push emissions almost 200 MT above last year. At the top of FY21, thermal power plants — mainly coal-based — comprised about 60% of the installed capacity but generated quite 80% of the electricity consumed within the country. Power demand slipped 0.9% annually to 1,272 billion units within the fiscal year. Under INDC targets, India also wants to possess about 40% cumulative electrical power installed capacity from non-fossil fuel-based energy resources by 2030. S&P Global Ratings has recently said that “India may overpromise and under-deliver” on its energy transition goals and having 450 giga-watt of renewable energy capacity by 2030 could also be difficult. The current installed renewable energy generation capacity stands at 94 GW and about 34 GW is under various stages of implementation and 30 GW under various stages of bidding. Additionally, 46.2 GW of hydro and 6.8 GW of nuclear capacities also are currently online.[5]

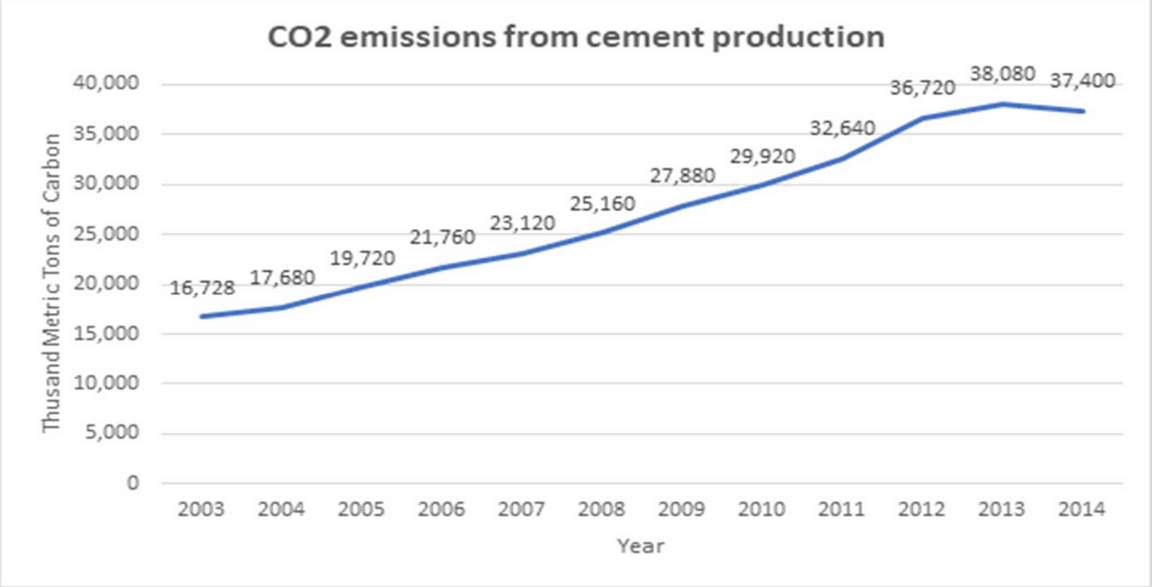
2) *Oil & Gas:* India’s proven reserves of oil are limited, where approximately 80% of current production is estimated to be from fields that have passed their peak. According to the IEA the proven reserves amounted to 5.6 billion barrels at the end of 2006, which is roughly 0.4% of the world’s reserves. The Indian oil reserves are primarily located in five sedimentary basins: Mumbai (38%), Cambay (20%), Assam Shelf (18%), Barmer (15%), and the Krishna-Godavari (KG) basin (7%). Due to this limited resource, India presently imports about 100 million tonnes (or ~2 Mb/d) of crude oil, predominantly from the Middle East. India’s current oil import dependence is at 70%, but this is projected to rise to 94% by 2030. There are 23 refineries in the Indian oil market. The domestic sale of petroleum products in India for the year 2015–2016 is shown in Table 5 [3]. During this time, the overall volume was 231.92 Mt.[5]. The projected annual emissions of CO2 from major point sources alone was 721 Mt, which was roughly half of India’s overall emissions [5]. Figure 5 presents the CO2 emissions from Indian petroleum during 2010–2016. In India, there are many facilities used in the fields of defence, farming, and space stations that constantly emit CO2 into the atmosphere.

B. *Industries*

Industries contribute approximately one-fourth of India’s total GHG emissions. The Industrial sector emissions have been developed using a systematic approach of assessing a wide range of fuel consumption, industrial process, and product use from more than two lacs industrial units.

The emissions have been estimated across 16 sub-sectors including chemicals and fertilisers, food and beverages, machinery, metals and mining, textile, etc. The data trend, disaggregated at the sub-sector level, can inform policymakers and industries to improve energy efficiency and emission intensity.

1) *Fertilizer Plants:* In India, agriculture is the primary occupation, and Indian farmers utilize an outsized amount of fertilizer in their farming. Fertilizer production units are the first source of CO2 emissions. Two main sources of fertilizers—phosphatic and nitrogenic—are produced effectively in 56 broad fertilizer units. Fertilizer plants emit a big proportion of CO2 emissions, which are mostly produced by ammonia factories. However, sometimes this amount of CO2 is insufficient for plants that produce urea. Hence, additional CO2 generation units are added to fertilizer plants. Approximately 18 ammonia processing plants produce quite 0.1 million tonnes of CO2 pollution a year with a CO2 emission rate of 2104 kg per tonne of ammonia[5]
2) *Cement:* The Indian cement industry, the second largest after China, at present, has an Installed Capacity of Cement as 500 MTPA with production of 298 Million Tonnes per annum. With 99% of the installed capacity using dry process manufacturing, the Indian cement industry has been adopting the latest technologies for energy conservation and pollution control as well as online process and quality control based on expert systems and laboratory automation. Over the past 20 years, worldwide cement consumption has increased by 30%. In India, cement factories have raised their share in overall CO2 discharges from 3.3% to 4.8%, while the world level is about 4% . Such facilities are now pursuing acceptable CCS technology.[5]



Indian CO2 emissions from Cement production [5]

III. ROUTES FOR CAPTURING CO2

The efficient collection of anthropogenic CO2 released on a wide scale, such as from large industrial units, is considered as a massive system for reducing CO2 levels in the atmosphere. This is because the quantity of CO2 is significant within the burning of hydrocarbon energies, which may be a day by day event among India's coal-fired thermal power plants. At the present , there are three technological routes used to capture CO2 content: post-combustion, pre-combustion, and oxyfuel combustion.

