

CARBON CAPTURE AND STORAGE: AN EFFECTIVE WAY TO MITIGATE GLOBAL WARMING

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Abstract: The purpose of this report is to show the importance of CCS as a climate change mitigation technology by comparing it with other climate change mitigation technologies currently being developed. Ever since industrialization occurred, there has been an increase in the burning of fossil fuels to meet the high energy demands. The use of such fuels causes emission of carbon dioxide (CO₂) and other greenhouse gases which lead to global warming. In order to objectively evaluate those technologies including CCS currently being researched and developed, the study conducted and compared these technologies in term of their potential in reducing GHG (Green house gas) emissions at two set points in the future. In the result of evaluation, it shows that in order for the CCS technology to become practical, risks must be more clearly identified and the economic viability must be improved. Therefore, preparing frameworks and building social systems that support CCS technology would be inferred to become critical elements. This study discusses the methods and economics associated with the same.

Keywords: Carbon capture and storage, climate change, global warming, greenhouse gases.

INTRODUCTION

Carbon sequestration can be defined as the capture and secure storage of carbon that would otherwise be emitted to, or remain, in the atmosphere. The removal of CO₂ directly from industrial or utility plants and subsequently storing it in secure reservoirs. We call this carbon capture and storage (CCS). The rationale for carbon capture and storage is to enable the use of fossil fuels while reducing the emissions of CO₂ into the atmosphere, and thereby mitigating global climate change. The storage period should exceed the estimated peak periods of fossil fuel exploitation, so that if CO₂ re-emerges into the atmosphere, it should occur past the predicted peak in atmospheric CO₂ concentrations. Removing CO₂ from the atmosphere by increasing its uptake in soils and vegetation (e.g., afforestation) or in the ocean (e.g., iron fertilization), a form of carbon sequestration sometimes referred to as enhancing natural sinks, will only be addressed briefly[1].

The climate change and climate variability is evident world over, which can be attributed to global warming. According to the IPCC 2007 “most of the observed increase in global average temperatures since the mid-20th century is very likely due to

the observed increase in anthropogenic GHG [Green House Gas] concentrations in atmosphere.” There are many greenhouse gases, of which CO₂ is main component, is emitted by various industrial processes and burning of various types of carbonaceous fuels. In addition many natural phenomena, agriculture, live-stock also emit greenhouse gases [4]. The nature has its own mechanism (carbon cycle) to absorb carbon dioxide from atmosphere to sustain biosphere balance. However, since the beginning of the industrial revolution the GHG emissions to atmosphere is increasing due to use of fossil fuel by industry, thermal power generating stations, transport and logistics. The UNFCCC was adopted in 1992 and has been ratified by 192 countries, including India. Its objective is “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.”

MOST industries and power stations today are dependent upon the exploitation of fossil fuels, i.e. coal, oil and natural gas to meet their demands. While these energy sources are able to meet the needs to a large extent, they have various problems associated with them. The afore-said fuels are all hydrocarbons and primarily release carbon dioxide (CO₂) on combustion. Apart from CO₂, these fuels are also known to emit other gases such as methane, oxides of sulphur, oxides of nitrogen and carbon monoxide, to name a few [2]. These gases, which allow the incoming solar radiation to pass through but do not allow the trapped heat to escape, are known as greenhouse gases (GHGs) [6]. These gases, in the right proportions are necessary for human survival on planet Earth. However, their excessive release causes rise of temperatures on Earth. This process is known as global warming.

Carbon capture and storage technology, which is one of several carbon sequestration methods, is an innovative method to mitigate global warming and the primary focus of this study. As the name suggests, in this method, CO₂ emitted from thermal power plants and CO₂ intensive industries is captured and stored in various reservoirs to lessen their polluting impact on the atmosphere. CCS is therefore hailed as the technology of the future. As our dependence on fossil fuels is not expected to decline radically in the near future, CCS can provide an excellent transition from conventional to non-conventional methods of generating power, such as solar power, wind power, geothermal energy, etc. CCS is referred to as ‘fictitious reduction’, since there is no decrease in the emission of CO₂ from the Earth, but the polluting impact is lessened.

