Carbon Capture and Storage: Science and Technology Focus for Mitigation of Climate Change

By Malti Goel*

Introduction

Global warming is attributed to increasing greenhouse gas emissions and mounting concentrations of carbon dioxide and other gases in the atmosphere. Since the middle of the 19th century, increasing worldwide anthropogenic activity is said to have given rise to a steady increase of carbon dioxide in the atmosphere. This is corroborated by direct measurement of CO_2 concentrations at Mauna Loa Laboratory in Hawaii (USA). The CO_2, present in the atmosphere as a trace gas, has an average atmospheric concentration of 280 ppmv. In 1958 the observed concentration was 315 ppmv, which suggested an increase of about 0.5 ppmv per year in the initial half of the 20th century. In 2005 the measured concentration of CO_2 was 374 ppmv, suggesting an increase of about 1 ppmv per year in the latter part of the 20th century.

The rising concentration of CO_2 is ascribed mainly to the use of fossil fuels—coal, oil and gas—for energy production and consumption. According to the International Energy Outlook 2007, world energy consumption is expected to grow from 442 quadrillion Btu (~ 750 billion boe) in 2004 to 702 quadrillion Btu (~ 1200 bboe) in 2030. In view of coal meeting 40% of world wide electricity needs and its high contribution to greenhouse gas emissions, it is imperative that options for reducing emissions from coal use be explored.

Carbon Capture and Storage

In this context CO_2 sequestration—carbon capture and storage (CCS)—is widely acknowledged as an emerging technology to address the problem of increasing carbon dioxide (CO_2) in the atmosphere. CCS is an effective means for reducing atmospheric CO_2 concentration, either through reduction of emissions using advanced clean technology or capture of excess CO_2 from the atmosphere. Although CCS is in the development stage, the International Energy Agency has estimated the potential contribution of CCS in removing CO_2 to be as high as 25 % of the global emissions in 2050.

To create awareness of the various technology options for carbon capture and storage as well as to keep pace with the future technology in coal based generation, a conference on Awareness and Capacity Building Programme on Carbon Capture and Storage (ACBCCS 2009) [1] was organized at the Indian National Science Academy in New Delhi from July 27 to 31, 2009. In this five day programme representatives from major stakeholder industries and academia participated with scientists from across the country and addressed the research frontiers associated with CCS. The conference was supported by the Ministry of Earth Sciences, Government of India and the National Environment Science Academy and highlighted current aspects of Indian research in CCS, as briefly discussed below.

Carbon Capture and Storage involves three basic steps.

- Capturing CO_2 from its point sources
- Liquefying and transporting the captured CO_2 to appropriate locations
- Permanently storing CO_2 away from the atmosphere in terrestrial or geological or oceanic formations.

CO_2 capture in coal based generation is approached in three ways, viz., pre-combustion, combustion and post combustion CO_2 capture (Figure 1).

Pre-combustion CO_2 Capture

The pre-combustion capture technology aims to remove or minimize CO_2 from the fuel before it is combusted. From natural gas CO_2 separation is routinely done by scrubbing before it is combusted. Coal needs to be, gasified before CO_2 separation. Integrated Gasification Combined Cycle (IGCC) technology is an appropriate choice. The CO_2 from coal gas should be removed at the higher temperature of gasification so as to reduce overall energy consumption. The CO_2 sequestration studies to find the materials—rare earths, composites and absorbents—which can perform at these high temperatures has been a research challenge. The development of the right materials that can withstand the required temperature for capturing CO_2 emanating from the coal Syn gas is the foremost requirement. Other requirements are regenerability of the material and the cost-effectiveness of the separa-

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See footnotes at end of text.

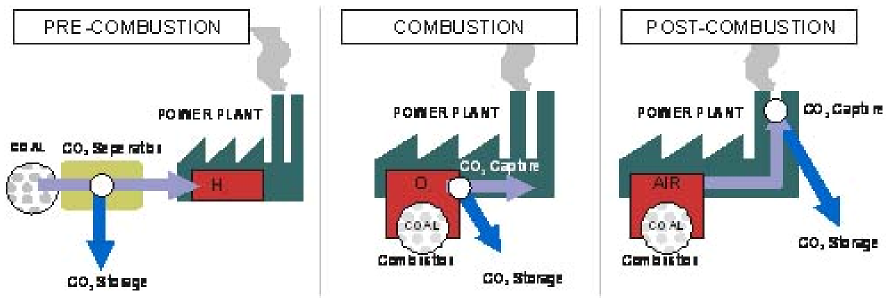


Figure 1
Pre-combusinton, Combustion and Post Combustion CO_2 Capture[2]

tion method. After removing CO_2 hydrogen remains as pollution free fuel.