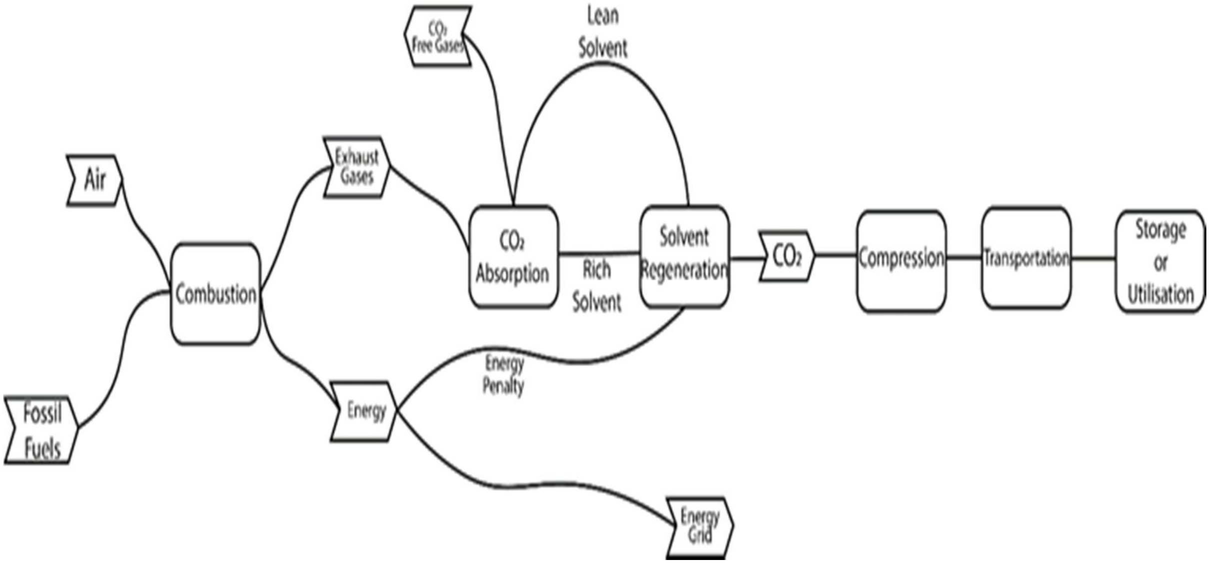
A. Post Combustion

The primary objective of this CO2 capture technology is to isolate and seize the CO2 available within the gases that are produced from the ignition of fossil fuels. This system is in a position to seize carbon gas from power-plants and is, therefore, sometimes called post-conversion capture. However, once this system is functional in power-plants, it's considered post-combustion CO2 capture. The post-combustion strategy for CO2 capture incorporates solvent absorption, cryogenic separation, membrane partitioning, and stable sorbent adsorption. Post-combustion capture is taken into account a totally developed CO2 capture methodology thanks to its effective and superior adaptability for fossil fuel-based power plants.

Post-Combustion Capture relies on the preferential affinity of certain materials for carbon dioxide. For example, a certain group of chemicals, called amines, can be mixed with water to selectively capture carbon dioxide from other combustion gases, such as nitrogen.

Post-Combustion Capture relies on a simple principle: a circulation loop between a section where CO2 is absorbed into the solvent and a section where CO2 is desorbed, i.e. released, from the solvent. In this second section, the solvent recovers its capacity to absorb CO2 and is recirculated to the first section.

1) CO2 mixed with other gases – this could be other combustion gases but also natural gas – passes the CO2 absorber, where the gases and the solvent are contacted.
2) The gas then leaves the absorber with most of the CO2 removed. Solvent enters at the top of the absorber, trickles on the packing and then
3) Leaves at the bottom of the absorber, rich with CO2.
4) It is then pumped and heated up before it enters the second section of the process,
5) The CO2 desorber. Like the CO2 absorber, the CO2 desorber contains large sections of packing material to contact the solvent with gas flowing upwards.
6) Energy, in the form of heat, is provided to the CO2 desorber to release CO2, as a gas, from the solvent.
7) CO2 then leaves at the top of the desorber as a gas.
8) It is then compressed into a liquid to facilitate transport to a geological storage site.
9) Solvent leaves at the bottom of the desorber, containing much less CO2 than before it entered the desorber. We say that the solvent is lean in CO2. It is then cooled down, and
10) Pumped to the return to the CO2 absorber to complete the circulation loop.



Post combustion carbon capture technology [3]

B. Pre Combustion

It is also possible to capture carbon dioxide before combustion takes place, by converting the fuel into another, carbon-free fuel: hydrogen.

Pre-combustion capture entails the removal of CO2 gases from fossil fuels before the completion of the combustion process. In pre-combustion capture, fossil fuel-based power-plants are partially oxidized in steam and oxygen under high and temperature to make syngas. This gas combination consists of H_2, CO, CO2, and little amounts of other gases (CH_4). The syngas reacts further through the water–gas shifts to vary CO and H_2O into H_2 and CO2, thereby producing a high concentration mixture of H_2 and CO2. The quantity of CO2 during this mix can lie between 20 and 45%. The CO2 is then ready to be trapped and isolated from the gas mixture.[3]

C +H2O → CO + H2

Carbon Steam Carbon monoxide Hydrogen

CO + H2O → CO2 + H2

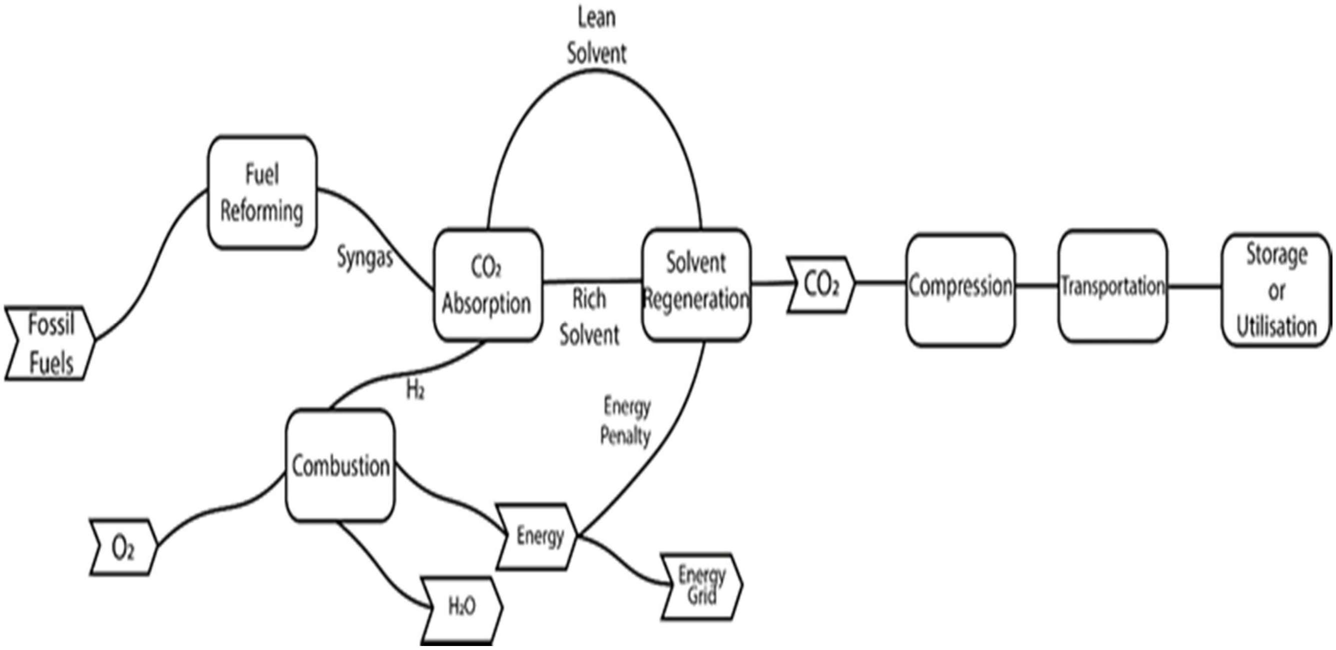
Carbon monoxide Steam Carbon dioxide Hydrogen

Air enters an Air Separation Unit where it is separated into its two major components, nitrogen and oxygen. High purity oxygen then enters the next conversion step, the gasifier. Solid fuel is reacted in the gasifier at high temperature and high pressure with oxygen and steam to form a synthesis gas, or syngas as it is commonly referred to. This high-pressure syngas is a mixture high-pressure of hydrogen and carbon monoxide – two gases which can be used for combustion - and carbon dioxide and water.

The second step after the gasifier is the shift reaction. The syngas now consists of high pressure hydrogen, carbon dioxide and water.

The removal of 90 to 95 % of the CO2 is carried out in the capture unit, where solvents selectively react with carbon dioxide but not hydrogen. CO2 is then compressed to be transported to permanent geological storage.

This leaves nearly pure hydrogen, which is burned in a gas turbine to produce electricity. Since the combustion of hydrogen produces water and no carbon dioxide, there are no emissions to the atmosphere from the power plant stack. The hydrogen can alternatively be stored or transported away to be used as a raw material for various chemical products or as a carbon-free energy vector.