The entire process involves three processes: capture, transport and storage of the CO₂. These methods have been discussed in this report.

CARBON SOURCES

Pathways for carbon capture come from three potential sources. By far the largest potential sources today are fossil fueled power plants. Power plants emit more than one-third of the CO₂ emissions worldwide. Power plants are usually built in large centralized units, typically delivering 500-1000 MW of electrical power. A 1000 MW pulverized coal fired power plant emits between 6-8 Mt/y of CO₂, an oil fired single cycle power plant about two thirds of that, and a natural gas combined cycle power plant about one half of that.

Second, several industrial processes produce highly concentrated streams of CO₂ as a byproduct. Third, future opportunities for CO₂ capture may arise from producing hydrogen

fuels from carbon-rich feed stocks, such as natural gas, coal, and biomass. The CO₂ byproduct would be relatively pure and the incremental costs of carbon capture would be relatively low. The hydrogen could be used in fuel cells and other hydrogen fuel based technologies, but there are major costs involved in developing a mass market and infrastructure for these new fuels.

METHODOLOGY

A. CAPTURE PROCESSES

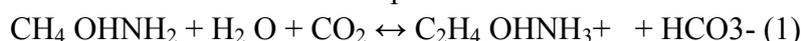
CO₂ capture processes from power production fall into three general categories: (A) flue gas separation; and (B) post-combustion separation. (C) Pre-combustion (D) oxy-fuel combustion in power plants. Each of these technologies carries both an energy and economic penalty. The efficiencies and economics of several technologies will be discussed in section.

1. Flue Gas Separation

Currently, flue gas separation and CO₂ capture is practiced at about a dozen facilities worldwide. The capture process is based on chemical absorption. The captured CO₂ is used for various industrial and commercial processes, e.g. the production of urea, foam blowing, carbonated beverages, and dry ice production. Because the captured CO₂ is used as a commercial commodity, the absorption process, while expensive, is profitable because of the price realized for the commercial CO₂.

Chemical absorption refers to a process where a gas, in our case CO₂, is absorbed in a liquid solvent by formation of a chemically bonded compound. When used in a power plant to capture CO₂, the flue gas is bubbled through the solvent in a packed absorber column, where the solvent preferentially removes the CO₂ from the flue gas [4]. Afterward, the solvent passes through a regenerator unit where the absorbed CO₂ is stripped from the solvent by counter flowing steam at 100-120oC. Water vapor is condensed, leaving a highly concentrated (over 99%) CO₂ stream, which may be compressed for commercial utilization or storage. The lean solvent is cooled to 40-65oC, and recycled into the absorption column.

The most commonly used absorbent for CO₂ absorption is monoethanolamine (MEA). The fundamental reaction for this process is:



During the absorption process, the reaction proceeds from left to right; during regeneration, the reaction proceeds from right to left. The cooling and heating of the solvent, pumping and compression require power input from the power plant thermal cycle, derating the thermal efficiency (heat rate) of the power plant.

In order to reduce the capital and energy cost, and the size of the absorption and regenerator (stripper) columns, new processes are being developed. One example is the membrane-absorption process, where a micro porous membrane made of polytetrafluoroethylene separates the flue gas from the solvent. The membrane allows for greater contacting area within a given volume, but by itself the membrane does not perform the separation of CO₂ from the rest of the flue gases. It is the solvent that selectively absorbs CO₂. It is possible to design a once through scrubbing process (i.e., no regeneration step). For example, one could scrub CO₂ from flue gas with seawater and then return the whole mixture to the ocean for storage [5]. However, to-date these approaches are not as practical as those using a regenerable solvent. In the seawater scrubbing example, the large volumes of water that are required result in large pressure drops in the pipes and absorber. Other processes have been

considered to capture CO₂ from power plant and industrial boiler flue gases, e.g. membrane separation, cryogenic fractionation, and adsorption using molecular sieves. Generally, these processes are less energy efficient and more expensive than the absorption methods [8].

