

# Use of Carbon Capture Storage Technique for Clean Power Generation

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**Abstract-** Global demand for energy shows no signs of slowing, carbon dioxide emissions keep surging to new records. More than ever, the need for a fundamental shift to a cleaner and more reliable energy system is clear. The technologies with the greatest potential for energy and carbon dioxide (CO<sub>2</sub>) emission reduction, however, are making the slowest progress. Carbon capture and storage (CCS) is not seeing the necessary rates of investment into full-scale demonstration projects and nearly one-half of new coal-fired power plants are still being built with inefficient technology.

The power generation sector is expected to contribute more than one-third of potential CO<sub>2</sub> emissions reductions worldwide by 2020 under the 2DS, and almost 40% of 2050 emission reduction. Enhanced power generation efficiency, a switch to lower-carbon fossil fuels, increased use of renewable and nuclear power, and the introduction of CCS are all required to achieve cleaner power generation.

## I. INTRODUCTION

The Indian power sector is growing at a rapid pace and coal is, and will continue to be, the primary energy source for the Indian power sector that underpins the country's economic development. About 68% of India's current power generation is from coal and that share is expected to remain in the same range for many years. A significant percentage of India's existing coal-fired power plants are aging and are no longer very efficient and reliable, especially those operated by state utilities. In recent years, India power generators have focused on increasing plant load factors (PLF, or capacity factors) to increase electricity output, but often at the expense of plant efficiency. Heat rates (i.e., fuel consumption per unit of electricity generated) higher than 3,000 kcal/kWh (i.e., efficiencies lower than about 28%) are common among the older, especially smaller (100-200 megawatt, MW) units operated by many Indian state utilities. Plant reliability and efficiency suffer as a result of:

1. The high-ash content of most Indian coals, which often exceeds 45%, and overall poor coal quality.
2. Limited maintenance of equipment.
3. Absence of incentives to maintain or improve efficiency and reliability.
4. Inadequate operating budgets: this includes the cost involved in the maintenance of the plant machineries and purchase of new technological instruments, the cost involved in the reduction of CO<sub>2</sub> emissions to the atmosphere etc.

5. Limited knowledge and experience on state-of-the-art operating and maintenance (O&M) practices, which adversely impacts both plant efficiency and reliability.

Several Energy Efficient R&M (Renovation and Modernization) projects have already been implemented under cooperative programs with Germany, Japan, and the World Bank. Since 1982, USAID/India has sought to promote and demonstrate better coal utilization technologies and practices in India.

## II. CARBON CAPTURE AND STORAGE

Carbon Capture and Storage refers to technology attempting to prevent the release of large quantities of CO<sub>2</sub> into the atmosphere from fossil fuel use in power generation and other industries by capturing CO<sub>2</sub>, transporting it and ultimately, pumping it into underground geologic formations to securely store it away from the atmosphere. The value of CCS as an important CO<sub>2</sub> abatement tool is already recognized by multiple authoritative organizations, including the UK Committee on Climate Change (CCC), the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA). The IEA asserts that the cost of reducing emissions to 2005 levels by 2050 will increase by 70% if CCS is not deployed. For many large industrial emitters, CCS is seen as the only viable long term solution to mitigating the future costs of CO<sub>2</sub> emissions.

There are three main approaches to CO<sub>2</sub> capture, for industrial and power plant applications.

1. *Post-combustion* systems: separate CO<sub>2</sub> from the flue gases produced by combustion of a primary fuel (coal, natural gas, oil or biomass) in air.
2. *Oxy-fuel combustion* systems: uses oxygen instead of air for combustion, producing a flue gas that is mainly H<sub>2</sub>O and CO<sub>2</sub> and which is readily captured. This is an option still under development.
3. *Pre-combustion* systems: process the primary fuel in a reactor to produce separate streams of CO<sub>2</sub> for storage and H<sub>2</sub> which is used as a fuel.

The basis for CO<sub>2</sub> capture:

The main application of CO<sub>2</sub> capture is likely to be at large point sources: fossil fuel power plants fuel processing plants and other industrial plants, particularly for the manufacture of iron, steel, cement and bulk chemicals. Capturing CO<sub>2</sub> directly from small and mobile sources in the transportation and residential &

commercial building sectors is expected to be more difficult and expensive than from large point sources. An alternative way of avoiding emissions of CO<sub>2</sub> from these sources would be by use of energy carriers such as hydrogen or electricity produced in large fossil fuel-based plants with CO<sub>2</sub> capture or by using renewable energy sources. In this report we concentrate our discussion on Post-Combustion capture technology since CO<sub>2</sub> is primarily obtained from burning the fossil fuels.