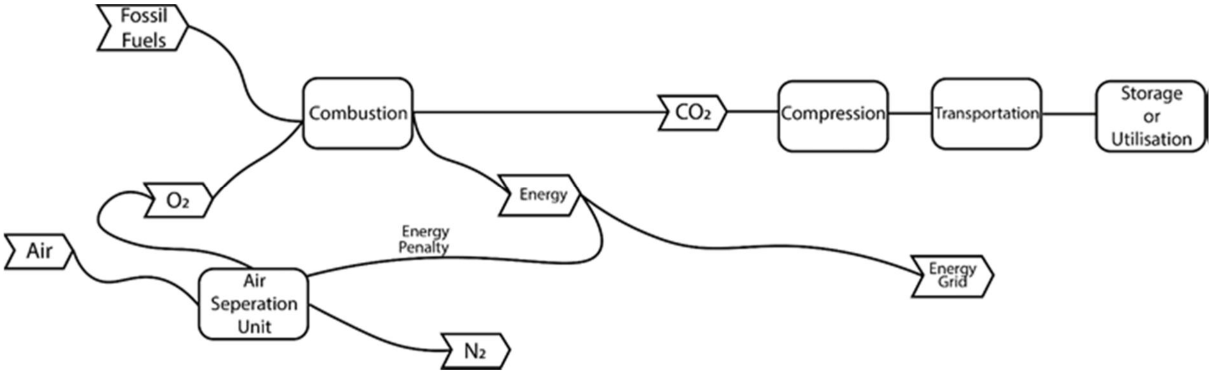
Pre combustion carbon capture technology [3]

C. Oxy Fuel Combustion

The simplest approach for grabbing CO2 in power plants with the use of a CCS mechanism is oxygen-fuel combustion. In most cases, this method involves the ignition of fuels in the presence of clean oxygen gas rather than air.The first benefit of using this method for hydrocarbons and plants is that it produces large amounts of CO2 and hydraulic vapour in the atmosphere, which can be easily captured or separated using a low-temperature dehydration process. Cryogenics, which include eating and igniting coal in pure oxygen, give clean oxygen. The fundamental advantage of oxy-fuel CCS is that even with a large CO2 accumulation of 75.69 mol%, the vent air remains accessible, allowing for a drop in the compression rate and effective CO2 evacuation.[3]

Air enters an Air Separation Unit, where it is processed to be separated into its two major components: nitrogen and oxygen. Very high purity oxygen enters the Boiler of the power station together with the fuel.

In the absence of nitrogen to dilute the combustion gases, a fraction of the combustion gases is recycled to the inlet of the boiler to play the role of the diluent that nitrogen would otherwise play. These recycled combustion gases don't contain fuel anymore and cool down the boiler to ensure that the temperatures stay at an acceptable level. The heat generated by the combustion taking place in the boiler is used to raise steam to drive turbines and produce electricity. The combustion gases leave the boiler consisting of around 90% CO2 and enter a step represented here as capture, where the other combustion gas – water – is condensed into a liquid. The resulting stream with 95 to 99% CO2 is compressed to be transported to permanent geological storage.[3]



Oxy fuel combustion carbon capture technology [3]

IV. SEPARATION TECHNIQUES FOR CO2

CO2 emissions from the combustion of fossil fuels are thought to be the principal cause of global warming. Around the world, many methods for separating CO2 from combustion exhaust gases are widely employed.

In the post-combustion process CO2 is captured from the power plant's exhaust gas after process of combustion. For the pre-combustion separation method, the fossil fuel is pre-treated before combustion. As a result of gasification (for coal) or reforming (for natural gas) a syngas is produced. The mixture of CO and H2 then undergo water gas shift reaction with steam where the CO gas is converted to CO2 and later separated in the capture subsystem. The CO2 level in combustion flue gas is lower when compared without processing. As a result, the energy penalty and associated costs for the capture unit are higher for these processes, So more efficient CO2 separation technologies can be applied to isolate the CO2 from the flue/fuel gas stream.

Processes existing today are either retrofitted into existing plants or in the design of new systems. The report will provide detailed description of each of the current major CO2 separation technologies, which are:

A. Absorption

The process of CO2 absorption by a liquid solvent or solid matrix is currently being investigated for scrubbing CO2 from flue gas streams. Absorption is a method of dissolving one species over another based on the chemical affinity of a solvent with the solute. A solvent is employed in CO2 absorption techniques that dissolves CO2, but not oxygen, nitrogen gas, or any other flue gas stream components. The CO2-rich solution is usually piped to a regeneration column, where the CO2 is removed, and the solvent is recycled for a new batch of flue gas. After the flue gas desulfurization (FGD) step, but before the stack, the absorption equipment should be installed.

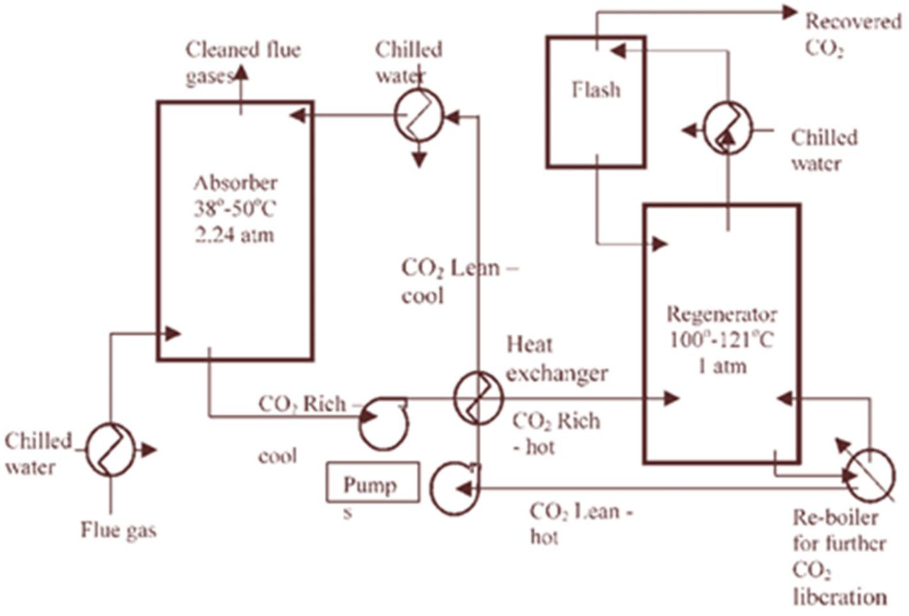
In addition, most solvents are easily degraded by compounds such as fly ash, other particulates, Sox (SO2, SO3, and SO4) and Nox (NO2 and NO3), so the absorption step must take place after electrostatic precipitation and flue gas desulfurization [8].

Monoethanolamine is a conventional example of CO2 absorption solvent that is both effective and cost-efficient. The flue gas from a fossil fuel power plant is passed through a column in which MEA selectively absorbs CO2. This CO2-rich solution is then pumped to a tower where the thermodynamic conditions are changed in order to release the CO2. Absorption is favoured by high pressure and low temperature, whereas regeneration is favoured by low pressure and high temperature. Absorption systems can use ambient pressure (Figure 1) or manipulate it to improve absorption and desorption. Temperature manipulation accounts for 70–80% of total operational costs

There are several design difficulties with the absorption process that must be addressed. The solvent's generatability is the most essential factor. The solvent activity must have an optimal balance between absorption and desorption rates since it is important to carry out the process with as minimal energy penalty as possible. If the solvent is highly attracted to the solute, absorption of CO2 at low temperatures (35–50^{o}C) and relatively low CO2 partial pressure (proportional to concentration) can occur; nevertheless, this high attraction between the solvent and CO2 causes regeneration energy to be high. Regeneration is simple if the solvent is not extremely attracted to CO2, but loading is possible.

So, the main area of improvement for this process is finding a new solvent or refining the existing method to minimize regeneration cycles.

