A Roadmap For "Carbon Capture And Sequestration" In The Indian Context: A Critical Review

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Abstract: Carbon capture and sequestration (CCS) technology is a process of capturing waste carbon dioxide from large point sources,such as fossil fuel stations, so that it will not enter the atmosphere. The technology has been accredited by IPCC and provides a path way as a key mitigation option for developing countries like India. Here we present a technological roadmap for CCS, depicted in terms of external factors and its development. We find that CCS is technically feasible and economically attractive within the range of carbon policies discussed domestically and internationally.The purpose and aim is to study the processes involved to prevent the release of large quantities of CO_2 into the atmosphere and to investigate various carbon mitigation, sequestration technologies and potential in Indian context.
Key Words: carbon, capture, sequestration, climate change, technology.

Introduction

In the past decades alternative fuels or switching from fossil fuels to less carbon intensive energy sources were the common opinions towards reduction in carbon-dioxide (CO_2) emissions. According to fourth assessment report from the IPCC, it now clear that carbon emission from fossil fuel combustion, industrial processes and other anthropogenic activities are leads to increase in atmospheric CO_2 concentrations[1] and consequent acidification of world oceans[2] .

This is a global challenge, the IRGC report[3] states that CO_2 levels of 450 ppm will be reached by 2035, with a 77-99% chance of exceeding 3°C warming and hence the commonly adopted definition of a dangerous level of climate change. However in recent years, researchers have recognized and came up with third option i.e. the development of "carbon emission reduction technologies" that would allow for the continued utilization of fossil fuel energy sources while significantly reducing carbon emissions. These technologies have collectively come to be known as **Carbon Capture and Sequestration (CCS)** technologies[4]. Using these technologies, CO_2 would be "captured" from large, stationary sources (e.g., power plant flue gases), preventing its release to the atmosphere. TheCO_2 would be compressed and transported to a location where it would be stored (e.g., a deep aquifer, depleted oil field, or deep ocean). In contrast to indirect forms of sequestration (e.g., forestation or

enhanced ocean uptake of CO_2), which rely on removing CO_2 from the atmosphere, CCS would avoid atmospheric emissions altogether.

The IPCC estimates that the economic potential of CCS could be between 10% and 55% of the total carbon mitigation effort until year 2100. The current India target is 20% reduction in CO_2 emissions by 2020, Achieving these milestones will require fundamental changes in how energy demand is conceived, coupled with low carbon fuels and alternative forms of supply. CCS applied to a modern Indian conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80–90% compared to a plant without CCS[5].

1 Long-term speculation

The long term road map shows key challenges for each of three main stages in the CCS chain: Carbon emission reduction technologies, transport and storage. These specific challenges or pathways towards the long term goal are elaborated in the following section.

1.1 Carbon Emission Reduction Technologies

Combustion of coal in oxygen and carbon dioxide (CO_2) concentration is relatively straight and pure, and could be directly processed. However impurities in CO_2 streams could have a significant effect on their phase behaviour and could pose a significant threat of increased corrosion of pipeline and well materials. In instances where CO_2 impurities exist and especially with air capture, a scrubbing process would be needed.