### III. CARBON CAPTURE

#### Post-Combustion capture

Capture of CO<sub>2</sub> from flue gases produced by combustion of fossil fuels and biomass in air is referred to as post-combustion capture. Instead of being discharged directly to the atmosphere, flue gas is passed through equipment which separates most of the CO<sub>2</sub>. The CO<sub>2</sub> is fed to a storage reservoir and the remaining flue gas is discharged to the atmosphere. Current anthropogenic CO<sub>2</sub> emissions from stationary sources come mostly from combustion systems such as power plants, cement kilns, furnaces in industries and iron and steel production plants. All the CO<sub>2</sub> capture systems described in this section are aimed at the separation of CO<sub>2</sub> from the flue gases generated in a large-scale combustion process fired with fossil fuels. Flue gases or stack gases found in combustion systems are usually at atmospheric pressure. Because of the low pressure, the large presence of nitrogen from air and the large scale of the units, huge flows of gases are generated, the largest example of which may be the stack emissions coming from a natural gas combined cycle power plant.

In principle post-combustion capture systems can be applied to flue gases produced from the combustion of any type of fuel. However, the impurities in the fuel are very important for the design and costing of the complete plant. Flue gases coming from coal combustion will contain not only CO<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub> and H<sub>2</sub>O, but also air pollutants such as SO<sub>x</sub>, NO<sub>x</sub>, particulates, HCl, HF, mercury, other metals and other trace organic and inorganic contaminants. There are several commercially available process technologies which can in principle be used for CO<sub>2</sub> capture from flue gases. However, comparative assessment studies have shown that absorption processes based on chemical solvents are currently the preferred option for post-combustion CO<sub>2</sub> capture. At this point in time, they offer high capture efficiency and selectivity, and the lowest energy use and costs when compared with other existing post-combustion capture processes.

### IV. TRANSPORTATION OF CO<sub>2</sub>

Transport is that stage of carbon capture and storage that links sources and storage sites. In the context of long-distance movement of large quantities of carbon dioxide, pipeline transport is part of current practice. Except when plants are located directly above a geological storage site, captured CO<sub>2</sub> must be transported from the point of capture to a storage site. Pipelines today operate as a mature market technology and are the most common method for transporting CO<sub>2</sub>. Gaseous CO<sub>2</sub> is typically compressed to a pressure above 8 MPa in order to avoid two-phase flow regimes and increase the density of the CO<sub>2</sub>,

thereby making it easier and less costly to transport. CO<sub>2</sub> also can be transported as a liquid in ships, road or rail tankers that carry CO<sub>2</sub> in insulated tanks at a temperature well below ambient, and at much lower pressures. The first long-distance CO<sub>2</sub> pipeline came into operation in the early 1970s. In the United States, over 2,500 km of pipeline transports more than 50 MtCO<sub>2</sub> per year from natural and anthropogenic sources, mainly to sites in Texas, where the CO<sub>2</sub> is used for EOR. These pipelines operate in the 'dense phase' mode (in which there is a continuous progression from gas to liquid, without a distinct phase change), and at ambient temperature and high pressure. In most of these pipelines, the flow is driven by compressors at the upstream end, although some pipelines have intermediate (booster) compressor stations.

In pipeline transportation, the volume is reduced by transporting at a high pressure, this is routinely done in gas pipelines, where operating pressures are between 10 and 80 MPa. A transportation infrastructure that carries carbon dioxide in large enough quantities to make a significant contribution to climate change mitigation will require a large network of pipelines. The carbon dioxide stream ought preferably to be dry and free of hydrogen sulphide, because corrosion is then minimal, and it would be desirable to establish a minimum specification for pipeline quality. However, it would be possible to design a corrosion resistant pipeline that would operate safely with a gas that contained water, hydrogen sulphide and other contaminants. Pipeline transport of carbon dioxide through populated areas requires attention be paid to design factors, to overpressure protection, and to leak detection. Liquefied natural gas and petroleum gases such as propane and butane are routinely transported by marine tankers; this trade already takes place on a very large scale. Carbon dioxide is transported in the same way, but on a small scale because of limited demand. The properties of liquefied carbon dioxide are not greatly different from those of liquefied petroleum gases, and the technology can be scaled up to large carbon dioxide carriers.

