A Study of Combating Climate Change with Carbon Capture and Sequestration

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***Abstract*— Carbon Capture has been framed 25 years ago as a theoretical concept, but CCS as a green- house gas abatement method is a relatively new development. The International Energy Agency and the Carbon Sequestration Leadership Forum recognizes the role of CCS to bring about equilibrium in carbon cycle. It aims to bring about public acceptance for CCS. Although technology has been developed extensively for carbon capture much work is required to address numerous issues like – Monitoring of CO_2 behaviour underground and the leak potentials over ages. Engineering and economic factors also need to be restructured to find a remedy to high costs of the current technologies involved. A major hurdle is retrofitting the current power plants with CCS capabilities. Compared to coal fired power plants, gasification process enables easier and less costly capture of CO_2. The Petra Nova project which will be the world's largest carbon capture facility is being currently built. Such a project will serve as a benchmark to gain widespread acceptance and awareness for this technology. Carbon Capture and Sequestration does not serve as a silver bullet but it is a significant method to combat climate change. CCS along with developments in cleaner energy sources will enable the world to lead towards a balanced carbon system.**

***Index Terms*— Green-house gas, Enhanced Oil Recovery, Carbon Capture, Sequestration, Climate change**

I. Introduction

Global Warming has been the most contentious issue of the 21st century caused by anthropogenic Green House Gases. Reduction of such gases has been the aim of various research groups. Efforts have been made to develop alternatives to fossil fuels. Large number of green house gas emitting facilities will continue to exist for times to come. Political agreements reached through Global co-operation have been sought after the Kyoto Protocol which targets reduction of green house gases; carbon dioxide being one of them. Scientists claim water vapour is the most abundant green house gas, as it amplifies the effect of carbon dioxide, making carbon dioxide lethal to environment and ecology. According to recent data, 32% of the total CO_2 production is from power plants. China emits more CO_2 than the US and Canada put together. India is world's third biggest emitter of CO_2 pushing Russia to fourth [1].

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This unparalleled rise of CO_2 concentration in the atmosphere calls for the need to address the issue. Carbon Capture and Storage (CCS) is a series of technologies for CO_2 control that promises trapping up to 90% of the CO_2 emissions from power stations and industrial sites.

It collectively involves accumulating, transporting and burying the CO_2 such that it does not escape into the atmosphere and subsequently contribute to climate change. However, there much deliberation and research on the long-term consequences of CO_2 trapped underground is necessary. The high costs involved with CCS have proved to be a deterrent in its implementation. Researchers and policy makers are thus urged to make the technology cost effective considering its significant role in combating climate change.

II. Carbon and Climate Change

The Earth witnessed the last ice age with atmospheric CO_2 levels of being around 280 ppmv (parts per million by volume). CO_2 concentrations have been on a rise since then. The recent rise is shown in **Fig. 1**, collected by Keeling (1960) since 1958 (shown in blue) and expanded on the right-handgraph. Ensuing to rise in CO_2 levels, there has been a substantial increase in the mean global temperature. The nexus between elevated levels of CO_2 in the Earth's atmosphere and rising temperatures is well established. Earth radiates much of its heat energy in form of terrestrial radiation in the infrared region.

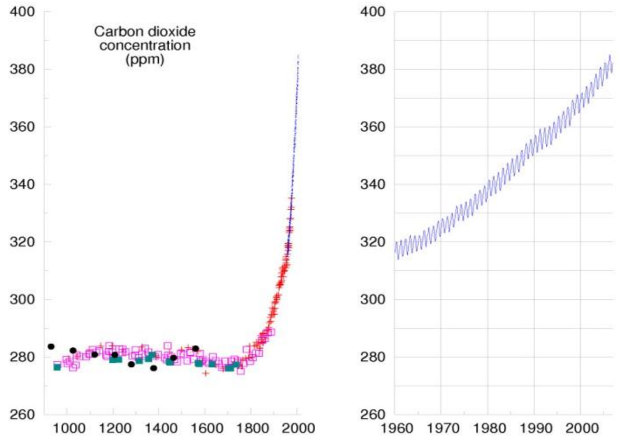

Figure 1[1]: Carbon dioxide Concentration rise

III. Soil Carbon Sequestration

Excretions and remains of plants and animals add carbon to soil on a continual basis. CO_2 is released from soil on an on-going basis, as microbes break down soil organic matter (SOM). Nature has a well an established carbon cycle.