Different technologies for scrubbing are:-

- Pre-combustion capture
- Oxy-fuel combustion capture
- Post combustion capture

The basic working principles and current stages of maturity of these technologies are depicted in Figure 1 and 2 respectively.
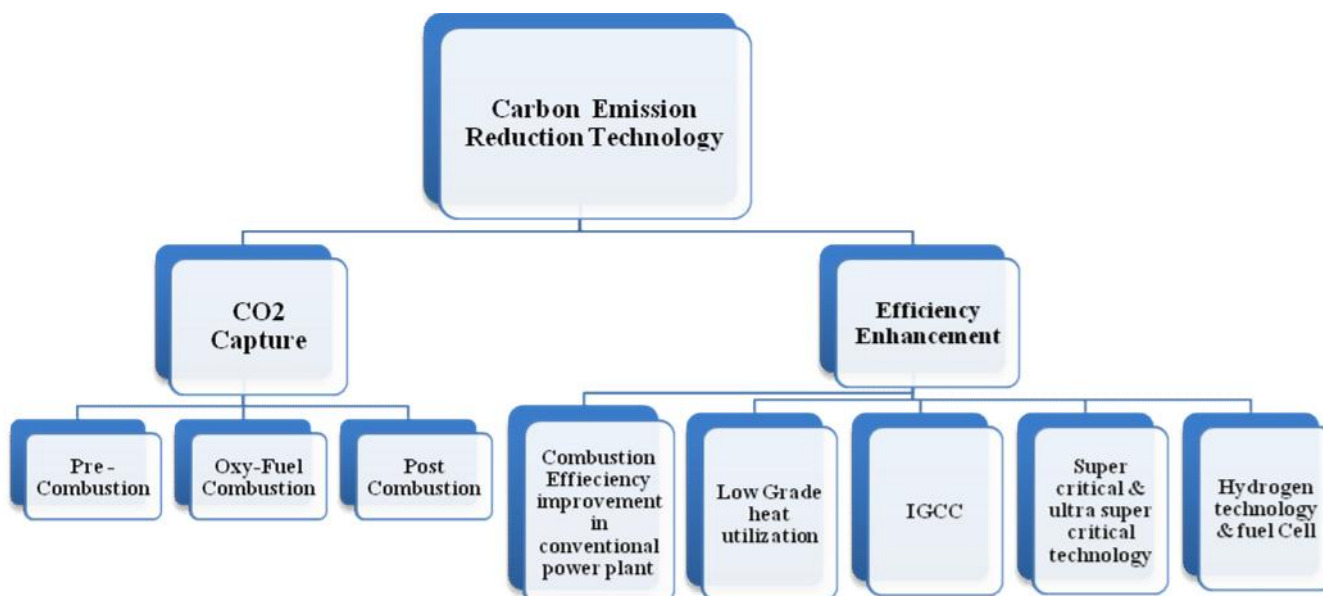

Figure 1: Stages of Carbon Emission Reduction Technology

- In **Pre-combustion** the fossil fuel is partially oxidized, for instance in a gasifier. The resulting syngas (CO and H_2O) is shifted into CO_2 and more H_2. The resulting CO_2 can be captured from a relatively

pure exhaust stream. The H_2 can now be used as fuel; the carbon dioxide is removed before combustion takes place. There are several advantages and disadvantages when compared to conventional post combustion carbon dioxide capture. The CO_2 is removed after combustion of fossil fuels, but before the flue gas is expanded to atmospheric pressure. This scheme is applied to new fossil fuel burning power plants, or to existing plants where re-powering is an option. The capture before expansion, i.e. from pressurized gas, is standard in almost all industrial CO_2 capture processes, at the same scale as will be required for utility power plants[6].

- In **Oxy-fuel combustion** the fuel is burned in oxygen instead of air. To limit the resulting flame temperatures to levels common during conventional combustion, cooled flue gas is recirculated and injected into the combustion chamber. The flue gas consists of mainly carbon dioxide and water vapour, the latter of which is condensed through cooling. The result is an almost pure carbon dioxide stream that can be transported to the sequestration site and stored. Power plant processes based on oxyfuel combustion are sometimes referred to as "zero emission" cycles, because the CO_2 stored is not a fraction removed from the flue gas stream (as in the cases of pre- and post-combustion capture) but the flue gas stream itself. A certain fraction of the CO_2 generated during combustion will inevitably end up in the condensed water. To warrant the label "zero emission" the water would thus have to be treated or disposed of appropriately. The technique is promising, but the initial air separation step demands a lot of energy[7].

- In **Post combustion** capture, the CO_2 is removed after combustion of the fossil fuel, this is the scheme that would be applied to fossil-fuel burning power plants. Here, CO_2 is captured from flue gases at power stations or other large point sources. The technology is well understood and is currently used in other industrial applications, although not at the same scale as might be required in a commercial scale power station[8].
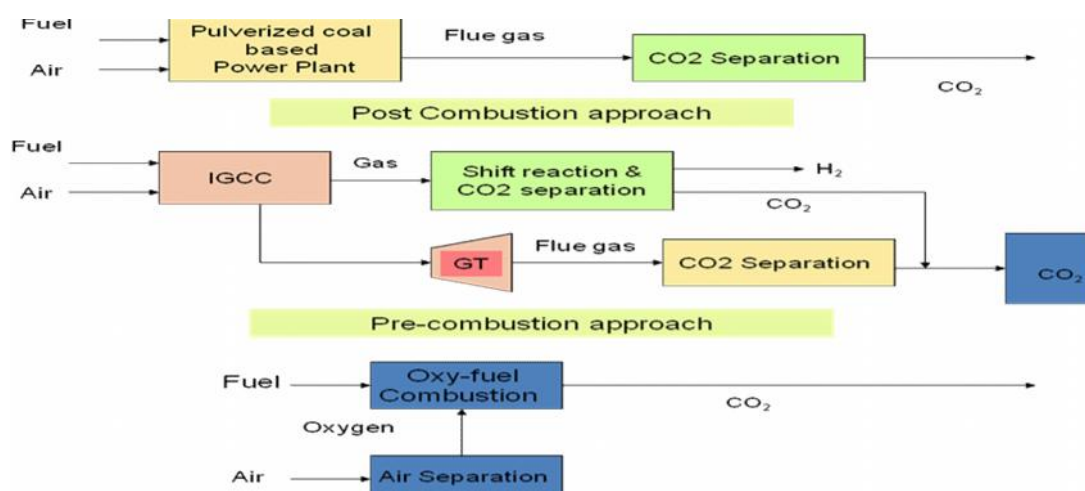
Figure 2: Carbon Capture Technologies

