

Carbon Capture and Storage (Sequestration) on Coal Deposits and Related Risk Management

Raghav Nayyar¹, Meha Jain² Pranav Khurana³ Manish Kumar Ojha⁴

¹ Department of Mechanical Engineering, Amity University, Noida

² Department of Mechanical Engineering, Amity University, Noida

³ Department of Mechanical Engineering, Amity University, Noida

⁴ Department of Mechanical Engineering, Amity University, Noida

Abstract:

Carbon sequestration is a way to reduce greenhouse gas emissions. It complements two other major approaches for greenhouse gas reduction, namely improving energy efficiency and increasing use of non-carbon energy sources. Interest has been increasing in the carbon sequestration option because it is very compatible with the large energy production and delivery infrastructure now in place. There are two primary types of carbon sequestration. One program focuses on carbon dioxide capture and storage, where carbon dioxide is captured at its source and subsequently stored in non-atmospheric reservoirs. This is called Geological Sequestration of Carbon. The other type of carbon sequestration focuses on enhancing natural processes to increase the removal of carbon from the atmosphere called Terrestrial Storage Processes. In our project we are going to focus on Geological Carbon Sequestration where capture and storage of carbon dioxide (CO₂) is done over a long period. Our emphasis will be primarily on the capture by adsorption on rocks and underground storage in reservoirs. On analysis of the risk associated with this method, it is found that there are some serious risks involved which cannot be ignored such as blowouts and triggering of earthquakes. However, the government of India has been working on various projects based on sequestration since 2007. Based on their data we can conclude that sequestration of carbon components has been successful and can be used efficiently in India towards the aim of reducing the effect of greenhouse gas emissions. This would thereby help control global warming.

1. INTRODUCTION

Bachu et al. define carbon sequestration as "The capture of CO₂ directly from anthropogenic sources and disposing of it deep into the ground for geologically significant periods of time"[1]. Carbon capture and storage can be done through various methods such as power generation from fossil fuels, production of ammonia and purification of natural gas.

Greenhouse gas emissions play key role in warming up the Earth's atmosphere. Highly toxic greenhouse gases are emitted by all sorts of industrial processes and combustion of countless types and mixtures of fuels. Also, natural phenomena, agriculture, live-stock emit greenhouse gases. Carbon emissions take place in all processes, whether they are biological or industrial. Even computation leads to Carbon emissions. An introduction to how the process of global warming works is given as follows. The solar radiations which have very high temperature and low wavelength enter the earth's atmosphere and the earth being relatively cooler, releases long wavelength radiation. The effect of solar radiations is such that they are absorbed by the Earth's atmosphere (water vapor, carbon constituents etc.). This phenomena warms up the Earth which is known as Global Warming. This phenomenon, for researchers and other organizations, has been an intense topic of research and discussions all over the world for several decades.CO₂,

which is human-induced is a major cause of global warming. From literature study, we have observed that CH₄ emissions and NO emissions trap more solar energy than Carbon constituents. In this study, the main focus will be geological sequestration of carbon, specifically in un-mineable coal seams. The following data shows a worldwide scenario of the total CO₂emissions.

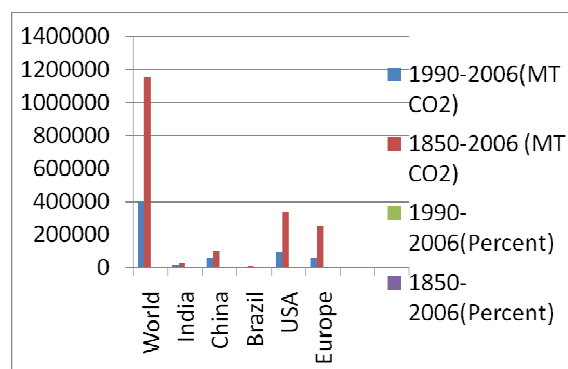


Fig. 1: Energy-related Cumulative CO₂Emissions up to 2006 (Source: Planning Commission interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth, page 8)

The next two charts will show greenhouse gas emissions in India.

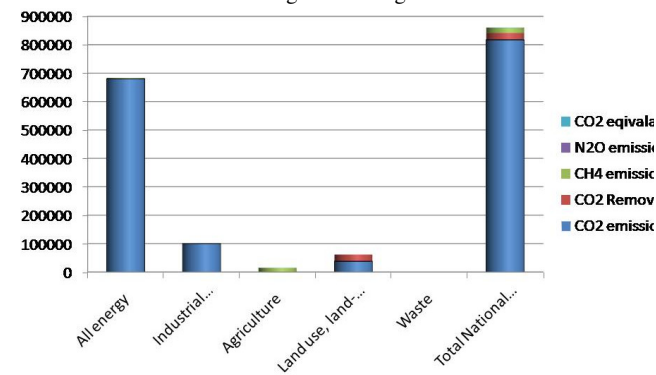


Fig. 2: Greenhouse Gas emissions from sources and sinks in India-1994 (Source: NATCOM-I, 2004)

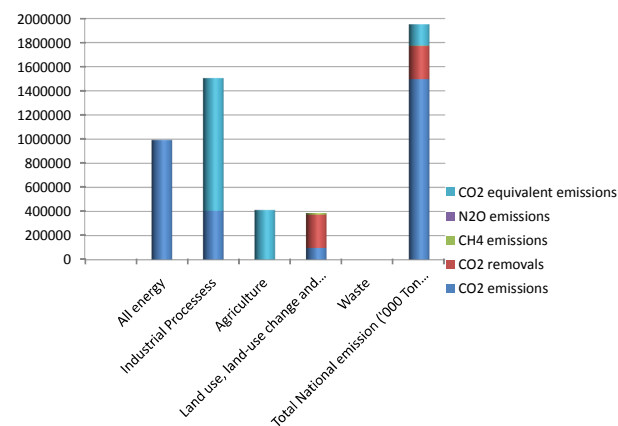


Fig. 3: Greenhouse Gas emissions from sources and sinks in India-2007 (Source: India-Greenhouse Gas emission 2007, Ministry of Environment, Forest and Climate Change)

From Figure 2 and 3 we can observe that there is a significant increase in Greenhouse gas emissions from 1994 to 2007. Maximum increasing factor is due to growth in industry. The overall energy production and release has also increased due to increasing demand for which there is a continuous supply. Geological sequestration comes under advanced techniques. Other storage techniques that can be used for geological storage are deep saline aquifers, salt domes, salt formations, depleted CO₂ domes, hydrocarbon-containing shales, and depleting natural gas formations that have the potential to produce value-added byproducts.