[1]Keeling and Whorf (2005); Neftel et al (1994); Etheridge et al (1998); Siegenthaler et al (2005); Indermuhie et al (1999)

Equilibrium in soil is reached when inputs equal outputs. Ecosystems like forests control Earth's climate by adding and removing CO_2 from the atmosphere. These forests and grasslands which primarily form the earth's terrestrial ecosystems store much more carbon than what the atmosphere does [2]. CO_2 is thus kept out of the atmosphere, where it would contribute to climate change. Numerous plants and soil over time store carbon, thereby sequestering additional carbon. Thus aping the technique of nature, the high tech Carbon Capture and Storage aims to bring equilibrium in the Carbon cycle.

IV. Carbon dioxide Capture and Sequestration

Humanity is slowly moving into a Carbon constrained world. The technique of Carbon Capture and Sequestration (CCS) will help us to sustain the benefits of using hydrocarbons to generate energy. The use of fossil fuels will determine the future levels of atmospheric CO_2, and consequently the future levels of the associated global warming. Fossil fuels serve as a dominant and relatively inexpensive source of energy and will continue to be widely used for remainder of the century.

CO_2 is inevitably produced as long as fossil fuels are used; if we are to prevent this CO_2 reaching the atmosphere, Carbon Capture and Sequestration (CCS) will be absolutely essential. In a *Special Report on Carbon Dioxide Capture and Storage*, the International Panel on Climate Change (IPCC) recognized CCS as one of the tools that can be used to reduce GHG releases to the environment [3]. CCS can be considered a 'waste management strategy' for carbon dioxide. It does not reduce the production of CO_2, but it provides a reservoir to prevent it from destroying the environment.

CCS is a three-step process that includes:

- CO_2 capture from power plants or industrial production houses
- Transportation of the captured and compressed CO_2 (usually through pipelines).
- Injection of the gas and geologic sequestration (also referred to as storage) of the CO_2 into deep underground rock formations.

Injection is done 7000 feet into the earth below the impermeable, non-porous layers of rock that trap the CO_2 and prevent it from transferring upward.

Numerous commercial operations are currently storing CO_2 around the world.

- EnCana's project at Weyburn in Saskatchewan uses CO2 gas to enhance the recovery of oil. CO_2 derived from a gasification plant in North Dakota is injected into oil reservoirs to push it to the surface.
- In Salah saline formation project in Algeria [4].
- Sleipner project in the Norwegian North Sea (**Fig. 2**) of Statoil has successfully pumped more than 1 million tons of CO_2 per year for the last 10 years into the deep saline Utsira formation, which lies approximately 1000 m beneath the seabed and is capped by a low-permeability shale layer. CO_2 is pumped deep into saline formations and eventually the gas moves up until it reaches the impermeable shale level.

These locations are an international focus for research into how CO_2 can be stored and monitored underground.

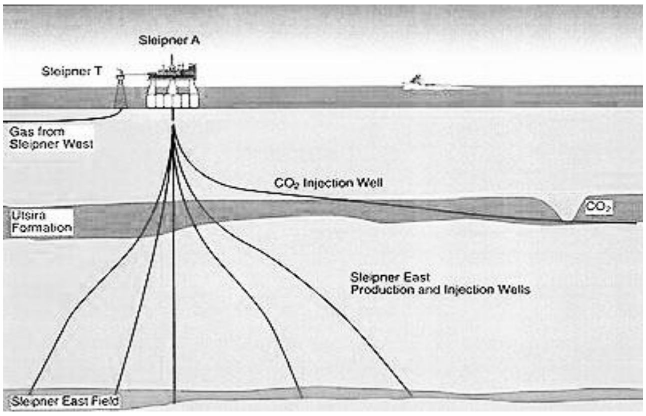

Figure 2: Schematic of Statoil's Sleipner CO2 Injection Project (Diagram courtesy SINTEF)

CCS when applied to a 500 MW coal-fired power plant, which emits roughly 3 million tons of CO_2 per year, [5] the amount of GHG emissions avoided (with a 90% reduction efficiency) is predicted to be equivalent to [6]:

- Planting more than 62 million trees, and waiting at least 10 years for them to grow.
- Avoiding annual electricity-related emissions from more than 300,000 homes.

V. Carbon dioxide Trapping

A. Post Combustion

CO_2 is separated from the flue gas of the power station by bubbling the gas through an absorber column packed with liquid solvents (monoethalomine) that preferentially take out the CO_2. The absorber column is regenerated by passing steam at around 150°. This releases the trapped CO_2, which can then be transported for storage elsewhere. Such an extraction process is inefficient and considerable energy is utilized for steam regeneration.