CO_2 Capture During Coal Combustion

In coal combustion, improvement in the efficiency of generation can go a long way to reduce emissions. Pulverized fuel combustion is the most practical technology and has been adopted by 97% of the thermal power plants, world over. Pulverized fuel power plants under super-critical conditions offer improved efficiency. Research is also being conducted in advanced coal based technologies like molten carbonate fuel cell, chemical looping combustion, etc. for low emissions. Burning of coal in 100% oxygen is another option to reduce air pollution and increase the efficiency of power generation. The flue gas becomes rich in CO_2, about 90%, which is easier to capture. The oxy coal combustion is beneficial, but technically highly challenging. An oxy coal combustion pilot plant facility of 30MW has been demonstrated in Germany (Vattenfall and Alstom) in 2008. To discuss research issues relevant to development of oxy-fuel combustion technologies on a commercial scale, the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG) organized the first Oxy-fuel Combustion Conference in Cottbus this year. A few other demonstrations are in the pipeline in USA, Canada and Australia.

Post Combustion CO_2 Capturing

The post-combustion CO_2 capture technology is concerned with CO_2 separation from the flue gas of a conventional power plant. The flue gas is dirty since it contains many other pollutants besides CO_2. The share of CO_2 is of the order of 8-14%. The CO_2 can be captured by using techniques of chemical absorption, physical adsorption, cryogenic separation and membrane separation. The amine based solvent separation is well known technology, but the challenge lies in regeneration of the solvent and development of cost-effective adsorbents. New techniques like pressure and volume swing absorption cycles and use of polymeric membranes are being investigated. Vast possibilities exist for materials development in CO_2 sequestration research.

The estimated cost of post combustion CO_2 capture and storage has also been worked out. In electricity generation, the application of CCS may double the cost of generation, depending on the technology used. CO_2 capture is estimated to cost about 70% of the total (the remaining is for transportation and storage) and the energy penalty is also significantly high. A comparison of recovery and capture cost according to the technology used is given in Table. 1.

S.No.	Technology/ Parameter	CO_2 recovery %	CO_2 purity Achieved%	Energy Penalty %	Capture Cost US$/ton CO_2
1.	Chemical absorption	90	> 98	36	47
2.	Physical adsorption	90	44	47	61
3	Membrane separation	90	43	52	78

Table 1: Comparison of Post Combustion CO_2 Capture Options
Source- Post combustion CO_2 capture, Anshu Nanoti and Amar N.Goswami in ACBCCS-2009

Post Combustion CO_2 Capture and Storage

Besides these physical and chemical methods, biological routes are also being tested for post combustion CO_2 capture and storage.

Biological Route: The biological route to capture CO_2 from flue gas requires an algae pond in the vicinity of a thermal power plant. Development of strains with high productivity appears to be the most cost-effective solution. But the greatest challenge is to isolate algae and genetically improve algal strain for both higher oil content and overall productivity. Marine algae could also form a possible solution for thermal power plants situated along the sea coast. Micro-mediated CO_2 sequestration using carbonic anhydrase offers another option. A proper understanding of enzymes and hetero-trophic microbial systems would help in stabilizing atmospheric carbon through photo-autotrophic and non-photosynthetic CO_2 fixation processes.

Ocean Sequestration: Oceans are vastly unexplored option for CO_2 storage. Oceans have higher CO_2 flux than the atmosphere. The options for storing CO_2 can be on the surface, below the surface and on the deep sea floor. However, its effect on the marine ecosystem and living resources is yet to be assessed. The lowest estimate of CO_2 that can be stored in the Sea floor of ocean basins in a super cooled liquid state permanently is approximately 5000 giga tones (Gt). In addition to these, iron fertilization studies for increasing phytoplankton productivity by CO_2 injection in Northern and Southern Oceans have been carried out. The most recent one is LOHAFEX (LOHA – Iron, FEX - fertilization experiment) conducted in 2009.

Terrestrial Sequestration: Some other methods for CO_2 sequestration and storage are also under investigation. Terrestrial sequestration aims at biological amplification of carbon fixation in soil and biota. Increasing forest cover is considered the most appropriate and cost-effective proposition as a means of mitigation of climate change. However, it requires enormous data on carbon stocks, rate of sequestration and soil emission over different land covers. Recent advances in modern biology, including advancement in genomic sciences, provide new methods for enhancement of the photosynthetic reaction rate in plants for CO_2 sequestration. Such genetic approaches are expected to increase crop productivity in the long-run.