2. *post-combustion*

Post combustion capture is an “end of pipe” technology which involves separating CO₂ from a flue gas consisting mainly of nitrogen, water, CO₂ and other impurities (sulphur oxides - SO_x, nitrous oxides - NO_x and dust). The inherent advantage of such a technology is that it is potentially suitable for retrofit without drastically affecting process operations, other than reducing the power output which is discussed below. The minimal impact on process operations may be particularly important in the future with greater penetration of intermittent renewable power sources and new challenges in demand forecasting with the increased use of decarbonized electricity in the transport sector. There is some concern about the degree of coupling between power and capture plants and there may be a trade-off in terms of flexibility and the amount of CO₂ captured in periods of high demand. [5, 4]

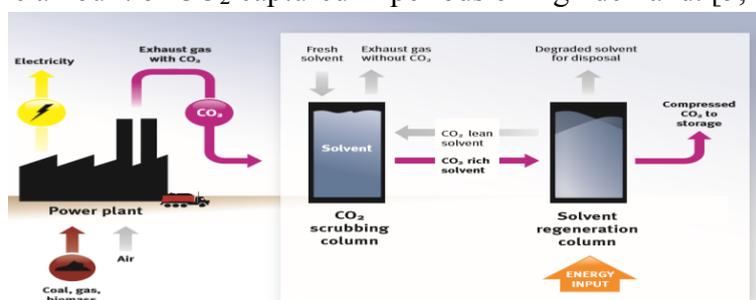


Figure 1. Post combustion capture process [2]

Solvent-based scrubbing, as applied to a power plant, is shown in Figure 4. First, the flue gas is cooled and cleaned of dust and other impurities, before contacting with a solvent in a “CO₂ scrubbing column” (kept at about 80° C, 0.1 MPa), which removes more than 90% of the CO₂ through absorption. Next, the solvent, now rich in CO₂, is passed to a “solvent regeneration column” (kept at about 120°C, 0.2 MPa) where heat transfer with hot steam, diverted from the power cycle, releases CO₂ from the solvent, resulting in solvent regeneration through the desorption process. In this way a nearly pure stream of CO₂ (over 99% of pure CO₂) is produced and the regenerated solvent is recycled. The CO₂ release and solvent regeneration process requires energy (otherwise used to produce electricity) and thus imposes an efficiency penalty on the process and results in a “de-rating” of the thermal efficiency of a generic modern power plant from about 45% to 35%^{5,16}, creating approximately a 20% reduction in the electricity generated. This means more fuel must be burned and more CO₂ is released (although not emitted) in order to maintain the same power output.[5]

3. *Pre-combustion*

Pre combustion capture involves a process called gasification whereby the fuel is reacted with insufficient oxygen (O₂) for complete combustion, producing a mixture known as synthetic gas or “syngas”, consisting mainly of carbon monoxide, methane, hydrogen and CO₂. Next, a series of reactions converts these gases to a mixture of CO₂ and hydrogen (H₂). After separating from the CO₂, the H₂-rich fuel gas can be used to fire a gas turbine or run a fuel cell. Operating flexibility is limited by the large capital cost of the gasifier meaning that it should be run at full load, constantly producing syngas. However, options such as gas storage (either H₂ or syngas), or potentially the production of liquid fuel from the syngas (taking into account the CO₂ emissions associated with the combustion of the fuel), may

allow operation even during periods of low electricity demand [9]. The conditions for CO₂ capture here are very different compared with post-combustion capture because the gas is already at elevated pressure (2–7 MPa) and the CO₂ concentration is significantly higher (15–60% by volume). Because of these conditions, a different range of solvents are used, known as physical solvents. Generally, physical solvents combine less strongly with the CO₂ resulting in a lower energy penalty for desorption. The status of demonstration of this option is discussed in detail in the following section on the Technology Research Agenda [5].