Advantages of Absorption technique	Disadvantages of Absorption technique
• Retrofit Compatible • Can work with low CO2 Concentration • Benchmark, well established technology • Recovery rates up to 95 %	• Energy penalty due to solvent regeneration • Need for removal of trace components like SOx, NOx, water, etc. • Limited operating temperatures to prevent solvent degradation. • Corrosion of equipment



Chemical absorption system

B. Cryogenic Distillation

Cryogenic CO2 Capture (CCC) uses phase change to separate CO2 and other pollutants from exhaust or process gases. Cryogenic separation relies on the assumption that all components of the flue gas are removed except for the N2 and CO2 prior to cooling. Once all the other gases and particulates are completely removed, the remaining gas is sent into a cryogenic chamber where the temperature and pressure are manipulated (low temperature about -140°C and to final pressures 100-200 atm) [8] to cause the CO2 to liquefy. Separating CO2 from the rest of the gas, pressurizing it, and delivering it at pipeline pressure. After CO2 and other contaminants are removed, the gas is almost pure nitrogen, which may be safely discharged into the environment. Because of the projected high cooling costs, CCC is currently regarded as an unfeasible candidate for post-combustion CO2 capture. Due to the additional cost burden, a similar technology known as “refrigeration under pressure” is utilized, which condenses CO2 from a mixture with N2, but at a higher temperature and with more intense pressurization than cryogenic distillation. Due to its multiple components, the refrigeration under pressure system is also significantly more sophisticated. Refrigeration under pressure has similar advantages and disadvantages as cryogenic separation. While cooling under pressure is less expensive than cryogenic separation, pressurizing the gases requires more energy. A heat exchanger may be used to aid in cooling entering gases and heating departing gases to save money. The exhaust gases also drive a turbine that creates electricity, repaying some of the energy used in the rest of the operation. Both of these methods of separating CO2 are fairly new and have room for improvement and optimization before their applications. Lowering the energy required and eliminating the limitations of both methods are the focus of current research.

C. Adsorption

Another method for separating CO2 from flue gases produced by fossil fuel power plants is adsorption. Adsorption is a heterogeneous process. CO2 molecules are attracted to and stuck on the surface of the sorbent or physiosorbed due to interactivity between sorbent and guest molecules. Conditions can be manipulated that facilitate adsorption or desorption.

Under certain temperature and pressure circumstances, many substances can selectively adsorb CO2 into small cracks, pores, or only their exterior surfaces. Adsorption can be done on naturally occurring materials like coal (a method of sequestering CO2 in unmineable coal seams) or more complicated human-made adsorbents like activated carbon or zeolites [8].

Three methods for adsorption are:

1) Pressure Swing Adsorption (PSA)
2) Electrical swing adsorption
3) Temperature swing adsorption (TSA).

All three cases are used in the process of adsorption, adsorption rates depend on temperature, partial pressures of CO2, surface forces, and pore size or available surface area of the sorbent. CO2 is adsorbed onto a molecular sieve in the electrical swing adsorption method, and then an electric current is sent through the sieve to efficiently release the CO2. Although the mechanism of electrical desorption is unknown, it is thought to be triggered by an increase in local temperature caused by an electrical current.

The mechanism of a typical single chamber adsorption system is that the flue gases enter the adsorption chamber after being cooled by a heat exchanger. This brings the temperature of the gases down from the flue gas temperature to the desirable 30^{o}C. The chamber is pressurized by flue gas with compressors to maximize adsorption of CO2, while the rest of the components of the flue gas are allowed to exit the chamber. A vacuum can then be applied to liberate the CO2 from the sorbent. This gaseous CO2 can then be sent via a separate outlet for sequestration. Physical adsorption requires only vessels capable of withstanding small pressure changes, unlike cryogenic separation equipment that must resist considerable temperature changes or liquid absorption where the solvent can form corrosive solutions with flue gases. PSA and TSA, like chemical absorption, are based on regenerability of the sorbent. It has been established that PSA is superior to TSA due to its lower energy demand and higher regeneration rate. There are two significant drawbacks that make adsorption currently unfavourable as a stand-alone process[13].

a) The first is that the system cannot handle large concentrations of CO2, usually between 0.04% and 1.5% because adsorption is only occurring on the surface. Most power plants have much higher concentrations of CO2 in flue gases, approximately 15% (in flue gas).
b) The second is that available sorbents are not selective enough for CO2 separation from flue gases. The sorbents’ ability is usually based on pore size. When CO2 is to be selectively adsorbed, gases smaller than CO2 can also penetrate the pores and could lower the sorbet capacity.

Research is currently being conducted to find more selective sorbents, sorbents with higher capacities, better-operating conditions, and more efficient packing structures. If these goals can be met, adsorption can be made a viable method for separating CO2 in the future.

D. Membrane

The use of membranes has been established as a means of separating CO2 from light hydrocarbons in the fuel and flue gas in chemical industries. Inorganic, metallic, polymeric, and solid – liquid are all forms of membranes used.

Membranes are only useful for separating CO2 when the amount of CO2 in the gas is greater than 10%. The innovative membrane separation procedure works by using differences in CO2 characteristics to where CO2 with chemical interactions is trapped, and other CO2 with physical interactions is allowed to pass through the membranes.

The capacity of polymeric membranes to interface with the target molecule determines their selectivity. Any molecule that needs to be separated interacts with the membrane and is permitted to diffuse over it. The principle behind porous ceramic and metallic membranes is that only gases of a specific size can travel through the holes of the membrane. As a result, these membranes operate as a sieve, separating CO2 from larger molecules of gas.

Flue gases simply enter the separation tank, and the CO2 diffuses across the membrane. The pressure on the permeate side is approximately 10% of the feed side; this pressure difference, once initiated by a vacuum, will continually pull CO2 across the membrane. The separated CO2 is blown to a collection tank, and the flue gases exit for further treatment, such as oxidation of Nox and Sox, recycling of O2 for combustion, and condensation of water vapor. But it is preferred to separate these gases prior so it could not corrode the membrane.

A two-stage separator can also be used in which the membrane separation is done twice which gives purer CO2 and squassation can be carried out. But these costs double the price as compared to the amine separation process [14].

The greatest asset to membrane separation is simplicity as there is no moving part or complex machinery but only fans. Membrane separators do suffer, however, because they are either not selective enough or they are not very permeable to CO2. Currently, it is a trade-off; membranes that are very selective are not very permeable, while permeable membranes allow other gases besides CO2 to permeate, requiring a secondary separation.

Research is being done to find new metallic, ceramic, and alumina membranes. These membranes would better withstand the high temperature of the entering gases and the pressure changes associated with the gas flow through the chamber.

V. CO2 TRANSPORTATION

Transporting carbon dioxide from where it is captured to a storage facility in a safe and dependable manner is an important part of the whole Carbon Capture and Storage process. It’s the link between huge industrial facilities and geological reservoirs, which will evolve over time into an infrastructure equivalent to natural gas transportation today [1].

CO2 transport is a well understood activity and is already working at a significant scale, in many parts of the world.

A. Two Important Questions.

1) How is CO2 transported?
2) And is the transport of CO2 safe?

The most prevalent technique of transporting millions of tons of CO2 is through pipelines. They’ll almost certainly form the foundation of our CCS infrastructure. CO2 can be transported either as a gas or as a liquid. Because liquids have a higher density than gases, which allows for greater volume transmission, liquid CO2 pipes are the favoured alternative for new infrastructure. However, in other circumstances, transporting CO2 as a gas will be desirable since it enables for the reuse of existing natural gas infrastructure as it reaches the end of its useful life.

Shipping CO2 from one part of the world to another with better geology for CO2 storage could be an alternate option for some parts of the world. Ships have more flexibility in matching capture and storage, and they require less capital investment than pipelines. But the unit transport cost of a ship, on the , is higher than that of pipelines for volumes estimated at the scale of an industrial zone. Shipping for food-grade CO2 is already underway, with ships a tenth of the size of the larger vessels necessary for a single CCS operation. Transport of CO2 by truck and rail is, in principle, possible but it is unlikely that truck and trains will be a significant part of a future CCS infrastructure, given that the volumes of CO2 of a commercial CCS facility are thousands of times larger than what they can handle.

Is the transport of CO2 safe? The transport by pipelines and ships is an industrial activity, and like any industrial activity it abides to safety standards and regulations. It poses no higher risk than the transport of hydrocarbons, natural gas and oil, which are safely managed. This is an industry with significant safety experience. The transportation infrastructure required to sustain CCS on a worldwide scale is enormous. We already have a lot of experience, skills, people, and rules and laws on which we have to build the transportation foundation of CCS.