1.2 Alternate Technologies for CO_2 separation

In the previous sections, we addressed the technologies for separating CO_2 from fossil fuel streams before or after combustion. In this section, we briefly identify some alternative approaches that have been proposed for CO_2 capture and sequestration. The topics that we have chosen to include in this section are ones that have received significant attention. Followings are such approaches:-

- Cryogenic separation
- Chemical Absorption process
- Membrane separation

a) Cryogenic separation

Cryogenic separation involves the compression and cooling of gas mixtures in multiple stages to induce phase changes in CO_2 and other gases, which allow them to be separated. This process is most effective when feed

gases contain components with very different boiling points. In practice, the process is complicated by contaminants water vapour, for example, can lead to the formation of CO_2 and ice formations (called clathrate hydrates) that plug equipment. In addition to water vapour, there are other gases (e.g., SO2 and NOX) that can interfere with cryogenic processes. Further, the phase behavior of CO_2 itself is complicated and can lead to the formation of solids that plug equipment and reduce heat transfer rates. Finally, because of the constant need for pressurization and refrigeration, cryogenic processes are inherently energy intensive. Nonetheless, cryogenic separation could be effective for certain large, highly concentrated source streams of CO_2.

Figure 3: Layout of the cryogenic CO_2 separation and compression section[9].

Key content of this process are:

- The separated CO_2 may also be used for making value added products.
- The injection of CO_2 to produce oil is generally called Enhanced Oil Recovery (EOR).
- It is also used for enhanced coal bed methane (ECBM) recovery.

Major concerns:

- Flue gas temperature is generally 140°C –160 °C and at this temp appropriate cryogenic cooling is required which is energy intensive process.
- Lower temp also pose risk of acid corrosion.
- Again CO_2 carrying solvent is regenerated at 120°C - 130°C.
- About 100 -150 mg/Nm3 of fly ash present in flue gases. This causes plugging, erosion, solvent degradation etc. in solvent based process.

b) Chemical Absorption Process:

Chemical and physical absorption currently represent the most promising options for CO_2 capture, but significant research has been devoted to exploring more speculative capture technologies. Most of these technologies have been developed for use in other applications, and some even enjoy commercial success in several industries. Adsorption technologies, for instance, are commonly used to separate CO2 from CO_2- H_2 gas mixtures during the production of hydrogen. The speculation surrounding these technologies, then, is whether they would be competitive with alternative capture techniques (i.e., MEA (monoethanol amine) and physical absorption) when applied outside industries—for example, in the electric power sector[10].

Figure 4: Schematic of a basic chemical absorption process for amine based CO_2 capture

Key content of this process are:
- Flue gas is cooled and scrubbed in a direct contact cooler.
- CO_2 is absorbed in 15-20 % aqueous solution of MEA at 40-45 ºC in an Absorption Tower.
- The absorbed CO_2 is regenerated by stripping around 120-130 ºC.
- Steam (3 kg/cm^2) required for regeneration which can be supplied by a boiler.
- Regeneration, the energy intensive process, requires 2 ton of steam per ton of CO_2.

Major Concerns:

- In amine process, 80-90% of total energy required which is consumed in solvent regeneration.
- For a 210 MW coal fired boiler the total energy requirement is about 65 MW of power.
- This will bring down total efficiency by at least 30-35%.
- This will approximately double the power generation cost.
- Corrosion is a major issue involve in this process.

c) Membrane Process

Membrane process-It includes "Absorption Process", further classified in two categories;

- Gas separation membrane
- Gas absorption membrane

Membrane process can also be used to capture CO_2. Here, the success of separation is determined by the permeability and selectivity of the membrane. The permeability of a gas through a membrane is defined as its rate of flow through the membrane, given its pressure differential across the membrane. The selectivity of a membrane is the relative permeability of gas components that is, the ability of one gas to permeate faster than another.

In the ideal case, separation of CO_2 would involve a concentrated CO_2 source stream with few contaminant gases, combined with a permeable membrane that is highly selective with respect to CO_2[11].