Carbon capture and storage prevents the release of CO₂ into the atmosphere. Up to 90% effectivity has been recorded from sites combustion of fossil fuels are used in electricity generation and other industrial processes. [21]

Natural Sources of CO₂

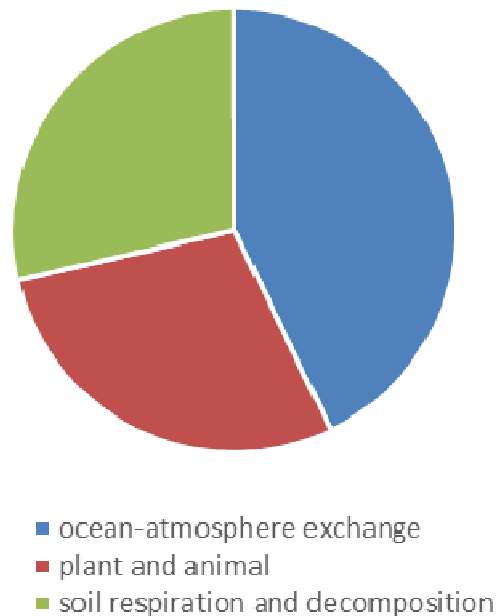


Fig. 4: Natural Sources of CO₂ in India

CO₂ emission from fossil fuel

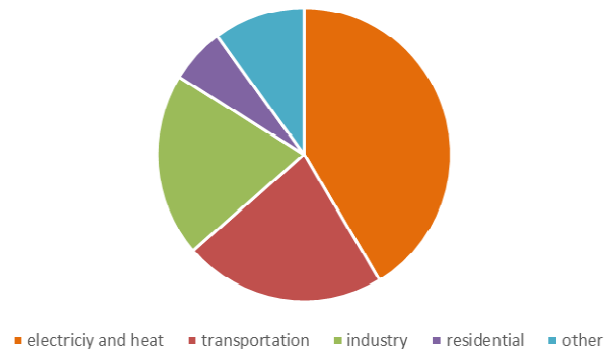


Fig. 5: CO₂ emission from fossil fuel

sources of carbon emission

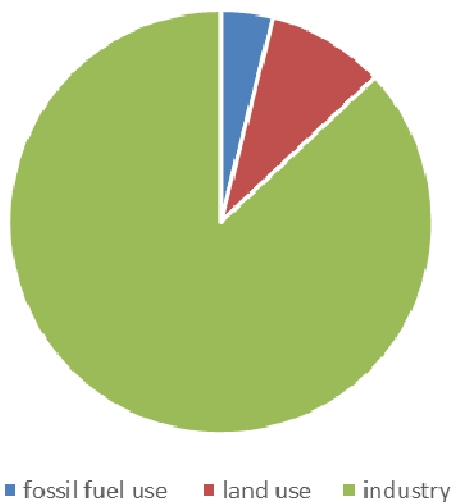


Fig. 6: Sources of Carbon Emission

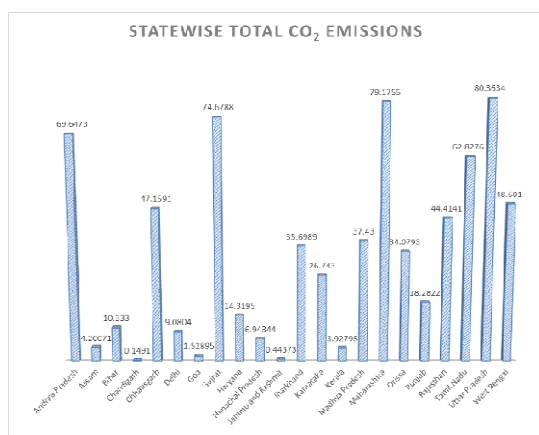


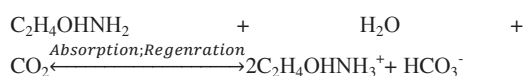
Fig.7: State wise total CO₂ emissions

2. STAGES OF GEOLOGICAL CARBON SEQUESTRATION

The process of Carbon Capture and Storage (CCS) involves three steps:

1. Capture- Capture of CO₂ from various sources which emit CO₂ in large amounts (industries, power plants, etc.)
2. Transport-Pipelines are majorly used in transporting the CO₂ captured to the distant storage sites.
3. Storage-Common storage sites are depleted oil/gas fields, un-mineable coal seams or Enhanced Oil Recovery (EOR) sites.

The processes involved in power plants and other industries are predominantly combustion and processing of fossil fuels which produce large quantities of CO₂ along with other by-products. The procedure that follows, currently, is the release of the CO₂ into the atmosphere and these add to the constituents of the greenhouse gases. By the process of CCS the potential greenhouse gas, CO₂, is captured and stored for a period of time that should essentially exceed the estimated peak periods of fossil fuel exploitation [6, 8]. The CCS process has three distinct elements. First, the emitted CO₂ is captured from industrial utility and compressed either in supercritical form or sub-cooled liquid form for underground storage. The captured CO₂ is transported via pipeline or ships to the storage site and injected into geological sites such as deep saline aquifers, depleted oil and gas fields and un-mineable coal seams. The process of transportation can also be done through an industrial process that permanently fixates the CO₂ into inorganic carbonates using chemical reactions for industrial use or production of carbon compounds and chemicals. An example is a reversible chemical absorption process using Monoethanolamine (MEA) as absorbent [6, 8].