VI. STORAGE OF CO2

After transporting CO2, it must be stored to a potential storage site where it is either locked away or converted into a useful product. Though it may feel like why plants do not store the CO2 at inhouse facilities and use them later. Well, it sounds easy at first place but looking at the amount of CO2 that we need to deal with is enormous.

To consider how large a volume of CO2 we are dealing with let's take an example of a single coal fired power station that emits about 10 Megatons of CO2 every year. As the density of CO2 is 2Kg/m^3(gas phase at 1 atm), it turns out to be a total volume of 5 Giga meter cube which is the same volume as two thousand 'Great Pyramids', for each year of operation. And the world emits about 43 billion tons of CO2 a year. So, building tanks to hold the carbon dioxide is impractical. Obviously, we have considered CO2 in the gas phase till now, but it was just for comparison purposes. And we will Compress the gas before storing.

The aim of storage is to keep the captured carbon dioxide out of the atmosphere for at least 10,000 years. About a 150-life cycle of the average human being. Also, to achieve a design of CO2 storage that must work without maintenance or intervention hence a good contender for this is Geological storage. The reason that I am confident that geological systems will work is that they have stored petroleum oils and natural gases for a very long time, about millions of years and even large catastrophic events like earthquake and meteor impacts have not caused these crude oil releases. So now let's see the details one by one.

A. Geological Sites for Sequestration of CO2

This method of CO2 sequestration is the most discussed topic among researchers. CO2 may be stored in basalt formations, deep saline aquifers, Unmineable coal seams and depleted hydrocarbon reservoirs.

B. Basalt Formations

Basalt is a volcanic rock composed of silicates of metals such as aluminium, iron and calcium which can combine with C)2 to form mineral carbonates. They are very good for storage of CO2 as they can cut it from the atmosphere for long periods. The advantages of CO2 storing in basalt rocks are:

1) Basalts provide solid cap rocks and thus prevent CO2 from leaking.
2) Basalts react with CO2 and convert it into carbonated mineral which provide high level of security.
3) This technique is considered stable.

C. Deep Saline Aquifers

Because of their salty character, saline aquifers are water reserves that do not provide potable water. But they could act as one of the greatest storage sites, since they have a large potential for CO2 storage and are also widely distributed geographically.

It seems counterintuitive that the oceans are becoming more acidic as a result of too much CO2, and yet we want to add even more CO2. It's a divisive concept, yet some people believe it makes logical sense. To be clear, this isn't a cure for climate change, but it could help us avoid the worst effects. With ocean storage of CO2, the gas is intentionally injected into the deep ocean and is either allowed to diffuse or be trapped in a specific location, depending on the depth and pressure.

There are three general methods that could be used to directly inject carbon dioxide into the ocean for storage.

The first would be a pipeline that extends from the shore to the depths of the ocean. This pipe would take a stream of CO2 from a capture or intermediate storage facility on the coast and send it offshore for long-term storage. Second, using a long hose or pipe trailed behind the vessel, CO2 held on board the vessel would be discharged at great depths, enabling rapid diffusion of the CO2 into saltwater. The third option would be to inject CO2 into a fixed site at or near the ocean bottom using a stationary vessel or platform. The way CO2 can be stored is completely dependent on its phase i.e., depth (pressure and temperature) at which CO2 is released. Pressure increases with depth, and we can use this to our advantage, carbon dioxide can exist as a gas, liquid, solid, or solid hydrate.

The weight of the water column compresses the liquid CO2 at depths greater than 3,000 meters, making it denser than seawater and sinking slowly to the seafloor. It will sink as a solid but will dissolve as it lowers through the water column. When carbon dioxide settles to the ocean's bottom, it forms an undersea pool, which is held in place by its own density.

D. Unmineable Coal Seams

Unmineable coal seams appear to be a very appealing and potentially economical form of CO2 storage. Adsorbed methane is collected from coal seams by depressurizing them as a result of pumping out water. This is referred to as coalbed methane, and it is a fantastic fuel. However, such recovery is not economically possible at deeper depths. As a result, the CO2 recovered can be injected into such seams, improving methane recovery. CO2–ECBM stands for enhanced coalbed methane recovery. It can be shown that injecting CO2 not only enhances methane extraction, but also helps to accelerate CO2 adsorption.

E. Depleted oil and Gas Reserves

Reserves of oil and gas have been depleted. Another possible CO2 storage place is depleting oil and natural gas deposits. In this case, CO2 is injected into depleted hydrocarbon reserves to boost hydrocarbon recovery. If well developed, this approach known as enhanced oil recovery (CO2–EOR) will be particularly useful in areas like Europe and India where oil and natural gas reserves are limited. According to research, under a high-price scenario, annual incremental oil output might reach 180 million barrels, while CO2–EOR could store roughly 60 million tons of CO2 annually.

While basalt and saline aquifers offer no additional benefits other than storage, Unmineable coal seams and depleted hydrocarbon reserves offer more efficient energy resource extraction and are hence more likely to be tried out first.

The basic geological storage (in rocky formations) site requires 3 major components to work as a CO2 storage site:

1) *The Reservoir:* That rock, where the CO2 is going to be stored, is known as the reservoir.
2) *The Seal:* (Mudstone layer), The carbon dioxide will rise through the reservoir until it hits the seal, and it won’t get through. However, the carbon dioxide could move sideways, especially if that seal on top of the reservoir is sloping. In order to prevent it moving too far sideways and leak, we need the third component i.e.,
3) *The Trap:* **(**trapping system) A trap is a three-dimensional arrangement of rocks in the subsurface that will hold the carbon dioxide inside a limited area. The simplest example is a dome. The carbon dioxide will rise buoyantly from where we inject it up into the centre of the dome.

VII. UTILISATION

Along with permanently locking carbon dioxide away in geological formations, the re-use of carbon dioxide is being proposed as a possible way of addressing CO2 emissions to the atmosphere. First of all, CO2 is already being routinely used in a range of applications, such as increasing the recovery of oil reservoirs, food preservation, or to make fizzy drinks. There is nothing new here. But there is also a growing interest in new ways of converting CO2 to a wide range of products such as fuels, construction materials, chemicals, and plastics. These novel processes, and the existing ones, are referred to as ‘Carbon Capture and Utilisation’. So for simplicity, we will refer to any process or technology that utilises CO2 for any other purpose than its permanent disposal in geological reservoirs as Carbon Capture and Utilisation.

Yet not all forms of Carbon Capture and Utilisation are the same when it comes to the atmosphere. They also differ greatly in terms of the scale of emissions that they can address.

The different categories of ‘Carbon Capture and Utilisation’ are.

Broadly speaking, they can be grouped into five categories. Construction Materials, Agriculture & Food, Chemicals & Plastics, Synthetic Fuels, Industrial Gases & Fluids.

A. Industrial Use

1) *Construction Materials:* Construction materials made with CO2 rely on the mineralisation of carbon. It involves the chemical reaction of CO2 with selected minerals to form a solid product. The molecules of CO2 are then trapped within the product. Carbon mineralisation may take place in emerging manufacturing processes to create economic products, such as cements absorbing CO2 instead of water to form concrete, asphalt, which is used to surface our roads, or aggregates, which are loosely compacted particles widely used in the construction industry.[1]
2) *Agriculture & Food:* In Agriculture and Food, CO2 is used commercially to make the bubbles in our fizzy drinks, or as an inert gas for food packaging and food preservation. It is increasingly being used in greenhouses to increase the yield of, for example, tomatoes. It could also be used, in the future, to mass produce algae to feed animals, to grow microbes to make fertilisers, bio-pesticides or bio-cosmetics. In the majority of these applications, CO2 then returns to atmosphere within minutes, hours or days.[1]

3) *Chemical & Plastics:* CO2 is already being used, every year, for the production of tens of millions of two of the most important chemicals: methanol and urea. Methanol is a widely used block of many chemical products whereas urea is widely used in the production of fertilisers. CO2 is also used, for example, as an anti-freeze, or to make certain types of foams or certain types of fibres to replace glass. In the future, it could also be used directly as a feedstock to replace methanol, which is made from fossil fuels, and, broadly speaking, to produce a wider range of chemicals, including polymers and plastics. The climate benefits of the applications are, however, very dependent on the fate of the final product.
4) *Fuels:* Technologies to make synthetic fuels from CO2 are currently at low levels of readiness. Synthetic fuels could be produced from waste CO2 by using steam, energy and a catalyst to split the CO2 molecules. It uses concentrated CO2, after the capture step in CCS, and effectively consists of reversing combustion and reversing reforming reactions, which we have previously discussed, to then produce a gas consisting of carbon monoxide and hydrogen. The syngas is then subsequently converted into a liquid fuel. Another concept is to replace the capture step in CCS to grow certain forms of biomass to make fuels. The use of combustion gas as a nutrient and a source of CO2 for the production of micro-algae is an example at the research phase. These micro-algae could potentially then be converted into biofuels. However, in all fuel applications where CO2 is a feedstock, it eventually returns to the atmosphere during the combustion of that fuel.