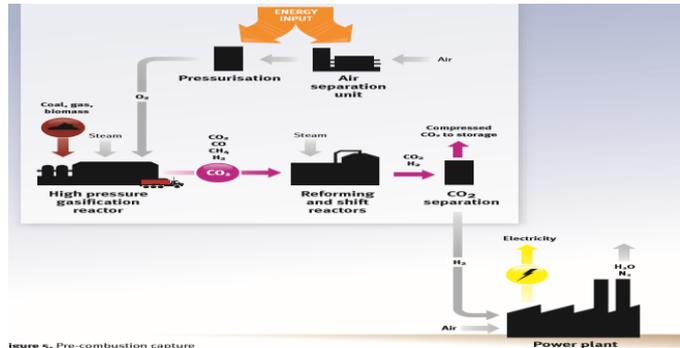


Figure .2 pre combustion capture process [2]

4. Oxy-combustion

Oxy-combustion involves burning fuel in a mixture of recycled CO₂ and pure O₂ instead of air and results in a flue gas that is composed mainly of CO₂ and water vapour, which is easily separated at low cost by the condensation process. Re-cycling CO₂ produced by this process moderates the otherwise extremely high flame temperature in the boiler. The major cost and energy penalty owing to CO₂ separation in post- and pre- combustion processes is traded here for the costly and energy intensive oxygen production, typically by cryogenic air separation. The key advantages of this process are the potential for high CO₂ separation efficiencies and the relative simplicity of the method, which potentially allows for retrofit. Flexible operation for oxy-combustion is limited by the rate of the air separation stage, making the possibility of intermittently switching to air firing desirable, though at the cost of stopping the CO₂ capture for this time period. One key challenge is the potential risk of ingress of ambient air into the boiler, typically operated at sub-atmospheric pressure, so reducing the concentration of CO₂. Oxy-firing is also important for gasification technologies and a range of other advanced technologies (see below for more details). On this basis, a breakthrough in terms of efficient oxygen separation is likely to represent a step-change in terms of process efficiency and a range of potential technologies have been identified, e.g. using polymeric membranes, high-temperature ceramic membranes, or O₂ production by chemical air separation.

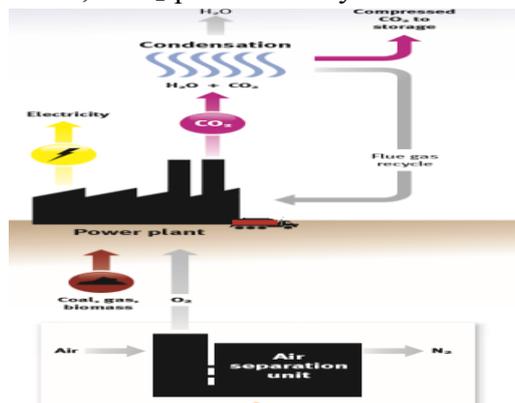


Figure.3 Oxy combustion capture process [2]

B. CO₂ transport

After CO₂ has been captured by any of the aforesaid methods, it needs to be transported to the storage site. This can be done in several ways – pipelines, boats, rail- ways or trucks. It is suggested that the initial pilot projects may involve transportation through trucks or boats, but it may prove to be costly when done on large-scale. Therefore, pipeline transportation is considered to be most viable⁶. The pipelines used must be of good quality as any compromise with it may lead to CO₂ leak, which is discussed later. Of course, carbon dioxide is not combustible like natural gas, which is rather inflammable. So, CO₂ transportation is more of an economic rather than a technological barrier.[6]

C. CO₂ STORAGE

Following the capture process, CO₂ needs to be stored, so that it will not be emitted into the atmosphere. Several key criteria must be applied to the storage method: (a) the storage period should be prolonged, preferably hundreds to thousands of years; (b) the cost of storage, including the cost of transportation from the source to the storage site, should be minimized; (c) the risk of accidents should be eliminated; (d) the environmental impact should be minimal; (e) the storage method should not violate any national or international laws and regulations.