Absorption process: left to right

Regeneration process: right to left

The objective of CCS Technology are:

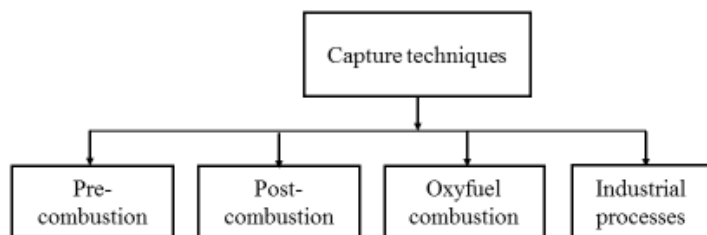
- Improving power plant efficiency to diminish capture technology's load.
- Capturing (isolating or separating) the CO₂ produced in combustion from streams of gas.
- Transportation of captured CO₂ to sub-surface storage.
- Storing CO₂ underground in geologically suitable sites (Example: Oil/Gas or Coal reservoirs).

Thus the CCS, technology aims at reducing CO₂ percentage in the atmosphere by storing the CO₂ produced by the fossil fuel fired plants in secure sinks at affordable prices for hundreds of years.

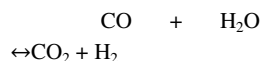
2.1. CAPTURE AND COMPRESSION

The capturing of GHGs is an old concept and has been used for several years for various reasons. The process of carbon capture focuses on the isolation of CO₂ from the power plant's flue or gas stream. The CO₂ is separated, under precise thermodynamic conditions, by preferential absorption/adsorption on a media and then later parting the media and CO₂. There are many other separation processes like cryogenic distillation and use of catalysts and membranes. The tangible cost sustained in the capture process is the maximum [9].

Pulverized-coal plants were commonly used in the early 2000's where coal is burnt to produce high pressure steam which in turn runs a turbine to generate electricity. This is done by heating coal in air which is generated and preheated by the flue gas. So, the carbon capture in the form of carbon dioxide gas takes place in between different paths of flue gas processing. A typical 500-MWe PC-fired power plant emits approximately 10,000 –12,000 t of CO₂ per day [10]. The CO₂ concentration in the flue gas from such a power system is near 4% by volume. This approach appears to be preferable when CO₂ recovery is desired. Capture of CO₂ may be performed by any of the four methods:



1. Pre-combustion capture: Fuel reacts with O₂ or steam to produce a mixture of CO and H₂. CO when catalytically reacted with steam gives CO₂ along with some H₂. This is ensured by obtaining equilibrium in the 'water-gas shift' reaction[11]-



The catalyst is called shift converter. CO₂ is then removed by absorption (physically or chemically) [12].

2. Post-combustion capture: Fuel (biomass and fossil fuels) is combusted in air. The flue gases directed to

a separator where CO₂ is separated. The remaining flue gas is released.

3. Oxy-fuel combustion capture: Pure O₂ used for combustion resulting in CO₂ and H₂O rich flue gas.
4. Industrial processes capture: In natural gas purification, steel and cement industry, etc. CO₂ is produced and captured as a part of the production process. Separating processes are same as those for other techniques.

2.2. TRANSPORTATION

After capturing and separating the CO₂, the process of transportation begins. Transportation is the process of receiving the captured CO₂ from capture site and safely deliver it to the geological storage site. In some cases it may also be transported to an EOR/EGR site. During transportation, CO₂ can be transported in gaseous, liquid or solid state depending upon the capacity and capability of the transport. For transport of carbon dioxide in liquid and gaseous states, usually tankers, pipelines and ships are used. While there can be many other means for transportation, the use of ships (off shore), pipelines (on and off shore) or a combination of both are considered economically viable as compared to tankers due to the problem of leakage which may occur on account of improper isolation of the tanks[13]. There are certain parameters which need to be kept within the prescribed limits to transport the CO₂ without any mishaps. At near atmospheric pressure, gas occupies large volumes. This requires respectively large transport facilities. To avoid this, the gas is compressed to reduce its volume during transportation (especially by pipelines). Reduction of volume can be achieved by other processes such as liquefaction, solidification or hydration. **Liquefaction** is already being used in transport of LNG/LPG. Since CO₂ transportation conditions are alike to LNG it can also undergo the same process of transportation and therefore is consistent [14]. **Solidification** process, from the viewpoint of economy and energy, is mediocre. In case of dry CO₂ (<10ppm of H₂O), carbon steel can be used to avoid hydrate crystallization and also reduce transportation cost [15].

2.2.1. Pipeline Transportation System

Pipeline transport of carbon dioxide is found to be the most practical of all other means of transport [16]. Usually, CO₂ is transported via pipelines from the capture site to the storage site. It is a fact that CO₂ can be transported by pipelines efficiently in supercritical fluid state, which is obtained by compressing and cooling the CO₂. This state is characterized by the fluid exhibiting the density of a liquid whereas occupying volume as a

gas. If this process is not applied then the CO₂ has to be transported in gaseous state. This requires pipelines with large values of diameter. Also there would be an increased pressure drop per unit length [17]. The supercritical fluid state for CO₂ occurs at conditions greater than the supercritical pressure and temperature- 7.38MPa (73.8 bar) and approximately 31°C Centigrade [9]. From literature study [9, 12], the lowest pressure that is permissible at outlet of pipeline is 10.3MPa (to prevent two-phase flow). Supercritical state allows the fluid to possess enhanced vapour-liquid properties such as low viscosities and high diffusivities [9]. Parikh gave the following characteristics CO₂ (fluid phase) at supercritical stage: [9]

- (i) Critical Temperature = 304.2 K
- (ii) Critical Pressure = 73.8 bar
- (iii) Vapour Pressure at 20° C = 57.258 bar
- (iv) CO₂(gas phase) Density at 0° C = 1.9767 Kg/m³
- (v) Critical Density = 468 Kg/ m³

There are several other concerns regarding the efficiency and safety of transportation of supercritical CO₂. Impurities present may cause inefficiency and even disintegrate the lining of the pipeline, if they chemically react. Certain processing is carried out to remove these impurities before transport. The commonly found impurities include water vapour, H₂S, N₂, hydrocarbons, O₂, mercury, etc. [9]. Formation of carbonic acid takes place if CO₂ reacts with H₂O. To prevent this, dehydration (up to <50ppm of H₂O) process is performed [12]. Dehydration ensures that H₂S does not react with water to give Sulphuric acid which degrades the pipeline. It may lead to leaks due to pipeline cracking [9]. Methane disrupts the vapour pressure of carbon dioxide and reduces ease of flow. For EOR sites, the tolerance of organic matter is only in traces (10ppm) [9]. Converting the CO₂ into its supercritical state requires significant amount of energy. Also the control and management of supercritical CO₂ is a matter of concern for engineers [9].