B. Enhanced Oil Recovery

The dominant use of CO2 as an industrial fluid, and by far the largest in terms of scale, is for increasing production in oil reservoirs. This is called CO2 Enhanced Oil Recovery. It is a mature technology currently implemented at a number of large-scale plants worldwide and using tens of millions of tonnes of CO2 every year. At present around two thirds of the CO2 used for Enhanced Oil Recovery comes from natural sources of CO2. The other third comes from industrial processes using fossil fuels with CCS and from two coal-fired power stations with CCS in the USA and Canada. Because CO2 mixes with oil and changes oil properties, CO2 is more effective at producing additional oil than water. A common analogy is salad dressing where CO2 plays the role of vinegar to create an emulsion with oil. Carbon dioxide is a valuable commodity in this context, both because of its ability to stimulate oil production from depleted reservoirs, and because of the limited volumes of naturally-sourced CO2. Therefore CO2 that is produced with oil is separated, compressed and re-injected and recycled numerous times. As CO2 is injected into oil reservoirs, a fraction is eventually gradually trapped in the reservoir, and the rest is recycled for re-injection and so forth.[5]

So how can we differentiate the contribution of these five categories to address CO2 emissions?

Some are routinely being used today, such as Enhanced Oil Recovery. Some are starting to be commercially deployed: The mineralisation of CO2 to produce aggregates for the construction industry. Others are still far away from commercialisation, such as synthetic fuels from algae. The ultimate fate of carbon dioxide matters greatly in the context of climate change.

There are some fundamental questions regarding it that will the CO2 return to the atmosphere and if so then over what timescale? Or does it permanently stay away from the atmosphere for centuries? Depending on the answer, Carbon Capture and Utilisation is a very different proposition to climate change. It is either the promise of turning a waste product into a useful commodity, the promise of creating new markets and decoupling economic growth from CO2 emissions, the promise of a solution to industrial facilities without cost-effective access to a CO2 transport and storage infrastructure; or it is a controversial proposition whereby the use of CO2 merely delays its emission to the atmosphere and undermines the ‘polluter pays’ principle.

The size of the potential market for CO2 utilisation obviously matters too. To evaluate whether CO2 utilisation can make a real difference to address climate change, it is useful to compare its potential against global emissions, and the expected CO2 capacity of geological storage. In 2015, the global market for CO2 utilisation was estimated at around 200 million tonnes of CO2 per year, with the largest proportion of CO2 being used for Enhanced Oil Recovery (EOR). This corresponds roughly to a quantity equivalent to 0.5% of global emissions. Globally, the European Zero Emission Technology and Innovation Platform estimates that the market for CO2 may be no more than 400 million tonnes CO2 per year by 2040. This would be about 25 times smaller than the scale of Carbon Capture with Geological Storage by 2050, estimated by the International Energy Agency. Although it is a small contribution, CO2 Utilisation may offer opportunities for investment in industrial innovation and manufacturing. It is an undoubtedly attractive opportunity to provide some economic incentives to invest in CCS projects. Yet, it is clear that it cannot be considered as a replacement for permanent geological storage of CO2. Combining CO2 capture with utilisation alone simply cannot achieve the levels of decarbonisation required to meet international climate goals.

It is, however, important to maximise the synergies between climate-drive CCS facilities and economically-driven CO2 utilisation facilities when it makes economic sense to do so. Indeed, this would help to mutualise costs between projects, in particular the sharing of a common infrastructure for CO2 transport.

VIII. DEVELOPMENT OF TECHNIQUES AND INNOVATION

CCS is all about capturing the CO2 and either storing it for eons or utilizing it for better use. Here are some innovations that are currently being practiced or can be focused in future.

A. Hemp Cultivation for Energy Efficient Carbon Cycle

Here comes the concept of Hemp cultivation, it can become the necessary innovation for the 21st century carbon capture program that'll be essential to keeping our global atmospheric temperature well below 1.5 degrees Celsius increment. Hemp is a variety of the cannabis sativa plant. It grows pretty rapidly, very much like a weed. Hemp is in fact an extremely useful and versatile plant. [15] It can grow in all sorts of soils and climates with little or no need for pesticides or fertilizers. We humans have been using it to make fabrics for thousands of years. It's six times as strong as cotton and much less environmentally impactful to grow when compared to other traditional fibre plants. Hemp is making a comeback in research after its use was suppressed due to its psychotropic properties. Hemp, like bamboo, is one of the world's fastest growing plants. As a result, it's an excellent contender for efficiently removing carbon from our atmosphere. The problem is determining where it can be grown without damaging current ecosystems (forests) and biodiversity. This was the painful lesson the world learned from crops like corn, soybeans, and sugarcane, which were the primary source of deforestation in major countries for agricultural purposes. To solve this issue of deforestation. It so happens that we have the technology available to build a big hydroponic crop growing warehouse on an industrial estate, similar to vertical farms, but instead of utilizing it for agriculture, we can grow lots of hemp and then utilize it to make useful items that permanently collect carbon. Thousands of hydroponic growing trays will be loaded with hemp seeds and placed in warehouse-style racking systems, just like a vertical farm. After filtering CO2, carbon dioxide will be extracted from the atmosphere or from industrial exhausts and utilized by plants during photosynthesis. Every three hours, a pumped irrigation system will distribute litres of water to each pallet site. The hemp plants in the factories that produce waste water will represent a rich source of nutrients that can be used by the plant's root systems to accelerate growth. The hemp effectively acts like a biofilter and after about 40 or 50 circulation cycles over a four- or five-day period the water coming out of the process will be clean enough to be discharged by local environmental agencies to potentially return back into local lakes and river systems. After this plant is fully grown it is harvested and used as the biomass, this enormous volume of carbon rich biomass will then be fed into a microwave plasma pyrolysis system. This is an existing technology normally used for the conversion of solid waste materials into usable fuels. Microwave plasma pyrolysis system is an industrial scale oven arranged in a tall stack with the capacity to process a thousand kilograms of biomass every hour. The system produces different outputs at different points in the combustion process. At the top of the pyrolyzer synthetic gas is drawn off, cleaned, condensed and stored. Then at the next level down heavier oils are formed which again are condensed and stored and then used as fuel which will drive a turbine providing all the power for the factory's working systems. And the exhaust gases can even be diverted back into the initial combustion process to ensure the maximum amount of CO2 is captured and the Hemp process can be repeated to form a carbon neutral cycle. [15] The product coming out of the bottom of the stack is biochar. That's a commercial product and is used in manufacturing of water filtration units and can be utilized as a soil additive to help deliver large quantities of carbon back into the earth. There are some far more commercially valuable commodities that can be derived out of this biochar are – graphene and industrial diamonds.

B. Direct Air Capture

Direct air capture is a technology to capture CO2 from the atmosphere. The CO2 can be permanently stored in deep geological formations or used in the production of fuels, chemicals, building materials and other products containing CO2. When CO2 is geologically stored, it is permanently removed from the atmosphere, resulting in negative emissions. Direct air capture is one of few technology options available to remove CO_2 from the atmosphere. Carbon removal is expected to play a key role in the transition to a net-zero energy system in which the amount of CO_2 released into the atmosphere is equivalent to the amount being removed. Because certain sectors such as aviation and heavy industry are difficult to decarbonise, carbon removal technologies can offset these emissions and support a faster transition.

