ISSN 2229-5518

Carbon Capture and Storage

Shubham Das, Jayant Kumar

Abstract— The blue planet is thawing and the consequences of climate changes could be detrimental, lest we act very soon it may well turn out to be a grey planet. What if we could prevent the CO2 released from entering the atmosphere? This idea is one of the hottest topics in the field of energy technology and is widely referred to as ''carbon capture and storage/sequestration'' or shortly CCS. It's an innovative approach to reduce greenhouse gas emissions responsible for global warming. If statistics are candid then CCS will contribute to 1/6th of total CO2 emission reduction come 2050 – as quoted by the International Energy Association. CCS enables capture of CO2 from energy intensive industries viz. cement, iron and steel, chemicals and refining, its transport via ships and pipelines and its subsequent storage. The three methods employed for CO2 capture are pre-combustion, post combustion and oxyfuel. Pre-combustion and post combustion involves capturing CO2 before and after combustion respectively. The last method represents storing all the gases produced as a result after burning the fuel in more oxygen. Critics assert post-combustion as the best and there-by affirm it to be applied to any power plant burning carbon based fuel. The liquefied CO2 is transported and stored by EOR (Enhanced Oil Recovery) practicing companies for tertiary recovery by reducing the oil density and hence mobilizing the oil. These are also used for Enhanced Coal Bed Methane recovery (ECBM), for extracting methane gas. CCS involves storage in deep geologic zones like deep saline formations and depleted oil reservoirs. It is also deployed at commercial natural gas processing, fertilizers production, synfuel production and hydrogen production facilities. Its future endeavors includes storage in basalt and shale basins although much has not been said about the same. Currently, there are 12 active CCS projects, 8 of which are being practiced in US. Investment for carbon capture is scrutinized for being expensive and a wastage of money which could be utilized in perfecting renewable sources like wind energy and solar energy. Furthermore, there exists uncertainty in the CO2 storage regulations which leads to a hindrance in its investment. Is it worth it? It certainly is. How do we know if we don't try? We ought to implement large scale CCS commercialization with further improvisation in face of what we will lose through climate disruptions.

Index Terms— carbon, capture, climate change, energy, oxyfuel, post combustion, pre-combustion, storage, sequestration

1. Introduction

The issue of "Global climate change" has been one of the most emphatic environmental and energy challenge of our age. The accumulation of so called greenhouse gases in the atmosphere through burning of fossil fuels, certain industrial process and the like has contributed greatly in trapping heat and block outward radiation. So far the most prevalent of these gases is Carbon dioxide (CO2) which further aggrandizes the problem. Earlier, improvements in energy efficiency and clamoring for a switch from fossil fuels towards less intensive sources of energy were the only realistic substitutive for reduction in CO2 emissions. However, in recent years both analysts and policy makers have recognized the vast potential for a more pragmatic option- "end-of-pipe" technologies thereby allowing continued utilization of fossil fuels and a simultaneous significant reduction in carbon emissions. The agglomeration of these technologies collectively is referred as "Carbon Capture and Storage (CCS)". These technologies allows CO2 to be "captured" from stationary (large) sources such as power plant flue gases preventing its release to the atmosphere. Post capture, the CO2 has to be compressed and then transported to a safe location where it is stored/sequestered (deep aquifer, deep ocean, depleted oil reservoirs). Contrary to the indirect forms of sequestrations like forestation or enhanced ocean uptake of CO2 which focusses on removing CO2 from atmosphere, CCS relies on avoiding atmospheric emissions altogether.

In this very paper, we synthesize the prevailing literature to explore the prospects for CCS in terms of its feasibility, timing, environmental effects and anticipated potential contribution to an overall climate policy. However, we have restricted the cost factor in our case study.

1.1 Main drivers of CO2 emissions

The below mentioned identity proves useful in understanding the main drivers of CO2 emissions.