2.2.2. Marine Transportation System:

Marine transportation system comprises of cycles of ship transport, temporary storage and loading facilities. The need for a temporary storage comes into play due to inconsistency in ship movement whereas the carbon capture process is continuous. The loading facility performs the task of loading CO₂ from temporary storage onto the ship.

Operations involved in marine transportation system are: [12]

1. Loading: Transfer of CO₂ from temporary storage on to the ship.
2. Transport to the site: Ships with specially designed tanks are used to transport the CO₂ to the sequestration site.
3. Unloading: At the site of geological sequestration the liquid CO₂ is unloaded.
4. Return to port: The ship after completing its task returns back to the port for another cycle of transportation.
5. Risk, safety and monitoring: The estimated risks are handled while also maintaining the legal safety guidelines.

Currently, there are several ships used for the transport of liquefied food-grade CO₂. But the transport of CO₂ by ships for sequestration purposes is a developing area. There are only four small ships being used for this at present [9].

Tank structures in transport ships are of three types: [9, 12]

- 1) Pressure type: Does not allow gas to boil under ambient air conditions.
- 2) Low temperature type: Engineered to be able to perform at low temperatures.
- 3) Semi-refrigerated type: Many of the existing carriers are of this type. Designed to maintain the gas in liquid state. When transporting 22,000 m³ of LPG, operating conditions are - 50°C and 7 bar [12].

Leakage of carbon dioxide during its transport is a major issue. The total losses range between 3-4% per 1000 km which can be reduced to 1-2% by on shore recapture [9]. Besides this there are other risks in transportation of CO₂ by ships such as failure by collisions, storms or aquatic life activity [12].

2.3. STORAGE

The first step towards storage of carbon is by capturing it from various anthropogenic sources [1]. White et al. define coal seam sequestration as "the storage of CO₂ from anthropogenic sources in deep un-mineable coal seams for geologically significant times with or without the concomitant recovery of natural gas"[2]. Current "Clean Coal technology" is focusing on production of hydrogen from water and storing the by-product, carbon dioxide gas and burning the rest of hydrogen [3]. However, over the years, carbon sequestration in coal beds has been found to be expensive and so the main challenge is to reduce its costs so as to make it economically feasible on a global scale. Reeves considered gassy coals in North America, Australia, and India to have a combined CO₂ adsorption capacity of 37.8Gt of Carbon dioxide [4]. There are various methods

which can be adopted to sequester carbon in coal seams. Carbon sequestration in coal beds has increasingly been seen as an efficient way of methane capture from coal seams. Separation of carbon dioxide from methane in natural gas wells has been in use over many years and has proven to be well effective and efficient. Hot potassium carbonate is another energy extensive process with a demerit of requiring a large plant [3]. Other processes include Monoethanolamine (MAE) process, amine scrubbing and other membrane processes. An Initial Set of Working Hypotheses Concerning Some Chemical, Physical, and Thermodynamic Events That Occur When CO₂ Is Injected into a Coal-bed includes the following[3]:(1) The transition temperature of the coal will reduce during sequestration of carbon and the coal will become plasticized due to sudden change in temperature and PH of the coal bed. (2)Due to plasticization, the rate of diffusivity will increase and so, both liquid and supercritical CO₂ moving through a coal-bed will extract small molecules trapped within the macromolecular network. This will also lead to homogenous solution of minerals in coal with water, (if both water and high-pressure CO₂ are present together in the coal). (3) Injection of dry CO₂ will dry the coal channel, especially where CO₂ flow rate is highest. This will create a pressure, temperature, and pH gradient across the coal-bed from injection well to the recovery well. The temperature gradient is caused by Joule-Thompson cooling. (4)When dissolved minerals and organics reach areas of the seam with lower pressure, they will precipitate, clogging the coal's pores. Larsen et al. studied and examined that the organic portion of the coal is thought to capture CO via surface adsorption, pore-filling, and solid solution. Less recognized is the possibility that the mineral phases present in the coal may assist via mineral carbonate formation. Thus, the nature of the coal seam itself is an important variable to be considered [5].

3. RISK ASSESSMENT

3.1. Advantages and disadvantages of major CO₂ capture technologies

Post combustion capture advantages

- Can be retrofitted to existing plants permitting the continued operation of valuable resources in either new build or retrofit application. It enables the continued deployment of the well-established Pulverized Coal (PC) technology familiar to power industries worldwide.
- The continuing development of improved materials for ultra-supercritical (USC) plants can increase the potency and scale back the carbonic acid gas emissions of future PC plants. This growth of R&D on improved

sorbents and capture equipment should lower the energy penalty of PCC capturing.

Sub-scale demonstration of PCC is proceeding. One such example of industrial process which was planned to be in use by 2014 is the 110 MW Boundary Dam project of Canadian province Power with PCC using the Cansolv method[23].