C. DAC Technologies

Today, many technology approaches are being used to capture CO_2 from the air.

1) Liquid systems pass air through chemical solutions (e.g. a hydroxide solution), which removes the CO_2 while returning the rest of the air to the environment.[12]

2) Solid direct air capture technology makes use of solid sorbent filters that chemically bind with CO_2. When the filters are heated, they release the concentrated CO_2, which can be captured for storage or use.[12]
3) Electrochemical reactor is a specialized battery that absorbs carbon dioxide from the air (or other gas stream) passing over its electrodes as it is being charged up, and then releases the gas as it is being discharged. In operation, the device would simply alternate between charging and discharging, with fresh air or feed gas being blown through the system during the charging cycle, and then the pure, concentrated carbon dioxide being blown out during the discharging.[11]

Other carbon removal options include nature-based solutions (e.g. afforestation, reforestation, restoration of coastal and marine habitats), measures to enhance naturally occurring processes (e.g. land management approaches to increase the carbon content in soil, biochar) and other technology-based solutions such as bioenergy with carbon capture and storage (BECCS).

Some benefits of direct air capture as a carbon removal option include its limited land and water footprint and the possibility of locating plants close to suitable storage or utilisation sites, eliminating the need for long-distance CO_2 transport.

The choice of location also needs to be based on the energy source needed to run the plant, which would help determine whether the system is carbon-negative, as well as the cost of the energy.

D. Cost

The CO_2 in the atmosphere is much more dilute than, for example, the flue gas from a power station or a cement plant. This contributes to the higher energy needs and costs for direct air capture relative to other CO_2 capture technologies and applications.

Costs and energy needs vary according to the type of technology and whether the captured CO_2 is going to be geologically stored or used immediately at low pressure. In fact, CO_2 needs to be compressed at a very high pressure in order to be injected into geological formations. This step increases both the capital cost of the plant (due to the requirement for additional equipment such as a compressor) and the operating costs (to run the compressor).

As the technology has yet to be demonstrated at large scale, the future cost of direct air capture is uncertain. Capture cost estimates reported in the literature are wide, typically ranging anywhere from USD 100/t to USD 1000/t.

Carbon Engineering recently claimed that capture costs of USD 94/t to USD 232/t were achievable depending on financial assumptions, energy costs and specific plant configuration.[12]

There are currently 15 direct air capture plants operating worldwide, capturing more than 9 000 tCO2/year, with a 1 MtCO2/year capture plant in advanced development in the United States. In the SDS, direct air capture is scaled up to capture almost 10 MtCO2/year by 2030. This is within reach but will require several more large-scale demonstrations to refine the technology and reduce capture costs.

However, the first large-scale direct air capture plant is now being developed in the United States by a Carbon Engineering and Occidental Petroleum partnership. The plant will capture up to 1 $MtCO_2$ each year for use in enhanced oil recovery and could become operational as early as 2023.

A plant of this size would be eligible for the 45Q tax credit (providing USD 35 per tonne of CO_2 used in enhanced oil recovery and USD 50 per tonne for CO_2 storage). Moreover, it could also be eligible for the California Low Carbon Fuel credit if the CO_2 is used to produce low-carbon transportation fuels. These credits traded at around USD 180/tCO_2 in 2019.[12]

In Iceland, the CarbFix project is currently capturing CO_2 from the atmosphere and blending it with CO_2 captured from geothermal fluids for injection and underground storage in basalt rock formations. This is the first operating application of this type, turning CO_2 into rocks within a couple of years through mineralisation.

Carbon removal technologies such as direct air capture are not an alternative to cutting emissions or an excuse for delayed action, but they can be an important part of the suite of technology options used to achieve climate goals. For this reason, direct air capture needs to be demonstrated at scale, sooner rather than later, to reduce uncertainties regarding future deployment potential and costs, and to ensure that these technologies can be available to support the transition to net-zero emissions and beyond. In the near term, large-scale demonstration of direct air capture technologies will require targeted government support, including through grants, tax credits and public procurement of CO_2 offsets. Technology deployment may also benefit from corporate sector initiatives and pledges to become carbon-negative, such as Microsoft's announcement of a USD 1-billion climate innovation fund for carbon reduction, capture and removal technologies. [12]

Longer-term deployment opportunities will be closely linked to robust CO_2 pricing mechanisms and accounting frameworks that recognise and value the negative emissions associated with storing CO_2 captured from the atmosphere.

IX. ECONOMICS

The development of CCS has been significantly slower than expected. Despite the enthusiasm of many governments and huge corporations, carbon capture and storage has clearly not progressed as quickly as many people would like around the world. There are two key reasons why industries and government haven't quite gotten around to making this business as usual and completely commercial. The first reason CCS is challenging is that many governments are concerned about long-term liabilities. If they take CO2 and store it underground, the government, not the firm that kept it, becomes liable in the long run. As a result, governments require a fairly clear view of confidence that it will remain in place for thousands of years. Scientists have lots of scientific evidence from natural CO2 deposits and engineered CO2 injection to show that we can forecast secure storage with less than 1% leakage every thousand years or even better. The second problem is the perceived cost of CCS, because CCS has been proposed on very big power plants. So if industries are building up a very big power plant they inevitably end up with a very large cost. But the crucial thing is that when you take CO2 storage and capture across the whole economy, the cost per tonne is really competitive. Also, the major factor that determines the success of CCS will be the monetization of CO2 emissions. There are two possible ways of doing this. The first is the imposition of taxes on heavy emitters. Another way is the emission trading mechanism. This method involves an upper limit on how much CO2 a country can emit. If the country emits less than this fixed amount, it can use it as a market commodity (just like a stock) to trade with and earn monetary profits. [6] Whatever the case with renewable energy, CCS will be the cheapest way of decarbonising across the whole economy. As a result, renewable energy will not fulfil our energy needs and they have to go along with the traditional energy generation technology. So it is better to capture what we produce.

There are markets around the world which try to reduce emissions of carbon dioxide by putting a price on emitting more CO2 into the atmosphere but arguably that's actually putting a price on the wrong thing. We don't want people to pay to emit, we want people to avoid having to pay and be rewarded for storage [6][7].

So, the proposition is that we should actually put certificates onto each tonne of carbon produced from oil gas or coal or from biomass because that's all carbon into the atmosphere. It is for the government of a country to ask or order each company who has brought in that carbon to the country or has extracted that from the ground. ``We want you to store one percent per year of that carbon, and then in five years' time we maybe want you to store ten percent. In fifteen years' time we want you to store thirty percent'. So that's a way of starting off very small to build a market, to build a competitive market, to discover the lowest cost way of storing CO2 and then very rapidly increasing the rate, and the amount of carbon dioxide storage to try and match the necessary objective: To get to net zero balance of carbon dioxide extraction and emissions by the mid-century.

As far as we can tell, coal, oil, and gas businesses extract carbon from the ground and then sell it to us, the consumers. And for some reason, those oil giants have been able to shift the burden for the problem of utilising carbon and producing carbon dioxide to customers, who have no option. That's rare and noteworthy because, in any other industry, whether it's manufacturing cars, washing machines, or operating nuclear power plants, the corporations that make, utilise, and generate waste must also be responsible for cleaning up the waste. [7] So the government should put a lot more bonus and a lot more encouragement onto oil and gas companies and coal companies to work with them to develop ways of pricing carbon dioxide, which make Carbon Capture and Storage by those oil companies and coal companies profitable and worthwhile. And then they can be involved not just in the production and the sale, but also in the disposal of the waste product.

X. CONCLUSION

Carbon Capture and Sequestration is the missing piece in the puzzle of protecting the environment. We must understand that CCS does not compete with renewable energy sources, it rather complements them. The development of CCS is necessary because the availability of a larger number of options would mean greater ease in combating climate change.