Transport of CO<sub>2</sub> through pipeline requires that CO<sub>2</sub> be compressed and cooled to the liquid state. The properties of CO<sub>2</sub> are considerably different from other fluids commonly transported by pipeline, such as natural gas. Thus, it is necessary to use accurate representations of the phase behaviour, density, and viscosity of CO<sub>2</sub> in the design of the pipeline. Transport of CO<sub>2</sub> at lower density results in high pressure drop per unit length which results in inefficient transport of CO<sub>2</sub>. To reduce difficulties in design and operation, it is generally recommended that a CO<sub>2</sub> pipeline operate at pressures greater than 8.6 MPa by which any sharp changes in the compressibility of CO<sub>2</sub> can be avoided across a range of temperatures that may be encountered in the pipeline system.

### V. STORAGE

This section examines types of geological formations that have received extensive consideration for the geological storage of CO<sub>2</sub>: oil and gas reservoirs, deep saline formations and unminable coal beds.

CO<sub>2</sub> storage in hydrocarbon reservoirs or deep saline formations is generally expected to take place at depths below 800 m, where the ambient pressures and temperatures will

usually result in CO<sub>2</sub> being in a liquid or supercritical state. Under these conditions, the density of CO<sub>2</sub> will range from 50 to 80% of the density of water. This is close to the density of some crude oils, resulting in buoyant forces that tend to drive CO<sub>2</sub> upwards. Consequently, a well-sealed cap rock over the selected storage reservoir is important to ensure that CO<sub>2</sub> remains trapped underground. When injected underground, the CO<sub>2</sub> compresses and fills the pore space by partially displacing the fluids that are already present (the 'in situ fluids'). In oil and gas reservoirs, the displacement of in situ fluids by injected CO<sub>2</sub> can result in most of the pore volume being available for CO<sub>2</sub> storage. In saline formations, estimates of potential storage volume are lower, ranging from as low as a few percent to over 30% of the total rock volume.

Once injected into the storage formation, the fraction retained depends on a combination of physical and geochemical trapping mechanisms. Physical trapping to block upward migration of CO<sub>2</sub> is provided by a layer of shale and clay rock above the storage formation. This impermeable layer is known as the "cap rock". Additional physical trapping can be provided by capillary forces that retain CO<sub>2</sub> in the pore spaces of the formation. In many cases, however, one or more sides of the formation remain open, allowing for lateral migration of CO<sub>2</sub> beneath the cap rock. In these cases, additional mechanisms are important for the long-term entrapment of the injected CO<sub>2</sub>. The mechanism known as geochemical trapping occurs as the CO<sub>2</sub> reacts with the in situ fluids and host rock. First, CO<sub>2</sub> dissolves in the in situ water. Once this occurs (over time scales of hundreds of years to thousands of years), the CO<sub>2</sub>-laden water becomes more dense and therefore sinks down into the formation (rather than rising toward the surface).

Next, chemical reactions between the dissolved CO<sub>2</sub> and rock minerals form ionic species, so that a fraction of the injected CO<sub>2</sub> will be converted to solid carbonate minerals over millions of years. Yet another type of trapping occurs when CO<sub>2</sub> is preferentially adsorbed onto coal or organic-rich shales replacing gases such as methane. In these cases, CO<sub>2</sub> will remain trapped as long as pressures and temperatures remain stable. These processes would normally take place at shallower depths than CO<sub>2</sub> storage in hydrocarbon reservoirs and saline formations.

## VI. CO<sub>2</sub> STORAGE MECHANISMS IN GEOLOGICAL FORMATIONS

The effectiveness of geological storage depends on a combination of physical and geochemical trapping mechanisms. The most effective storage sites are those where CO<sub>2</sub> is immobile because it is trapped permanently under a thick, low-permeability seal or is converted to solid minerals or is adsorbed on the surfaces of coal micro pores or through a combination of physical and chemical trapping mechanisms.