Post combustion capture challenges

- Amine processes are commercially out there at comparatively little scale and considerable re-engineering and scale-up is required.
- The addition of capture with current alkane technologies leads to a loss of gross power output of about half-hour and a discount of about eleven share points in potency. Within the case of retrofit this is able to imply the necessity for replacement power to form up for the loss.
- Most sorbent materials want terribly pure flue gas to attenuate sorbent usage and value. Usually 10ppm or as low as 1ppm of SO₂ and NO₂ is needed looking on the actual sorbent material.
- Steam extraction for solvent regeneration reduces flow to low-pressure rotary engine with important operational impact on its potency and switch down capability.
- Water use is increased considerably with the addition of PCC particularly for water cooled plants wherever the water consumption with capture is doubled per gross MWh. For air cooling the water consumption is additionally enhanced with capture by regarding thirty fifth per gross MWh.
- Plot space necessities are important. The back-end at existing plants is usually already packed by alternative emission management instrumentation. Additional prices could also be needed to accommodate PCC at some additional remote location [23].

Pre combustion capture advantages

- Pre combustion capture using the water-gas shift reaction and removal of the CO₂ with AGR processes is commercially practiced worldwide.
- Pre combustion capture of the CO₂ stressed incurs less of an energy penalty (~20%) than current PCC technology (~30%) at ninetieth CO₂ capture.
- Ongoing R&D on improved CO shift catalysts, higher temperature gas close up and membrane separation technology for H and CO₂, has the potential to supply a

step-change reduction within the energy penalty of capture

- Water use has reduced with use of PCC
- The current continued development of a larger and more economical gas turbines can markedly improve the potency of future INTEGRATED GASIFICATION COMBINED CYCLE plants
- The Kemper County plant in Mississippi, an INTEGRATED GASIFICATION COMBINED CYCLE plant with pre combustion capture, is below construction with planned operation in 2014 [23].

Pre combustion capture challenges

- While the energy loss with addition of pre-combustion capture is below with the addition of PCC the energy loss continues to be significant
- The industrial demonstration of enormous F or G gas turbines firing H has however to be demonstrated in an Integrated Gasification Combined Cycle plant with capture
- In the event of a requirement to vent the CO₂, additional purification is also required
- Integrated Gasification Combined Cycle isn't yet terribly widely used in the power industry
- The capital prices of Integrated Gasification Combined Cycle without capture are much higher than SCPC without capture. The Integrated Gasification Combined Cycle prices ought to be reduced to contend more effectively [23].

Oxy combustion advantages

- Oxy-combustion power plants ought to be able to deploy standards, well-developed, high potency steam cycles without the need to get rid of significant quantities of steam from the cycle for greenhouse gas capture.
- The additional method instrumentality consists for the most part of rotating instrumentation and heat exchangers; equipment acquainted to station owners and operators. (No chemical operations or significant on-site chemical inventory).
- Ultra-low emissions of standard pollutants are often achieved largely as a fortuitous result of the greenhouse gas purification process.
- On a value per metric weight unit greenhouse gas captured basis, it ought to be attainable to attain more than 98% greenhouse gas capture at an incrementally lower value than achieving a baseline ninetieth greenhouse gas capture.

- Development of chemical combustion with advanced ultra-supercritical steam cycles may lead to an oxy-combustion station (with greenhouse gas capture) that has higher potency than air-fired power plants being engineered nowadays (without greenhouse gas capture).

- The best advancement seen is that oxy-combustion with greenhouse gas capture has little or no competition with pre- and post-combustion greenhouse gas capture [23].

Oxy combustion challenges

- It isn't potential to develop sub-scale oxy-combustion technology at existing power plants. An oxy-combustion powerhouse is an integrated plant and oxy-combustion technology development would require commitment of the entire powerhouse to the technology. Thus, the technology development path for oxy-combustion could also be a lot expensive than that for either pre-combustion or post-combustion capture which might be developed on slip streams of existing plants.
- The auxiliary power related to air compression refrigerant air separation unit and greenhouse gas compression within the greenhouse gas purification unit can scale back gross plant output by up to twenty fifth compared to an air fired powerhouse with constant gross capability (without greenhouse gas capture).
- There is not any geologic or regulative agreement on what purity levels are going to be needed for greenhouse gas compression, transportation and storage. For this reason, most oxy-combustion plant styles embrace a partial condensation greenhouse gas purification system to provide greenhouse gas with purity admire that achieved by alkane post combustion capture. Oxy-combustion prices could also be reduced if the purity needs may be relaxed.
- Air-fired combustion is usually anticipated for start-up of oxy-combustion power plants. The terribly low emissions achieved by oxy-combustion with greenhouse gas purification cannot be achieved throughout air-fired start-up operations while not specific flue gas qc for air-fired operations that area unit redundant throughout steady state oxy-fired operations. If a big variety of annual restarts area unit

such, either these supplemental flue gas qc are going to be needed (at extra capital cost) or provisions should be created to begin up and pack up the unit solely with oxy-firing and while not emanation vital amounts of flue gas.

- Plot house needs area unit vital for the air separation unit and greenhouse gas purification units. [23]

3.2. Enhanced Oil Recovery

Though not a process of sequestering CO₂, Enhanced Oil Recovery (EOR) is a process by which the oil (or gas in case of Enhanced Gas Recovery) trapped in rocks and cracks in reservoirs can be successfully recovered by injecting pressurised CO₂. For EOR purposes, it is preferred to have low N₂ content [12]. The process of EOR also enhances the quality and rate of oil production by the reservoir [9]. Primary production recovers 5–40% of the oil in the reservoir [18]. The additional 10–20% is recovered by water flooding (secondary recovery) [19–20]. Studies for carrying out CO₂-EOR in India is under progress in mature oil fields [7].

3.2.1. Operational Risks in CO₂-EOR

- Pipeline Accidents
- Well Blowouts
- Induced Earthquakes
- Seal Leakage
- Earthquake Rupture of Reservoir
- Groundwater Contamination

Holloway[24] advised that risks associated with the “transport and injection of carbon dioxide” are square measure “reasonably well understood and already borne by the improved oil recovery trade within the USA”. This conclusion was supported by Heinrich et al. [26] who noted that such risks are “successfully managed” for many years within the context of economic EOR operations. Equally The First State Figueiredo [25] has declared that the risks related to CO₂ injection into a brine reservoir has been “successfully managed” for many years in EOR operations. Recently this conclusion has been echoed by Guard et al. [24], declaring that “Operational liability [for CO₂ sequestration in brine reservoirs] is comparable to it already proscribed within the oil and gas trade and so few new problems ought to arise once applied to CCS”. Though the assertions of those authors may be correct there square measure very little revealed knowledge or analysis to support them. In reality Little Mo Connolly [25] has declared that “There is comparatively very little expertise worldwide in managing the risks related to CO₂,

compared with oil and gas”. One major issue studied by many is the issue of induced earthquakes due to CO₂ injection underground.