Overall Highlights

- Over 80% recovery of high purity (>90%) CO_2 from flue gas at moderate temperature and low pressure can be achieved.

- Preliminary estimates of power requirements 0.30 Kw-hr/kg, CO_2 recovered at 55^{0}C, lower than current amine based absorption processes.

- Process does not generate any waste stream requiring further treatment.

2 Carbon dioxide Storage Options and Potential Impacts

After the capture process, CO_2 needs to be stored, so that it will not be leaked into the atmosphere. Several key criteria must be are taken care before employing 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[12].

Storage may include geologic sinks and the deep ocean. Geologic storage options include deep saline formations for example-subterranean and sub seabed, depleted oil resources and gas reservoirs, for formations of enhanced oil recovery operations, and abandoned coal mines. Deep ocean storage approaches include direct injection of liquid CO_2 into the water body at intermediate depths (1000–3000m),or at depths greater than 3000m, where liquid CO_2 becomes heavier than seawater, so CO_2 would drop to the ocean bottom and form a''CO_2 lake.''.

Table I lists the estimated worldwide capacities for CO_2 storage in the various media. Current global anthropogenic emissions amount to close to 7 GtC per year (1GtC = 1billion metric tons of carbon equivalent =3.7GtCO2) [13].

Table I: The Worldwide estimates of potential capacities for CO_2 storage reservoirs

Sequestration option	Worldwide capacity (GtC)
Oceans	1000–10,000s
Deep saline formations	100–10,000s
Depleted oil and gas reservoirs	100–1000s
Coal seams	10–1000s
Terrestrial	10–100s
Utilization	Currently < 0.1GtC/yr

2.1 Storage of CO_2 in Geological formation

Geo-sequestration, this method involves injecting CO_2, generally in supercritical form. The depleted oil and gas formations in India can be used for storing CO_2.This will result in increase oil recovery. The framework supporting this concept is based around the containment historically afforded by such formations over geological time frames. Similarly, deep saline aquifers have been identified as natural formations where injection of CO_2 followed by its reaction with minerals to form carbonates would essentially lock up the gas permanently. A similar rationale attaches to the recovery of methane from deep abandoned coals beds where CO_2 would be used to displace the methane and enhanced coal bed methane recovery (ECBM).

Disadvantages of old oil fields are their geographic distribution and their limited capacity, as well as the fact that subsequent burning of the additional oil so recovered will offset much or all of the reduction in CO_2 emission.
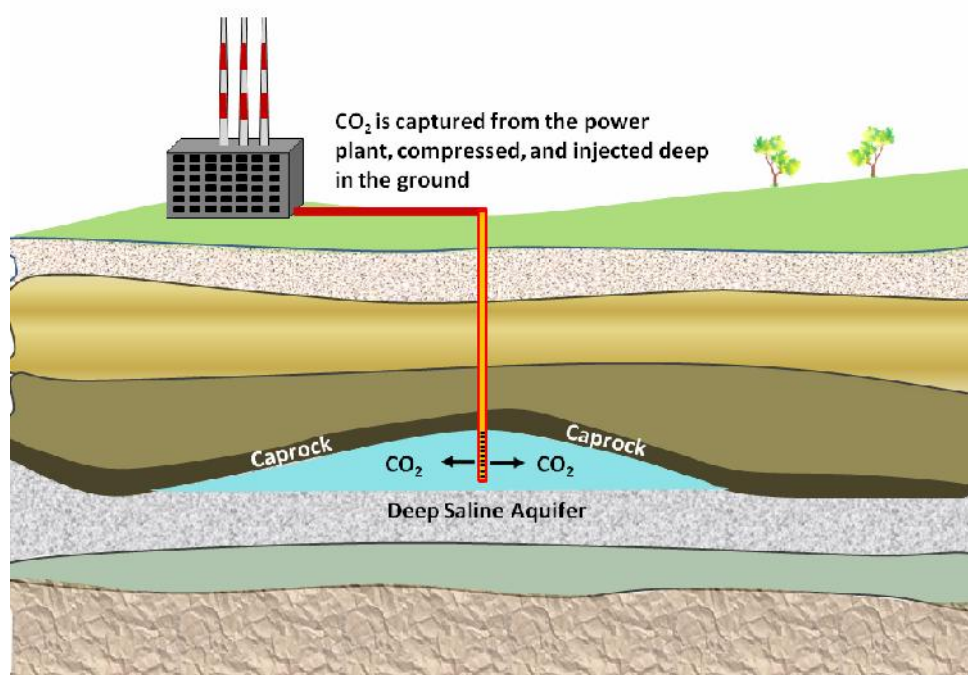
Figure 5: Example of such option is schematically represents a system involving the injection of carbon dioxide into geological formation[14].