CO2 emissions = GDP x (Energy consumption/unit GDP) x (CO2 emissions/ unit energy consumption)

Where, GDP- gross domestic product; measure of size of economy

Energy consumption/ unit GDP- measure of 'energy intensity' of economy, hence policies are aimed at reducing CO2 emissions through increased energy efficiency like setting a standard for fuel economy in cars or energy standards for appliances.

CO2 emissions per unit of energy consumption- measure of 'carbon intensity' of the energy in use. To mitigate this

- *Shubham Das is currently pursuing bachelors degree program in petroleum engineering in University of Technology and Management, Shillong,India, PH-+91-7587711994. E-mail: dasshubham1@gmail.com*
- *Jayant Kumar is currently pursuing bachelors degree program in petroleum engineering in University of Technology and Management,Shillong,India, PH-+91-9089149820. E-mail: singhaniajayanty2jk@gmail.com*

factor the policy makers have emphasized the need to switch to low-carbon fossil fuels (coal and natural gas) or renewable sources of energy (carbon-free alternatives; wind, biomass, solar power, hydropower).

1.2 Role of Carbon Capture and Storage

Critics believe that the problem of CO2 emissions could be solved by promoting the use of renewable energy sources. Others see that the fossil fuel combustion is a solution itself for they affirm that there is a limited supply of fossil fuels and in future they will become too costly inviting alternative sources of energy. Thus, the solution would be to wait until all the fossil fuels are depleted inducing the development of renewable sources of energy. But the above argument remains vague as by that time the atmospheric buildup of GHGs would become both costly and obnoxious when we talk of its effect on terrestrial ecosystems and human civilization. To add to that it is certain that future years promises to bring development of even more reserves and by going at the current rate of extraction, it would not be wrong to assume that it could be well above 80- 100 years before the prevailing fossils are all but exhausted. Further, rapidly developing countries like China and India alone are estimated to account for the 22% of global annual emissions come 2020 (International Energy Association, IEA). These facts all indicates that we will continue to utilize fossil fuels for many years to come, in this way releasing a vast portion of CO2 into the atmosphere. Given our likely reliance on fossils for many years to come, many view CCS technologies as a promising alternative to increasing energy efficiency and switching to less carbon intensive energy sources.

2. Carbon-dioxide Capture

CCS enables capture of CO2 from energy intensive industries viz. power plants, cement, iron and steel, chemicals and refining. These sectors emit significant proportions of carbon and are well suited large stationary sources of CO2 emissions. The cost of capture is primarily a function of the properties of flue gas streams. It has been observed that the cost generally falls with higher concentration of CO2 and low temperatures. To add to the above listed sources, natural gas operations too produce concentrated CO2 as by products. Similarly, the decarbonization of fossil fuels to derive hydrogen (for ammonia manufacture, oil refining) also generates CO2 as by product.

The three methods employed for CO2 capture are pre-combustion, post combustion and oxyfuel. Pre-combustion and post combustion involves capturing CO2 before and after combustion respectively. The last method represents storing all the gases produced as a result after burning the fuel in more oxygen.

2.1 Chemical & Physical absorption of CO2

In most coal burning power plants for flue gas streams with either low or moderate concentration of CO2, so far the best capture method is 'absorption'. Chemical absorption makes use of alkaline solvents such as monoethanol amine (MEA). The absorbed CO2 is then released in a stream by applying heat which involves regeneration of the solvents used and their further recycle. This has been the conventional method so far to recover by product CO2. Although the chemical absorption can remove CO2 at low concentration, but breaking the chemical bonds between the solvent and CO2 involves a lot of energy. Further to aggravate that problem, contaminants of flue gas (SO2, NO2, hydrocarbons and particulates) needs to be removed prior to capture as they will limit the ability of solvent to absorb CO2.