While technically alternatives for CCS exist, and storage capacity are many, the issue remains whether and under what conditions CCS may become a crucial component in the implementation of climate protection plans. To answer this question, an integrated technology evaluation is required covering technical, economic, environmental, and social considerations. In order to play a decisive role in climate protection strategies, five key challenges are identified, that must be overcome:

A. Industrial and commercial availability,
B. Environmental and safety requirements,
C. Cost efficiency and economic viability,
D. Coordination with energy and climate policy, and
E. Public acceptance.

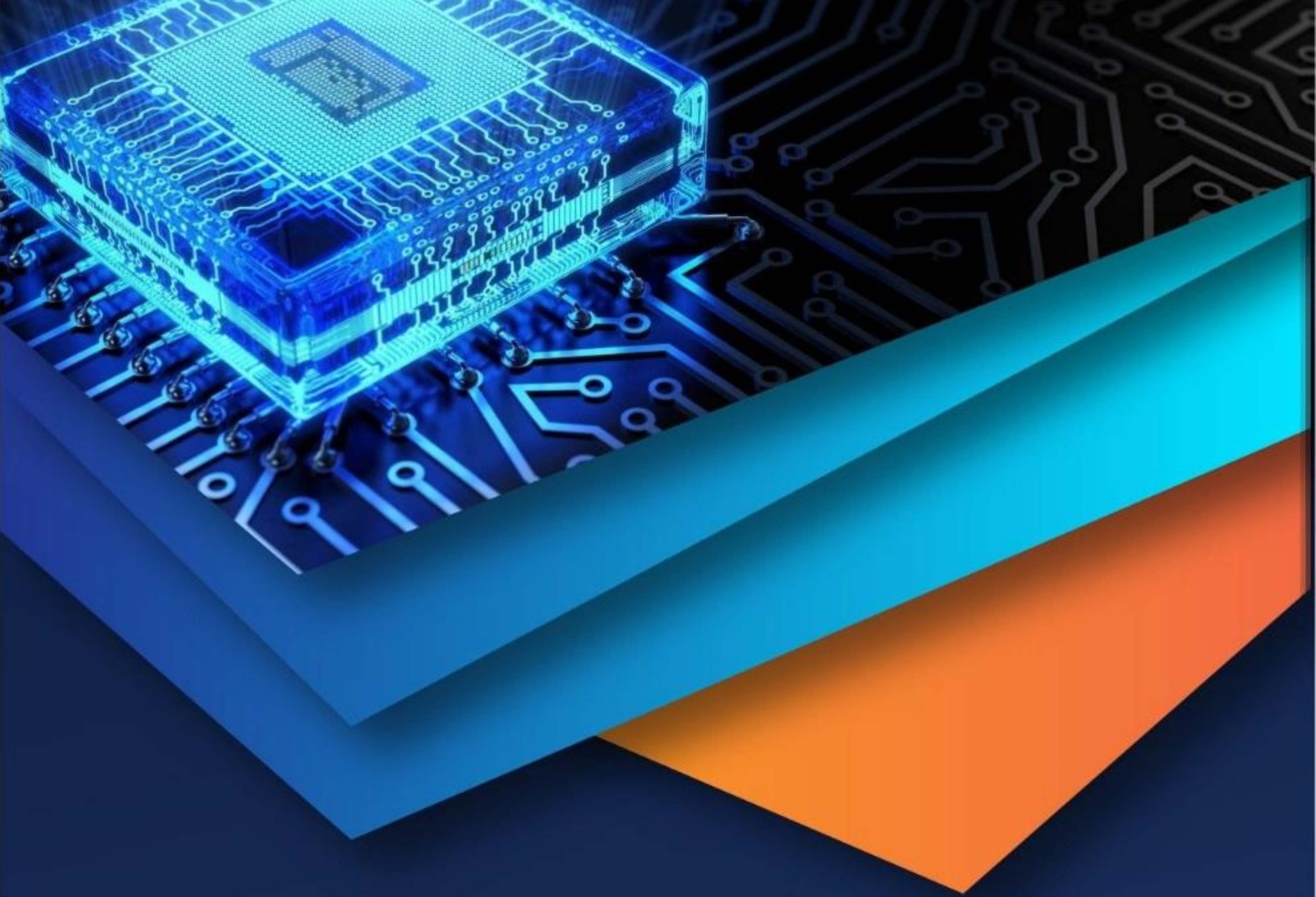
A number of technologies have been proposed which would potentially allow CO2 to be captured directly from the air, or to utilise captured CO2 to produce useful products. Extreme care should be exercised when evaluating the climate benifits and scalability of such processes.

Based on commercial experience in a range of applications, CO2 capture technologies are rather well understood today. Similarly, there are no significant technological or knowledge impediments to implementing pipeline transfer or geological storage of captured CO2. Still for a more widespread deployment of CCS technology, R&D is required to expand future of CO2 capture, enabling technologies that have the potential to lower capture costs for both new and existing facilities. Furthermore, large scale deployment is required to acquire more accurate estimations of the costs to performance data of CCS in industry in India because big CO2 emitters have little or no experience with CO2 capture, such as the cement and steel sectors.

CCS is already possible from our current technology it is just that the advancement of cost-effective technologies along with monetization of the whole process and governmental policies.

CITATIONS

[1] Singh, Udayan. (2013). Carbon capture and storage: An effective way to mitigate global warming. Current science. 105. 914-922.
[2] Gupta, A., & Paul, A. (2019). Carbon capture and sequestration potential in India: A comprehensive review. Energy Procedia, 160, 848–855.
[3] Araújo, O. D. Q. F., & de Medeiros, J. L. (2017). Carbon capture and storage technologies: present scenario and drivers of innovation. Current Opinion in Chemical Engineering, 17, 22–34.
[4] Kapila, R. V., & Stuart Haszeldine, R. (2009). Opportunities in India for Carbon Capture and Storage as a form of climate change mitigation. Energy Procedia, 1(1), 4527–4534.
[5] Kumar Shukla, A., Ahmad, Z., Sharma, M., Dwivedi, G., Nath Verma, T., Jain, S., Verma, P., & Zare, A. (2020). Advances of Carbon Capture and Storage in Coal-Based Power Generating Units in an Indian Context. Energies, 13(16), 4124.
[6] Balat, H., & ÖZ, C. (2007). Technical and Economic Aspects of Carbon Capture and Storage — A Review. Energy Exploration & Exploitation, 25(5), 357–392.
[7] Hardisty, P. E., Sivapalan, M., & Brooks, P. (2011). The Environmental and Economic Sustainability of Carbon Capture and Storage. International Journal of Environmental Research and Public Health, 8(5), 1460–1477.
[8] Robert , C., Ewa , K., Jerzy, S., Damian, J., & Paweł, W. (2019). Carbon Dioxide Separation Technologies. Committee of Mining PAS.
[9] Kuckshinrichs, W., Hake, J., & Hake, J. (2014). Carbon Capture, Storage and Use. Springer International Publishing Switzerland 2015.
[10] Aaron, D., & Tsouris, C. (2005). Separation of CO2 from Flue Gas: A Review. Separation Science and Technology, 40(1–3), 321–348.
[11] MIT Engineers Develop a New Way To Remove Carbon Dioxide From Air | MIT News | Massachusetts Institute Of Technology. (2019, October 24). MIT engineers develop a new way to remove carbon dioxide from air.
[12] Budinis, S. (2020, June 20). Direct Air Capture. Direct Air Capture.
[13] Leung, D. Y., Caramanna, G., & Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. Renewable and Sustainable Energy Reviews, 39, 426–443. https://doi.org/10.1016/j.rser.2014.07.093
[14] Songolzadeh, M., Soleimani, M., Takht Ravanchi, M., & Songolzadeh, R. (2014). Carbon Dioxide Separation from Flue Gases: A Technological Review Emphasizing Reduction in Greenhouse Gas Emissions. The Scientific World Journal, 2014, 1–34. https://doi.org/10.1155/2014/828131
[15] Poisa, L., & Adamovics, A. (2010). Hemp (Cannabis sativa L.) as an Environmentally Friendly Energy plant. Scientific Journal of Riga Technical University. Environmental and Climate Technologies, 5(1), 80–85. https://doi.org/10.2478/v10145-010-0038-z
[16] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.



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INDEX
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IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

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