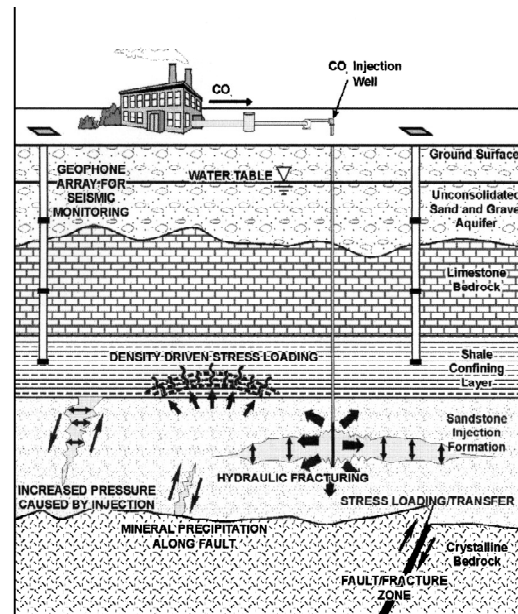


Fig. 8: A conceptual model of phenomena associated with inducing seismicity through underground injection wells [30]

Gale and Davidson have advised that the transportation of CO₂ pipeline is analogous to it of fossil fuel transport. They co-jointly counsel that the accident rate for CO₂ pipelines is comparable to it for fossil fuel pipelines, the quantity of damages related to incidents for fossil fuel pipelines is far more than for CO₂ pipelines. Considerably no serious injuries or deaths are caused by accidents related to CO₂ pipelines. Within the Permian Basin pipeline advanced the accident records started within the mid-1970s. Svensson et al. Have advised that applied math knowledge on pipeline safety for CO₂ pipelines utilized by the CO₂-EOR trade demonstrate that the risks for pipeline run “are not up to for fossil fuel or dangerous pipelines”. Dramatist et al. noted that the CO₂ pipelines represent a smaller applied math sample compared to fossil fuel pipelines [24].

3.2.2. CO₂ Well Blowouts

The blowout of a well happens once the operator of the well loses management of the pressure within the well leading to fluid effuse of the well. Damen et al. [26] have instructed that the most important risk related to dioxide injection for sequestration in deep brine reservoirs is well failure. Such failures result from a failure to adequately management pressures within the injection system. This can be generally as a result of mechanical failure of a part or associate degree external event directly moving the well. This leads to temporary loss of management of the method

and therefore the pressure of the reservoir drives dioxide and alternative entrained fluids upwards out of the well. Four varieties of blowouts have occurred related to CO₂-EOR activities:

1. Blowouts of production wells trained into natural dioxide reservoirs.
2. Blowouts of dioxide injection wells.
3. Blowouts of active boring wells that are associated with the degree integral, which is a part of the CO₂-EOR project.
4. Blowouts of inactive or blocked and abandoned wells inside the realm of raised pressure related to dioxide injection wells

In the USA expertise with dioxide well blowouts is copied back to March, 1982, once a blowout occurred within the Sheep Mountain dioxide field (one of 3 massive natural reservoirs of dioxide serving the Permian Basin's EOR activities), settled within the plateau space of southern Colorado. During this context, a well blowout happens once the drilling crew fails to contain the belowground pressure. In most cases blowouts are caused by mechanical failures on the far side human management, for instance the failure of a back-flow preventer. This loss of containment in real time leads to the pressure unharness vaporizing the super essential dioxide.

In this context a blowout is driven by the high growth ability of the free gas leading to a full of life eruption of the vapor up the well bore (with the probably entrainment of particles of solid debris). If this happens throughout drilling into a dioxide reservoir the pace of this development might create it a challenge to activate manual Blowout hindrance devices (BOPs) in time to stop a blowout. Adiabatic cooling of dioxide throughout this speedy growth ends up in the gas being cooled below the purpose melting point temperature} (the triple point for dioxide being at -63°F and seventy six psi). This leads to the nucleation of solid and/or solid ice-like CO₂-hydrates. These solids may result in an exceedingly blowout turning into a sprig of solid particles. Such icy particles may injury pipes and alternative infrastructure within the path of the spraying particles. Whether or not this development is a smaller amount risky than the dioxide erupting as a fountain of dense dioxide remains to be determined. If a lot of the dioxide in an exceedingly massive blowout is in an exceedingly frozen kind then the risks display by the initial blowout to the native are in all probability lowered.

The blowout at the Sheep Mountain Field occurred March 17-April three, 1982, throughout the drilling of a dioxide production well on the west slope of very little Sheep Mountain (Lynch, et al. [26]). The reservoir containing the dioxide is at depths of one thousand to 1800m depth in sand stones of Cretaceous and Jurassic period age, sealed by fine grained marine sediments of Cretaceous age (Allis et al.[12]). A contractor known as in to "kill" the blowout ab initio had issues associated with the high flow of dioxide (estimated at two hundred million normal cube-shaped feet/day) out of the well. The dioxide was

processing out the brine-based "kill fluid" (and nut trained lubricant and debris). The well came in restraint consecutive month through the injection of drag-reduced brine followed by mud (Lynch, et al. [11]). The trade currently has associate degree raised understanding of handling dioxide wells.