B. Oxyfuel

Burning of fossil fuels in normal air produces a mixture of flue gases. More energy is required to separate CO2 from such a mixture. An alternative method is to burn the fossil fuel in an atmosphere of pure oxygen. This way all waste gases will comprise of CO_2 and water vapour. Water vapour can be condensed and CO_2 can be piped or transported directly to a storage facility. In the oxyfuel system, the air fed into the boiler has to be separated into liquid oxygen, gaseous nitrogen, argon and other trace gases. There is still a considerable energy cost associated with the cryogenic separation to obtain pure oxygen atmosphere.

C. Pre Combustion

Coal-gasification combined cycle power plants involve gasification of coal to produce a synthetic gas made from carbon monoxide and hydrogen. The former is oxidized with water to produce CO_2, which is captured. The hydrogen is usually diverted to a turbine where it can be burned to produce electricity. This hydrogen can also be bled off and used a fuel. One disadvantage of the pre-combustion method is that it cannot be retro-fitted to the conventional coal power plants.

Such an extraction of the CO_2 from the pre-combustion stream is potentially more efficient than in the post-combustion case. The overall cost of capture would be reflected in an increase of the retail price of the electricity produced of about 20% [7].

Since these processes separate CO_2 with other components in the emissions and reduces the entropy, a certain amount of energy is required. The minimum energy required by the second law of thermodynamics is [8]

$$W_{min} - RT \left[X_{CO_2} \ln(X_{CO_2}) + X_{gas} \ln(X_{gas}) \right]$$

Where

X_{CO2} = Mole fraction of CO_2

X_{gas} = Mole fraction of other gases without CO_2

Thus it can be concluded that less energy is required for higher concentration of CO_2 in the emissions.

Considering the exorbitantly high energy consumption for separating CO_2 from air, CCS technologies evidently are only feasible when the CO_2 concentration in air is rackingly high. Energy required to separate CO_2 from emissions can be derived from the boilers in the power plants.

VI. Carbon dioxide Transportation

CO_2 can be transported by pipelines or ships. The density of CO_2 should be that of a liquid during transport [9] for maximum efficiency. Pipelines are usually very long and the transport temperature of CO_2 has to be close to ambient soil temperature, ranging from a few degrees below zero to 20 °C [10]. If the pressure of CO_2 is maintained over the critical pressure of 7.38 MPa, there will be no gaseous CO_2 in the pipeline from temperature fluctuations. Since CO_2 is corrosive, the risk of leaks may be greater than with other substances transported by pipeline. The gas must be dried to reduce the risk of corrosion. Local geological conditions play a crucial role to determine the piping costs.

For shipping, CO_2 is kept quite cold at reduced pressures. The temperature in that case is generally around -54 to -50 °C and the pressure is around 0.6 to 0.7 MPa [11].

VII. Storage of Carbon dioxide

Two locations have been found appropriate for storing CO2 – oceans and in geological structures beneath the Earth's surface. Sequestration in the oceans is troubled with political and technical problems. Geological sequestration involves pumping of supercritical CO_2 deep into aquifers. Spent oil and gas reservoirs are usually preferred as they are more docile. Spent hydrocarbon reservoirs provide capacity for hundreds of billions of tons of CO_2, while deep saline aquifers provide capacity for a hundred times this amount [11]. Due to the abundance in availability, CO_2 storage in saline aquifers is the most studied storage form.

The sedimentary rocks serve as the most suitable kind of CO_2 storage for spent oil and gas reservoirs. Their high porosity and permeability assist in the storage. This way CCS may thus also help to recover natural gas and oil reservoirs.

Evidence from modeling studies and observation of natural CO_2 reservoir suggest that the gas can be confined in geological reservoirs for time scales well in excess of 1000 years and that the risks of leakage from geological storage can be small [12].

VIII. Enhanced Oil Recovery (EOR)

CO_2 is injected into already developed oil fields where it mixes with and releases the oil from the formation, thereby freeing it to move to production wells. CO_2 that emerges with the oil is separated in above-ground facilities and re-injected into the formation. CO_2-EOR projects are essentially a closed-loop system where the CO_2 is injected, produces oil, is stored in the formation, or is recycled back into the injection well.

The gas is primarily used as an injectant, which changes the properties of crude oil and allow it to flow more freely within the reservoir. The gas detaches the oil from the rock surfaces, and causes it to flow more freely within the reservoir to producer wells. CO_2-EOR typically produces between 4-15 percent of the original oil in place. [13].