a) Potential Impact

The potential impacts related with CO_2 injection in geological formations is largely threaten with the possibility of its leakage. There is a chance that large quantity of gaseous carbon dioxide can release from formations used for CO_2 storage could take place with associated mortality of humans and their livestock. The potential for such leakage will depend upon cap rock integrity and the security of well capping methods in the longer term together with the degree to which the CO_2 is eventually 'trapped' through solubility in e.g. residual oil, formation waters or by reaction with formation minerals to form carbonates. Even in formations with adequate nominal capacity some of the injected CO_2 is expected to leak as a result of the buoyancy of the separate phase carbon dioxide, the induced pressure gradients from the injection and the variable nature of strata acting as barriers to upward migration. In addition it is possible that the reaction of CO_2 with reservoir minerals could affect permeability and porosity. Accordingly, CO_2 leaking from storage formations could intercept aquifers, surface waters and the land surface.

b) Research Needs

• Identification and characterization of natural analogues.
• Site specific assessments of storage formation integrity.
• Assessment of potential leakage pathways through fractures and porous media.
• Potential impact on water resources, surface ecosystems.
• Potential for solubility, mineral trapping and impacts on formation porosity.
• Potential for catastrophic release.
• Monitoring and remediation methods.
• Development of geophysical monitoring techniques.
• Characterization of soil micro-organisms and potential ecological impacts.
• Evaluation of impacts due to co-recovered acids gases and other contaminants[14].

2.2 Storage of CO_2 in Ocean

Table 2 Estimates of carbon reservoirs of different biosphere compartments[15]

Reservoir size	Gt (billion tonnes) carbon
Oceans	44 000
Atmosphere	750
Terrestrial	2 200

From table 2, the ocean holds the largest potential for anthropogenic CO_2 sequestration. Apart from the surface layer, deep ocean water is unsaturated with respect to CO2. It is estimated that if all the anthropogenic CO_2 that would double the atmospheric concentration were injected into the deep ocean, it would change the ocean carbon concentration by less than 2%, and lower its pH by less than 0.15 units. Furthermore, the deep waters of the ocean are not hermetically separated from the atmosphere. Eventually, on a timescale of 1000 years, over 80% of today's anthropogenic emissions of CO_2 will be transferred to the ocean. Discharging CO_2 directly to the ocean would accelerate this ongoing but slow natural process and would reduce both peak atmospheric CO_2 concentrations and their rate of increase.
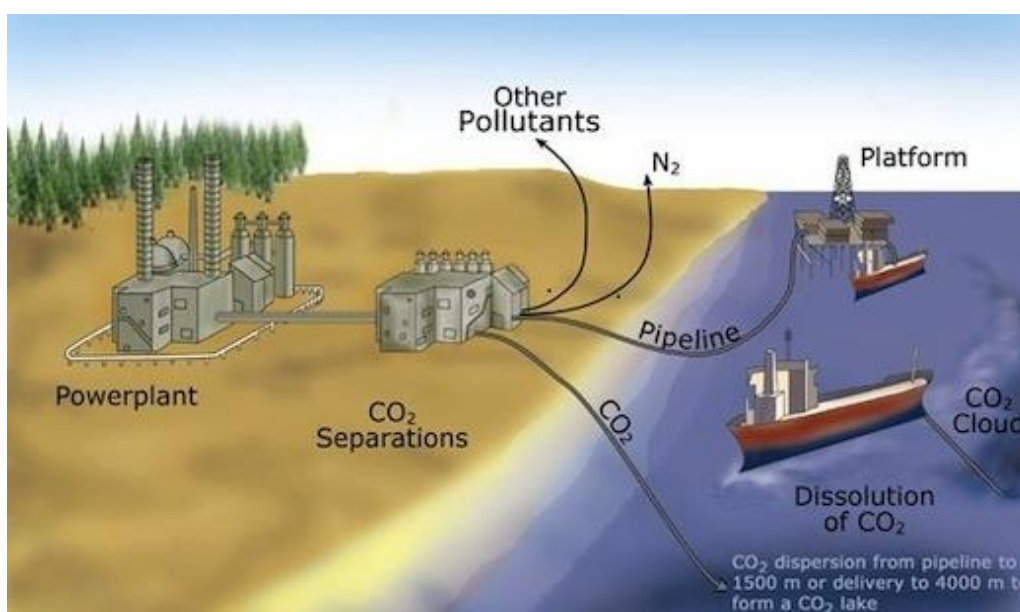
Figure 6: Example of such option is schematically represents a system involving the injection of carbon dioxide into a deep oceanic site[15].