Storage media include geologic sinks and the deep ocean. Geologic storage includes deep saline formations (subterranean and sub-seabed), depleted oil and gas reservoirs, enhanced oil recovery, and unminable coal seams. Deep ocean storage includes direct injection of liquid carbon dioxide into the water column at intermediate depths (1000-3000 m), or at depths greater than 3000 m, where liquid CO₂ becomes heavier than sea water, so it would drop to the ocean bottom and form a so-called “CO₂ lake.” In addition, other storage approaches are proposed, such as enhanced uptake of CO₂ by terrestrial and oceanic biota, and mineral weathering.

1. Depleted Oil and Gas Reservoirs.: Though a relatively new idea in the context of climate change mitigation, injecting CO₂ into depleted oil and gas fields has been practiced for many years. The major purpose of these injections was to disposing of “acid gas,” a mixture of CO₂, H₂S and other byproducts of oil and gas exploitation and refining. Essentially, acid gas injection schemes remove CO₂ and H₂S from the produced oil or gas stream, compress and transport the gases via pipeline to an injection well, and re-inject the gases into a different formation for disposal. Proponents of acid gas injection claim that these schemes result in less environmental impact than alternatives for processing and disposing unwanted gases.

2. Unmineable Coal Seams.: Abandoned or uneconomic coal seams are another potential storage site. CO₂ diffuses through the pore structure of coal and is physically adsorbed to it. This process is similar to the way in which activated carbon removes impurities from air or water. The exposed coal surface has a preferred affinity for adsorption of CO₂ than for methane with a ratio of 2:1. Thus, CO₂ can be used to enhance the recovery of coal bed methane (CMB).

3. Deep Saline Formations.: Deep saline formations, both subterranean and sub-seabed may have the greatest CO₂ storage potential. These reservoirs are the most widespread and have the largest volumes. These reservoirs are very distinct from the more familiar reservoirs used for fresh water supplies. Research is currently underway in trying to understand what percentage of these deep saline formations could be suitable CO₂ storage sites.

The density of CO₂ depends on the depth of injection, which determines the ambient temperature and pressure. The CO₂ must be injected below 800 m, so that it is in a dense phase (either liquid or supercritical). When injected at these depths, the specific gravity of CO₂ ranges from 0.5 to 0.9, which is lower than that of the ambient aquifer brine. Therefore, CO₂ will naturally rise to the top of the reservoir, and a trap is needed to ensure that it does not reach the surface. Geologic traps overlying the aquifer immobilize the CO₂. In the case of aquifers with no distinct geologic traps, an impermeable cap-rock above the underground reservoir is needed. This forces the CO₂ to be entrained in the groundwater flow and is known as hydrodynamic trapping. Two other very important trapping mechanisms are solubility and mineral trapping. Solubility and mineral trapping involve the dissolution of CO₂ into fluids, and the reaction of CO₂ with minerals present in the host formation to form stable, solid compounds like carbonates. If the flow path is long enough, the CO₂ might all dissolve or become fixed by mineral reactions before it reaches the basin margin, essentially becoming permanently trapped in the reservoir.

4. *Basalt formations*: Basalt is a volcanic rock composed of silicates of metals such as aluminum, iron and calcium which can combine with CO₂ to form carbonate minerals. They are very good for storage of CO₂ as they can isolate it from the atmosphere for a very long period. The advantages of storing CO₂ in basalt formations are enormous, some of them, Basalts provide solid cap rocks and thus high level of integrity for CO₂ storage. Basalts react with CO₂ and convert the CO₂ into mineral carbonates which provide high level of security.

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