CO_2-EOR provides a laboratory for observation, testing, scaling and modeling of technologies required for routine sequestration that is driven by the commercial incentive to improve recovery of the oil from older reservoirs. Moreover, in a world where CO_2 is much more readily and cheaply available, there will be an encouragement to use CO_2 earlier in the oil-recovery stage to better exploit diminishing resources.

Enhanced Oil Recovery provides for economic incentive to implement CCS technologies with the added benefits of greater yield of oil extraction.

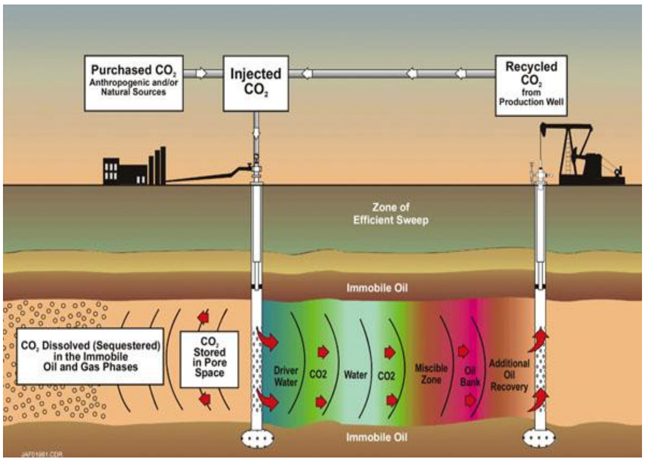

Figure 3[2]: Enhanced Oil Recovery

IX. Petra Nova Carbon Capture Project

A commercial scale post-combustion carbon capture and sequestration (CCS) project is being developed at NRG Energy's WA Parish coal-fired Generating Station. It is one of

[2] Source: Advanced Resources International and Melzer Consulting, Optimization of CO2, Storage in CO2, EOR Projects, Prepared by UK Dept. of Energy and Climate Change, November 2010.

the ten biggest power stations in the US. The plant is located in Thompsons, Fort Bend County. The WA Parish CCS project is also known as the Petra Nova Carbon Capture Project. It is estimated that it will capture 90% of the carbon dioxide (CO_2) from a 240MW stream of flue gas from the power station's existing 610MW coal-fired unit. Approximately 1.6 million tons of CO_2 will be pumped each year. Carbon dioxide will be purified and compressed into a liquid to be piped 80 miles away to the West Ranch Oil Field for enhanced oil recovery (EOR). The Petra Nova Project will eventually be the world's largest carbon capture facility [14].

The Petra Nova system will collect carbon dioxide using gas absorption with help of amines. Petra Nova captures carbon dioxide to help people mine ever more oil, which creates its own emissions once it's burned to make electricity. EOR will be able to recover an estimated 60 billion barrels of oil from the field. The Petra Nova CCS project is expected to boost the field's production from 500 barrels per day (bpd) to 15,000 bpd.

The project's carbon capture capacity is expected to be 4,776 tonnes per day [15]. A cogeneration plant consisting of a combustion turbine and a heat recovery boiler will provide the thermal energy required for the CO_2 capture and compression system's operation.

X. Leakage Risks

There exist potential risks in pipeline transportation of carbon dioxide gas as well as in geological storage.

Cracks and crevices in geological storage volume can leak the gas into upper formations. The subsequent migration of the released CO_2 will then be determined by the permeability of these overlying formations. Further injection of CO_2 may increase the failure intensity leading to migration of CO_2 with the flow of brine to locations where it can escape to the atmosphere or to a body of water. CO_2 entering water bodies can have severe environmental consequences, as the gas makes water acidic. Furthermore it may also dissolve hazardous constituents such as Arsenic and lead from minerals into the water bodies. The injection sites are thus chosen in which the geological formations provide several seals, consisting of shale with very low permeability, over the reservoir [16]. The risks potentially increase many fold if CO_2 is co-sequestered with other hazardous gas such as H_2S and SO_2, since they are more poisonous and caustic in solution.

A critical aspect of CO_2 storage is thus the monitoring of these possible processes.

XI. Conclusions

Carbon Capture and Sequestration is a promising technology to combat climate change. Coal Gasification and Pre-combustion techniques will prove to be a boon for CCS. With implementation of projects like Petra Nova, widespread recognition and awareness is required. Policy makers and researchers need to work in synergy to promote CCS. Critics point at the high risks and high costs pertaining CCS, but man will otherwise pay a greater price in form of ecological collapse if balance is not restored.

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