- Blowouts of boring wells inside CO₂-EOR reservoirs are a better-known hazard (Lynch et al. [27]; In 2003, Skinner paper in "World Oil" specializing in blowouts within the dioxide-EOR trade within the USA instructed that there had been an "increased frequency of CO₂ blowouts in injection projects". Four of the 5 blowouts given within the case studies of Skinner [27] occurred throughout remedy (or work-overs) of wells. Well work-overs are normally done to use pre-existing wells to be used in dioxide EOR comes. For industrial dioxide sequestration comes it's extremely unlikely that previous wells would ever be reused as injection wells.

3.2.3. Business Risks of CO₂ Sequestration

- Project Financing Issues
- Regulatory Environment
- Legal (pore space ownership, liability)
- Technology Risks
- Operational risks (Including Project Delays)
- Leakage Risks (contamination of groundwater, climaterisk)
- Induced Earthquakes and Earthquake Rupture
- Contamination of Natural gas reservoirs
- Injectivity Decline [28]

3.2.4. Other Risks

- 1- Leakages
- 2- Collateral (Ecosystem) Damage – oceans, geological formation
- 3- Technology failure and non-availability of tested and performing technologies of capture and storage on affordable terms
Brine and/or CO₂ leakage through wells, faults, deficient seals wells, faults, deficient seals – Impact on CO₂ atmospheric concentration (carbon credits) – Impact on ground water (contamination, displacement) – Impact on mineral resources [21]

4.CARBON CAPTURE AND STORAGE: INDIA'S CONCERNS

- 1- Economies of Scope – Oil/CBM production at low marginal prices as a result in increase and economic recovery of Potential tapping with learning costs and reduced unit/average costs.
- 2- Ignorance of accustomed Mitigation possibilities.
- 3- Enable Continuing reliance on fossil fuels [22].

Most Indian research and Development (R&D) activities associated with CCS occur underneath the Department of Science and Technology (DST) of the Indian Ministry of Science and Technology. The DST started the National Program on Carbon Sequestration (NPCS) research in 2007, with a view to competing with different countries during this area with reference to each pure/applied research and industrial applications. Four thrust areas of analysis were known underneath this programme, viz. dioxide Sequestration through small prototypist Bio-fixation Techniques; Carbon Capture method Development; Policy development Studies; and Network Terrestrial Agro-forestry Sequestration Modelling. An indicative list of outcomes relevant to CCS approved by the Science & Technology advisory Committee (IS-STAC) of the DST is given in Table 1 [23].

Sr. No.	Project title	Organisation	Year approved	Duration (years)
1.	Modelling and simulation of Carbon Recycling Technology through conversion of CO ₂ into useful multi-purpose fuel	Rajiv Gandhi Technological University, Bhopal	2007-08	3
10.	CO ₂ Sequestration using Micro algae – Efficient use of CO ₂ from bio-hydrogen production	AMM MurugappaChettiar Research Center, Chennai	2008-09	3

	facility			
14.	Mechanism and the dynamics of carbon storage in the Sundarban Mangrove	University of Calcutta, Kolkata	2009-10	3
20.	Development of carbon composites Materials for CO ₂ capture	Indian Institute of Chemical Technology, Hyderabad	2010-11	3
25.	Mineral CO ₂ sequestration by carbonation of industrial; Alkaline solid residues	Anna University, Chennai	2011-12	3

Table 1: List of DST projects related to CCS [23].

From literature review of Indian Sequestration projects, ONGC Ltd. was in the process of putting in a pilot experimental EOR project in Gujarat, with carbon dioxide from the gas process plant at Hazira to be provided to the Ankleshwar oil field. The set up was to supply a high purity gas stream from the offshore Hazira plant, that processes forty MMSCMD of bitter gas per day, by exploiting amino alkane absorption followed by H₂S removal, dehydrate and compress the gas at Hazira, before transporting it via pipelines to the depleted onshore reservoir at Ankleshwar, where it would be recompressed and injected for increased recovery of fossil oil. However, ONGC is reportedly re-thinking this project because of its value.

- Bharat heavy Electrical Ltd. (BHEL), the state-owned engineering and producing enterprise, and APGENCO, the power generating company of Andhra Pradesh, are putting in a 125 MW demonstration IGCC plant in Andhra Pradesh. while not directly associated with CCS, provided that IGCC is one in every of the most affordable choices for carbon capture, however is troublesome to implement for Indian coal, it may be said that this development will eventually result in the preparation of pre-combustion capture technology within the power sector in Asian nation.

- In addition to putting in India's initial IGCC plant, BHEL is additionally coordinating with Indira Gandhi Centre for Atomic analysis (IGCAR) and NTPC to design, develop and build radical super-critical boilers, which can be an addition to the critical technology boilers that it already manufactures. BHEL is additionally collaborating with TREC-STEP (Tiruchi Regional Engineering college – Science and Technology Entrepreneurs Park) to implement a collection of initiatives in CCT and CCS, as a part of a 3 year EU funded project.
- TREC-STEP, together with Ernst and Young, also organised an EU-funded 2-day coaching programme on 'Introduction to CCS and CCT' in December 2011, and a 3-day 'Skill Leverage Programme on CCT-CCS Technologies' in January 2012.
- Indian Institute of petroleum (IIP) has been engaged on developing new adsorbents for post-combustion carbon dioxide capture. during this regard, they have set up a 3 column Pressure Swing surface assimilation/Vacuum Swing Adsorption unit in their laboratory in Dehradun. During this column, adsorbents are being tested beneath flue gas conditions as offered in power plants. The work is being administered together with IIT Mumbai that handles the simulation and method style aspects, NTPC, which deals with power station operation, and Central Salt & Marine Chemicals research Institute (CSMCRI) and National Environmental Engineering Institute (NEERI), who are liable for adsorbent development.
- Private players in the power sector, like Tata Power and Reliance Power, have conjointly been considering CCS seriously, however problems like regulatory approval and storage challenges seem to own prevented any large scale demonstration activities from coming out.