The integrated gasification combined cycle (IGCC) process for flue gas with higher concentration of CO2, goal is gasified to form a mixture of carbon monoxide (CO) and hydrogen (H2) called synthetic gas or syngas. To capture the CO2, syngas has to go an additional reaction with steam (in the presence of catalyst) to form a mixture of CO2 and H2. The solvents used in this physical absorption are selexol (dimethylene of polyethylene glycol) or rectisol (cold methanol). The absorbing capacity of these solvents increases with increased pressure while decreases with temperature. Also the regeneration of physical solvents is not energy intensive unlike chemical ones.

2.2 Oxyfuel or Pure oxygen Combustion

The best alternative to the absorption techniques is to combust fossil fuels in pure oxygen (contains 78% nitrogen by volume) instead of air. Once the nitrogen is removed from the process, flue gas streams would eventually have a higher concentration of CO2, thus eliminating the need for the costly CO2 capture. Moreover trace pollutants like NOX and SO2 can also be compressed and stored along with CO2 reducing overall pollutants. The only drawback to this method is that production of oxygen in an air separation is a costly affair altogether.

2.3 Potential for Carbon Capture

Of all industries 'Petroleum refining' is the single largest source of carbon emissions. It is most likely to incur slightly greater capture potential. In such processes the chemical absorption features to be the most promising method for CO2 capture. After Petroleum, 'Chemical Industries' has the largest potential for CO2 capture followed by 'Iron and Steel Manufacture' and 'Cement' industries. Natural gas also contains up to 20% of CO2 by volume which has to be sequestered to meet the pipeline quality of gas. For this MEA solvents were developed 70 years ago dedicated for this purpose.

3. Carbon-dioxide transportation and Storage

Now that the CO2 has been captured, cleaned and compressed it has to be transported and stored at a suitable safe location free from human interference. Several storage options are available, the most common being depleted oil and natural gas reservoirs, deep coal beds, saline aquifers and the ocean. Even though the estimated storage expenditure are small compared to capture the storage capacity and integrity, feasibility and the potential environmental implications if any are uncertain.

3.1 Transportation

Transportation through dedicated pipelines has been the most promising method so far for delivering captured CO2 to storage sites. Other methods of transportation includes barges or ships for ocean storage.

According to Block et al., 1997 investment cost *I* ($) for pipeline transportation is given by:

I = (190+955.d to power 0.9). L,

Where d = diameter of pipeline (m)

L = pipeline length (m)

3.2 Geologic Storage

The best possible method for CO2 storage have been geologic formation particularly depleted oil and gas reservoirs as environmental risks and uncertainties associated with geologic storage are much lower than ocean storage. The liquefied CO2 is transported and stored by EOR (Enhanced Oil Recovery) practicing companies for tertiary recovery by reducing the oil density and hence mobilizing the oil. Current research suggests that the storage of CO2 in depleted oil and gas reservoirs presents the least potential environment risk. This has already been tried and the sites have demonstrated their ability to store fluids (pressurized) for millions of years. However, environmental risks do exit as there may be chances of potential leakage of CO2 through fractures with possible contamination of ground water.

Apart from depleted oil and gas reservoirs deep aquifers represents a promising option in the long run. Also the transportation costs involved in aquifers is relatively less. There is uncertainty regarding the environmental effects of CO2 in aquifers but these implications can be mitigated by choosing suitable storage sites. Ideally aquifers will have an impermeable cap, preventing the release of injected CO2, but will have both high porosity and permeability below, allowing the injected CO2 to be distributed in uniform proportion. Such aquifers are saline and remains isolated from shallow freshwater aquifers and surface water supplies. In theory, there is still a very small chance of seepage into groundwater drinking supplies. Chemical reactions between CO2 and surrounding and the surrounding rock would eventually lead to formation of stable carbonates, in the process ensuring longer storage times.

Deep coal beds also provides huge potential for CO2 storage. The CO2 is injected into a coal seam and displaces fossil fuel methane adsorbed on the coal surface, allowing the recovery of methane and put to commercial utilization. However, this technology is still in its early stage of development.