a) Potential Impacts
Potential impacts upon marine biological systems which need to be considered are those due to:
• PH reduction.
• Carbonate dissolution.
• Co-recovered materials such as sulphur oxides, nitrogen oxides and metals.
• Changes in speciation of e.g. metals and ammonia.
• 'Smothering' effects.

b) Research needs
• Structure and function of deep sea ecosystems.
• Effects of reduced pH on deep ocean organisms at all levels of biological organization.
• Temporal and spatial extent of changed pH regimes and of associated biological impacts.
• Possible interactions of CO_2 storage with other biogeochemical cycles and onward effects.

• Ecological impacts of carbonate dissolution on fauna with calcareous structures.
• Ecological impacts of carbonate dissolution on microflora of calcareous sediments.
• Extent of 'smothering' impacts at scale of likely storage operations[16].

3 Biological CO_2 Fixation Initiative

India's focus for CO_2 mitigation is directed towards biological fixation and utilization of CO_2, in addition to efficiency improvement and use of renewable energy resources[17].

- CO_2 to Bio-oil : Micro Algal Process provides;
  - Oil content up to 40%.
  - Potential algal species are Dunaliella, Nannochloris and Spirulina.
  - Algae generate 7-30 times more oil production than other energy plantations for same land.
  - No need for agricultural land may avoid bio-oil crop conflict.
  - Able to produce bio-oil, neutraceuticals, cattle food, etc.
  - Typical CO_2 consumption 100 gm/m^2/day, dry algae production rate 20 gm/m^2/day   .

Major Concerns:
  - Requirement of land for algal cultivation is an issue.
  - Commercial process for algae to bio-oil using CO_2 from power plant yet to establish.
  - Extensive global R&D required for development of the process.

Figure 7: 1000 sq. meter algae based pilot plant.

2 Transportation Cost Review

Transport in dedicated pipelines is the most promising method for delivering captured

CO_2 to storage facilities, though other methods, such as barges or ships for ocean storage are there. The oil and gas industry has years of experience with CO_2 pipelines, transporting CO_2 hundreds of kilometers for use in EOR operations in outside India. Large-scale CO_2 transport would undoubtedly require the development of additional infrastructure, though there may be limited opportunities to use existing oil and gas pipelines when the fields they serve are retired and converted to storage sites.

Transport costs are dominated by the investment in pipeline infrastructure. Investment costs(I) are given by[18].

I = (190 + 955 x d^0.9) x L,

Where,

Diameter (d) of the pipeline in (m) and L is the pipeline length in (m).

Operation and maintenance costs are small in comparison to its manufacturing, and the average cost of transporting CO_2 falls dramatically with scale. Transport costs are also reduced significantly when CO_2 has been

pressurized to its liquid form, though most storage options require pressurized injection of CO_2 anyway. Transport costs are estimated approx. to be about Rs 500/tC to Rs 700/tC per 100 km.

3.0 The Potential role of carbon capture in country

Global climate change has rapidly become one of the most prominent environmental and energy policy issues in this current scenario. The current India target is 20% reduction in CO_2 emissions by 2020, Achieving these milestones will require fundamental changes in how energy demand is conceived, coupled with low carbon fuels and alternative forms of supply.CCS applied to a modern Indian conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80–90% compared to a plant without CCS.

The following identity has proven useful as a way of understanding the main drivers of

CO_2 emissions[19]:

$$CO2\ emissions = GDP \ \ x \ \ \underline{\text{Energy consumption}} \ \ \ x \ \ \ \underline{\text{CO2 emissions}} \ \ \ \ \ ,$$
$$\text{Unit GDP} \qquad\qquad \text{Unit energy consumption}$$

Where,

GDP (gross domestic product) is a measure of the size of an economy. Energy consumption per unit of GDP is a measure of the "energy intensity" of the economy.

3.1 Opportunities for CO_2 capture in India

In India about 40% of carbon emissions came from the generation of electricity. The transportation and industrial sectors also accounted for a significant portion of emissions, at 32% and 15%, respectively. Finally, the commercial and residential sectors accounted for a combined 11% of CO_2 emissions.

These sectors all emit significant quantities of carbon, but not all are amenable to CCS. Because of their high capital costs and economies of scale, CCS technologies are particularly well suited to large, stationary sources of CO_2 emissions, power plants are the clearest contenders. But energy intensive industries like oil refining, iron and steel manufacturing, and cement production also combust large quantities of fossil fuels and have significant carbon emissions. The cost of capture from these sources depends primarily on the properties of their flue gas streams costs generally fall with higher concentrations of CO_2 and lower temperatures[20] .