5. FUTURE SCOPE & CONCLUSION OF CCS

Carbon Capture and Storage has been in use for over a decade in many countries and with its development and technological advancements, the process has become more efficient and reliable in reducing GHG emissions. While the studies reveal quite a few limitations, it is due to lack of study on the subject that these limitations have not been properly proved and so the subject requires further study. Restricted earth science storage choices and small study regarding saline aquifers and ocean storage makes matters a bit difficult [23]. Few issues which need rectification for immediate use of the technology are such as huge power and water consumption, precision and consistency in the chemical reactions involved (requires complete purification of chemical components involved), energy loss, cost, location of plant, Seal Leakage, Earthquake Rupture of Reservoir, and Groundwater Contamination upto a

certain small level. Many remedies have also been studied such as monitoring of the injected carbon inside the geological sites (known as Geophysical Monitoring), use of Chemical Tracers, leak detection using flux measurements, pressure monitoring, bio-fixation etc. For the development of CCS in India, deep study of potential sites and storage techniques according to the environment is required [29]. From Risk Assessment data, it is recorded that both the pre combustion and post combustion processes carry alot of practical problems which cannot be ignored. One major issue studied by many is the issue of induced earthquakes due to CO₂ injection underground. Others are operational risks such as blowouts, leakage, technological failures etc. Most Indian research and Development (R&D) activities associated with CCS occur underneath the Department of Science and Technology (DST) of the Indian Ministry of Science and Technology. The DST started the National Program on Carbon Sequestration (NPCS) research in 2007, with a view to competing with different countries during this area with reference to each pure/applied research and industrial applications. The ongoing research on Carbon Sequestration is one of the major projects of the Government of India Initiatives in order to make the process viable.

6. REFERENCES

1. Dr. Curt M. White, Brian R. Strazisar, Evan J. Granite, James S. Hoffman & Henry W. Pennline, "Separation and Capture of CO₂ from Large Stationary Sources and Sequestration in Geological Formations—Coalbeds and Deep Saline Aquifers", Journal of the Air & Waste Management Association.
2. White, C.M.; Smith, D.; Jones, K.; Goodman, A.; Jikich, S.; LaCount, R.; DuBose, S.; Ozdemir, E.; Morsi, B.; Schroeder, K.T. "Storage of Carbon Dioxide in Coal with Concomitant Enhanced Coalbed Methane Recovery—A Review".
3. Source available online at <http://www.world-nuclear.org/information-library/energy-and-the-environment/clean-coal-technologies.aspx>
4. Reeves, S. Seminar at National Energy Technology Laboratory, 2001.
5. Larsen J.W., Hall P., Wernett P.C. (1995) Pore structure of the Argonne premium coals. Energy & Fuels 9, 324-330 and Risk Assessment for future CO₂ Sequestration Projects Based CO₂ Enhanced Oil Recovery in the U.S. Ian J. Duncan*, Jean-Philippe Nicot, and Jong-Won Choi
6. Herzog H., Golomb D. "Carbon Capture and Storage from Fossil Fuel Use".

7. Bumb P., Rituraj “Carbon dioxide capture and storage (CCS) in geological formations as clean development mechanism (CDM) projects activities (SBSTA)”.
8. Herzog H., Golomb D. “Carbon Capture and Storage from Fossil Fuel Use”(Both are same).
9. Parikh J. IRADe “Analysis of Carbon Capture and Storage (CCS) Technology in the Context of Indian Power Sector”.
13. R. Svensson et al. “Energy Conversion and Management”
14. Ormerod W.G. et al. “Ocean storage of CO₂” Cheltenham: IEAGHG; 2002
15. Jain N., Srivastava A., Singh T.N. “Carbon Capture, Transport and Geologic Storage: A Brief Introduction”.
16. Svensson R., Oden Berger M., Johnsson F., Stromberg L. “Transportation systems for CO₂—application to carbon capture and storage”.
17. McCoy S.T., Rubin E.S. “An engineering-economic model of pipeline transport of CO₂ with application to carbon capture and storage”.
18. Holt, T., J. L. Jensen and E. Lindeberg, 1995: “Underground storage of CO₂ in aquifers and oil reservoirs”.
19. Bondor, P.L., 1992: “Applications of carbon dioxide in enhanced oil recovery”.
20. Melzer L.S. “Carbon Dioxide Enhanced Oil Recovery (CO₂ EOR): Factors Involved in Adding Carbon Capture, Utilization and Storage (CCUS) to Enhanced Oil Recovery”.
21. Project risk assessment for carbon capture and storage, James Ekman, Leonardo Technologies, Inc.
22. Carbon Capture and Storage: India’s Concerns, Indian Institute of Management Bangalore
23. Source <https://hub.globalccsinstitute.com/publications/india-ccs-scoping-study-final-report/4-current-ccs-activity-india>
24. Risk Assessment for future CO₂ Sequestration Projects Based CO₂ Enhanced Oil Recovery in the U.S. Ian J. Duncan*, Jean-Philippe Nicot, and Jong-Won Cho.
25. S. Holloway, The underground disposal of carbon dioxide (contract no. J0U2 CT92 0031): Final report of the JOULE II Project, British Geological Survey, 355 p. (1996)
26. S. Holloway, Safety of the underground disposal of carbon dioxide. Energy Conversion and Management 38, pp. S241–S245, (1997)
27. L. Skinner, CO₂ blowouts: an emerging problem. World Oil 224(1):38–42 (2003)
28. Quantifying Risks Associated with Geologic Sequestration Ian Duncan
29. Sminchak, J.; Gupta, N.; Byrer, C.; Bergman, P. “Issues Related to Seismic Activity Induced by the Injection of CO₂ in Deep Saline Aquifers”; National Energy Technology Laboratory: Pittsburgh, PA, 2001; pp 1–15. Source available online at:
10. Mittal M.L. “Estimates of Emissions from Coal Fired Thermal Power Plants in India”.
11. Jain N., Srivastava A., Singh T.N. “Carbon Capture, Transport and Geologic Storage: A Brief Introduction”.
12. Metz B., Davidson O., de Coninck H., Loos M., Meyer book L. IPCC Special Report on “Carbon Dioxide Capture and Storage”

http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/p37.pdf.