Physical trapping: stratigraphic and structural

Initially, physical trapping of CO<sub>2</sub> below low-permeability seals (cap rocks), such as very-low-permeability shale or salt beds, is the principal means to store CO<sub>2</sub> in geological formations. In some high latitude areas, shallow gas hydrates may conceivably act as a seal. Sedimentary basins have such closed, physically bound traps or structures, which are occupied

mainly by saline water, oil and gas. Structural traps include those formed by folded or fractured rocks. Faults can act as permeability barriers in some circumstances and as preferential pathways for fluid flow in other circumstances. Stratigraphic traps are formed by changes in rock type caused by variation in the setting where the rocks were deposited. Both of these types of traps are suitable for CO<sub>2</sub> storage. Care must be taken not to exceed the allowable overpressure to avoid fracturing the cap rock or re-activating faults.

Physical trapping: hydrodynamic

Hydrodynamic trapping can occur in saline formations that do not have a closed trap, but where fluids migrate very slowly over long distances. When CO<sub>2</sub> is injected into a formation, it displaces saline formation water and then migrates buoyantly upwards, because it is less dense than the water. When it reaches the top of the formation, it continues to migrate as a separate phase until it is trapped as residual CO<sub>2</sub> saturation or in local structural or stratigraphic traps within the sealing formation. In the longer term, significant quantities of CO<sub>2</sub> dissolve in the formation water and then migrate with the groundwater. Where the distance from the deep injection site to the end of the overlying impermeable formation is hundreds of kilometres, the time scale for fluid to reach the surface from the deep basin can be millions of years.

Geochemical trapping

Carbon dioxide in the subsurface can undergo a sequence of geochemical interactions with the rock and formation water that will further increase storage capacity and effectiveness. First, when CO<sub>2</sub> dissolves in formation water, a process commonly called solubility trapping occurs. The primary benefit of solubility trapping is that once CO<sub>2</sub> is dissolved, it no longer exists as a separate phase, thereby eliminating the buoyant forces that drive it upwards. Next, it will form ionic species as the rock dissolves, accompanied by a rise in the pH. Finally, some fraction may be converted to stable carbonate minerals (mineral trapping), the most permanent form of geological storage (Gunter *et al.*, 1993). Mineral trapping is believed to be comparatively slow, potentially taking a thousand years or longer. Nevertheless, the permanence of mineral storage, combined with the potentially large storage capacity present in some geological settings, makes this a desirable feature of long term storage.

## VII. COST OF CO<sub>2</sub> CAPTURE AND STORAGE OPERATIONS

CCS applied to a modern conventional power plant could reduce CO<sub>2</sub> emissions to the atmosphere by approximately 80-90% compared to a plant without CCS. Capturing and compressing CO<sub>2</sub> requires much energy and would increase the fuel needs of a coal-fired plant with CCS by about 25%. These and other system costs are estimated to increase the cost of energy from a new power plant with CCS by 21-91%.

	<b>Natural gas combined cycle</b>	<b>Pulverized coal</b>	<b>Integrated gasification combined cycle</b>
Without capture (reference plant)	0.03 - 0.05	0.04 - 0.05	0.04 - 0.06
With capture and geological storage	0.04 - 0.08	0.06 - 0.10	0.06 - 0.09
With capture and Enhanced oil recovery	0.04 - 0.07	0.05 - 0.08	0.04 - 0.08

**Table 1: Costs of energy with and without CCS (2002 US\$ per kWh)**

### VIII. CONCLUSION

Large reductions in emissions of CO<sub>2</sub> to the atmosphere are likely to be needed to avoid major climate change. Capture and storage of CO<sub>2</sub>, in combination with other CO<sub>2</sub> abatement techniques, could enable these large reductions to be achieved with least impact on the global energy infrastructure and the economy. Capture and storage is particularly well suited to use in central power generation and many energy-intensive industrial processes. CO<sub>2</sub> capture and storage technology also provides a means of introducing hydrogen as an energy carrier for distributed and mobile energy users.

For power stations, the cost of capture and storage is about \$50/t of CO<sub>2</sub> avoided. This compares favorably with the cost of many other options considered for achieving large reductions in emissions. Use of this technique would allow continued provision of large-scale energy supplies using the established energy infrastructure. There is considerable scope for new ideas to reduce energy consumption and costs of CO<sub>2</sub> capture and

storage which would accelerate the development and introduction of this technology.

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