- **Electric power generation**

The electricity sector in India had an installed capacity of 210.936 GW as of November 2012, the world's fifth largest. Captive power plants generate an additional 31.5 GW. Non Renewable Power Plants constitute 88.55% of the installed capacity and 12.45% of Renewable Capacity. India generated 855 BU (855 000 MU i.e. 855 TWh) electricity during 2011-12, resulting more than 2.1GtC of emissions [21]. About 78% of these emissions came from coal-fired power plants, and 14% came from natural gas–fired power plants. The remaining 8% came from the combustion of petroleum, light oil, methane, coal-oil mixture, propane gas, blast furnace gas, wood, and refuse. Coal plants, which account for the majority of emissions, emitted 0.32 kg C/kWh during this period, compared with only 0.17 kg C/kWh for natural gas. As large, stationary sources of CO_2 emissions, these plants represent the foremost opportunity for CCS. Given current technology and gas prices, recent estimates may suggest that the incremental cost of applying CCS to new conventional coal or natural gas plants would be very much advantageous and can control GHG emission. The cost of retrofitting an existing conventional coal plant with CCS technologies is still under investigation but these costs are within the range of mitigation costs estimated by several models for domestic Indian compliance with the Kyoto Protocol.

- **Industrial Application**

Within the industrial sector, manufacturing alone approximately accounts for 80% of energy related to carbon emission. Energy intensive industries like petroleum refining, petrochemicals, iron and steel manufacturing and cement, lime, and soda ash production all depends on significant process of heat and steam, which are typically derived from the combustion of the fossil fuels. In principle, it is possible to capture CO_2 from the flue gases of these industries, most like with a chemical absorbent like MEA in essentially the same process as far power plants.

In addition to emissions from fossil fuel combustion, industries such as natural gas and hydrogen production (e.g., in petroleum refining and ammonia manufacture) currently employ capture technologies to separate CO_2 from gas mixtures. Although there are some commercial uses for this CO_2, most is simply vented to the atmosphere. These industries represent relatively inexpensive first options for CCS, since incremental costs would include only transportation and storage. The total estimated cost of CCS is 55% to 80% lower for these industries than for electric power generation.

- **Petroleum Refining Firms**

Within the manufacturing sector, the single largest source of carbon emissions is the petroleum refining industry in our country, which accounted for about 16% of industrial emissions, not including emissions from industrial electricity use. About 78% of these emissions came from the combustion of waste products (e.g., petroleum coke and still gas), petroleum fuels, and natural gas to produce the heat and steam required by all processes. CCS applied to these emissions would likely incur comparable or slightly greater capture and storage costs than for electric power plants, with chemical absorption being the most promising method for CO_2 removal. The remaining 22% of refinery emissions resulted from the non combustion use of fossil fuels, such as the production of hydrogen from natural gas in dedicated facilities or from the gasification of petroleum residues and waste products.

- **Chemical Industries**

The chemicals industry is the second-largest source of carbon emissions and accounted for about 12% of industrial carbon emissions, not including electricity. The cost of capture from the flue gases of various petrochemical industries (e.g., ethylene, propylene, butadiene, and benzene manufacture) using an MEA solvent has been estimated approx Rs 18k/tC. The remaining 23% of these emissions came from the nonfuel use of fossil fuel resources, such as hydrogen production from natural gas during ammonia manufacture.

- **Iron and Steel Manufacture Industry**

Iron and steel production is the third-largest source of emissions among manufacturing industries, accounting about 7% of industrial emissions, most flue gas emissions result from the direct combustion of fossil fuels, a small fraction comes from the oxidization of metallurgical coke in the blast furnace. In an integrated steel plant that uses a basic oxygen furnace to convert pig iron to steel, approximately 80% of carbon emissions are contained in flue gas from the blast furnace, and an additional 20% is contained in coke-oven gas and basic oxygen furnace gas. Preliminary calculations suggest that 71% of iron and steel emissions could be avoided by applying CCS technologies to blast furnace gases at a very low cost.

- **Natural Gas Production**

Natural gas contains up to 20% CO_2 by volume, most of which must be removed to produce pipeline-quality gas. In fact, MEA solvents were developed some 60 years ago specifically for this purpose. Some of this CO2 is used for industrial applications—20% of the

CO_2 used in EOR operations, for example, comes from the purification of natural gas .But most of the CO_2 from natural gas purification is simply released to the atmosphere. This CO_2 could, however, be compressed and stored in various geological formations, Compression and injection of CO_2 at raised total commercial gas production costs by about 1%.