3.3 Ocean Storage

Speaking in terms of capacity, the ocean will serve as the largest potential location for storage of captured CO2. Direct injection of the CO2 captured increases the acidity of the ocean but at such slower rate that it will allow marine organisms to adapt. Researchers and analysts affirm that injection at depth of 1000-1500 meters by means of a pipeline or say towed pipeline that would create a stream of CO2 to be adsorbed in the surrounding water. Another research states that if CO2 is injected at depths exceeding 3000 meters it exceeds the density of sea water and would sink to the ocean floor forming a stable isolated lake. Some even suggest that the blocks of dry ice could be dropped into the ocean and it would sink to depth ensuring long term storage. However, the refrigeration and compression are both costly. Transport distance and depth of injection are the two factors that guides cost and technical feasibility for ocean storage. The only issue regarding storage in oceans, as mentioned earlier is the increased acidity, though it must be noted that ocean eventually absorb around 90% of present atmospheric emissions thus leading to increased acidity. So, the direct injection of CO2 would only increase average acidity slightly more and would direct the CO2 at greater depths where is little or no marine life.

3.4 Other options

Excluding storage options mentioned above, there are some limited opportunities for direct economic use of captured CO2. Industries make use of CO2 for EOR, food processing and chemical industries. The CO2 utilized in these industries currently comes from natural formations, so if the captured CO2 is put to use then it would result in a net reduction of carbon emission.

ISSN 2229-5518

4. Summary

We, human are greatly contributing to the agglomeration of CO2 including other greenhouse gases in the atmosphere, primarily via unchecked combustion of fossil fuels. The significant wealth investments in fossil fuels and alternative sources of energy still at its early stages of development, it is certain that we are likely to be dependent on fossil fuels in for seeable future. Carbon capture and storage provides a better alternative in facilitating less costly reduction in carbon emission with the continued use of fossil fuels. Past experience with these techniques in oil, gas and other manufacturing industries has compelled that application to carbon mitigation is technically feasible. To further support the above statement, existing evidence too suggests that these technologies could be economically attractive under stringent climate policies. Unfortunately, a number of technical, environmental as well as political issues needs to be addressed which arise regard to transportation and storage of CO2. Even after overcoming these issues there is still dilemma regarding how much CO2 the reservoirs can hold, how long the injected CO2 will remain trapped, and whether they would pose any risk (leakage) whatsoever.

Given our likely reliance on fossils for many years to come, many view CCS technologies as a promising alternative to increasing energy efficiency and switching to less carbon intensive energy sources. CCS enables capture of CO2 from energy intensive industries viz. power plants, cement, iron and steel, chemicals and refining. These sectors emit significant proportions of carbon and are well suited large stationary sources of CO2 emissions. CCS involves storage in deep geologic zones like deep saline formations and depleted oil reservoirs. It is also deployed at commercial natural gas processing, fertilizers production, synfuel production and hydrogen production facilities.

Is it worth it? It certainly is. How do we know if we don’t try? We ought to implement large scale CCS commercialization with further improvisation in face of what we will lose through climate disruptions.

In sum, current time prospects appear to be the most promising for CCS. Therefore, it would see prudent for policymakers and analysts to seriously ponder and consider ‘Carbon Capture and Storage’ in the portfolio for fighting against global climate change as well as fuel switching to less carbon intensive energy sources. Diligent efforts are needed, however, for demonstrating the economic and technical feasibility of large scale CCS, as well as lowering the cost of CCS technologies, research on technical aspects and uncertainties in environmental effects.

5. References

[1] Anderson, Soren and Newel, Richard, “ Prospects of Carbon Capture and storage Technologies”, Resources for the future, RFF-DP 02-68, January 2003

[2] L. D. Danny Harvey, “Carbon-free Energy Supply ”, pg 389-424, Earthscan, UK ,2010