4.0 Carbon capture and storage cost modeling for electricity generation in India.

Plant-level calculation of carbon capture and storage

To assess the competitiveness of CCS versus other carbon mitigation options, we need some measure of the cost of mitigation using CCS technologies. Unfortunately, thus far the literature has struggled to provide clear answers in this regard. Given cost and performance data for two sample power plants (i.e., a plant with CCS and its non-CCS counterpart), a number of studies have calculated average plant-level cost (Rs/tC) by dividing the difference in the cost of electricity generation (Rs/kWh) by the difference in carbon emissions (tC/kWh), recent

estimates put current CCS costs at about Rs 15K/tC for new pulverized-coal(PC) plants, Rs 12.5K/tC for new natural gas combined-cycle plants (NGCC), and Rs 9K/tC approx. for new integrated gasification combined-cycle (IGCC) coal plants, relative to those generation technologies without CCS. The current estimated cost of retrofitting an existing pulverized-coal plant with MEA capture of CO_2 is about Rs11K/tC.

Plant-level analyses of CCS in the electricity generation sector by incorporating uncertainty and variability for about 30 independent model parameters. These include both plant and CCS performance parameters (e.g., energy penalty and capture efficiency), as well as various cost parameters (e.g., fuel prices and CCS storage costs), Ignoring uncertainty, the incremental cost of applying CCS to a new PC plant approx is about Rs12K/tC.

These results suggest that the deterministic estimates discussed above may misstate mean costs while failing to reflect the true range of potential costs. As those and other researchers have been quick to point out, however, plant-level cost estimates are sensitive to the reference plant chosen, and the appropriate base case is the closest competitor at the margin. One way of visualizing this margin is to compare the cost of electricity for competing options at different carbon prices. When the price of carbon emissions is zero, plants without CCS produce electricity at a lower cost than their CCS counterparts. As the price of carbon rises, however, adding CCS becomes increasingly attractive by virtue of its lower rate of emissions.

In this example, we see that existing coal plants produce the cheapest electricity for all carbon prices up to about 9K/tC. Then new NGCC plants produce the cheapest electricity until carbon prices reach12.5K/tC, at which point NGCC with capture produces the cheapest electricity. PC plants retrofitted with CCS are uneconomic at any carbon price under the assumptions of the figure, even though the CCS costs for coal retrofits are only 11K/tC, whereas the incremental cost of adding CCS to a new NGCC plant is 12.5K/tC.

However, useful those analyses, its embedded assumptions (e.g., fuel prices, fuel characteristics, and plant efficiencies) are subject to uncertainty and change. Were gas prices higher, for example, the NGCC lines would both be shifted upward, implying that replacement of an existing PC with a new NGCC plant would be economical only at a higher carbon price.

Summary And Conclusion

Indian Contribution in accumulation of CO_2 and other GHG in the atmosphere is mainly due to improper combustion of fossil fuels though significant capital is invested in fossil fuel procurement and their maintenance, domestic reserves and infrastructure, combined with relatively costly and limited alternative energy resources e.g., solar power, wind, and biomass. In addition to that meeting international CO_2 emissions-reduction targets will be extremely difficult to achieve, therefore CCS can play a viable technological role in the above matters, although integrated large-scale projects need further demonstration, R&Ds program to reducing the cost of CO_2 capture, and technological breakthroughs are expected.

Projects are now commercial in the EOR sector, which is the main driver in the CCS industry today and will remain so during the current decade.

Carbon capture and sequestration technologies will definitely provide and act as a partial solution to this dilemma by facilitating less costly reductions in carbon emissions through the continued use of fossil fuels. CCS may be economic under stringent climate policies, a number of technical, environmental, and political issues arise with regard to transportation and storage of captured CO_2 but the results indicate that fuel switching from coal to natural gas and energy efficiency improvements would be the least costly options for moderate reductions in emissions.

For larger reductions and higher carbon prices, however, CCS substantially lowers mitigation costs. Assuming no barriers to implementation other than cost (i.e., ignoring political and environmental issues) and given certain assumptions (e.g., regarding fuel prices and energy demand), these studies suggest that a significant number of new plants with CCS would enter the power supply sector within the next few decades, though CCS retrofits could enter in just a few years given a sufficiently high price on emissions. The availability and use of CCS technologies would decrease reliance on renewable energy sources while encouraging electricity production to shift from natural gas to coal power. CCS would significantly reduce the present value of the cost of mitigation over time. Finally, CCS would result in the capture of significant quantities of CO_2 without exceeding most current storage capacity estimates.

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