Underground Storage: Many new concepts and also being developed for CO_2 sequestration and storage. For example, the use of deep underground formations like saline aquifers and basalt rocks for storage of bulk of CO_2. While saline waters at a depth of 800m or more could safely dissolve CO_2 without contamination of ground water, basalts are expected to provide solid cap rocks and thus a higher level of integrity for CO_2 storage on geological time scales. Basalt rocks react with CO_2 and can convert it into mineral carbonates. Such inter-trappean zones between basalt flows are considered to be most stable. The Columbia River basin in USA has shown encouraging results in CO_2 storage in basalts.

Enhanced Oil Recovery: CO_2 injection as a secondary method of enhanced oil recovery is another promising technology. The CO_2 injected in depleting oil or natural gas reservoirs is expected to increase the viscosity of leftover crude and result in oil recovery. Enhanced oil recovery from oil fields and coal bed methane recovery in coal seams are additional options for CO_2 storage. Business models on these lines are also being developed. However, very little knowledge base exists in these areas and results are still in their infancy. It requires a greater thrust to make CO_2 sequestration commercially viable.

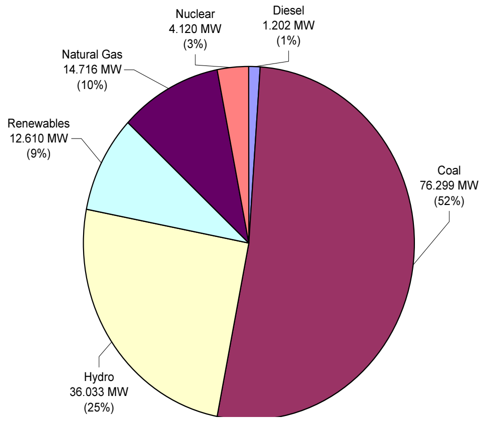
New Breakthrough Concepts: Advanced concepts of CO_2 sequestration are also being examined to achieve cost-effective solutions.

- Application of plasma for decomposition of coal before combustion may lead to an efficient route of carbon free power generation.
- Advances in nano-sciences to find more efficient nano-material compositions for selective capture of CO_2 can offer cost-effective solutions for large-scale separation process in the long run.
- Nano catalysis to enhance the reaction rate of CO_2 with other chemicals and thus help the removal of CO_2 from the atmosphere.
- The above mentioned research on carbon sequestration has focused on capture from large point sources, however, attempts are also being made to capture CO_2 directly from the air. The advantage is that CO_2 emissions from anywhere can be captured, including emissions from mobile sources such as automobiles, airplanes and other diffused sources like agriculture. In addition the capture unit can be located at a favorable sequestration site away from the point source, avoiding the need for extensive CO_2 transportation infrastructure. Global Research Technologies have demonstrated such air extraction device to capture the carbon dioxide molecules from free-flowing air.

The Indian Situation

The energy situation in India is unique. India's share of global CO_2 emissions is 3%, but on per capita basis it is much lower than the world average. Coal is used in 69% of electricity generation (52% of the installed capacity) and 70% of the energy needs of manufacturing and process industries like steel, cement, fertilizers and others are met through coal. The share of different fuels in the total installed capacity in 2008 is shown in Figure 2. India has made tremendous strides in renewable energies. In wind energy utilization the share has increased from almost nil to 9% in the last two decades. India has retained its position as the fifth largest country in the world in wind installed capacity for more than a decade.

The Indian economy is currently growing at a rate of 7 to 8% per annum. India's policy for sustainable development includes: increasing the use of renewable energy, promoting energy efficiency and changing the fuel mix to cleaner sources, controlling energy pricing, pollution abatement and increasing forestation. This is expectsed to result in a relatively low carbon development path. In the energy mix, the share of fossil fuels is expected to be 50- 60%, depending mostly on coal as natural gas supplies are inadequate. In the projected growth in 2031-32 (the installed capacity approaching 800 GW - Integrated Energy Policy of India 2006) the coal requirements for three different scenarios, namely; (i) coal dominant, (ii) reference scenario and (ii) renewable dominant with energy efficiency measures has been



Total Installed: 144,980 MW

Figure 2. Contribution of Various Sources of Energy in the Installed Capacity in 2008.

Source- All India Electricity Statistics, General Review 2008, CEA, Min. of Power, Government. of India.

worked out[3]. The coal demand is expected to grow to 2.0 Bt in 2031-32 for the reference scenario, 2.6 Bt for coal dominant scenario and 1.6 Bt for renewable dominant case.

In India, plans are underway to introduce new capacity additions using super-critical boilers for increased generation efficiency. An advanced coal based Integrated Gasification Combined Cycle (IGCC) demonstration was made way back in 1989 at Bharat Heavy Electrical Ltd.(BHEL) in a pilot plant of 6.2 MW capacity. Coal with up to 40% ash was tested at temperatures of 960 ^{o}C and 1050 ^{o}C at 0.8 MPa in a fluidized bed gasifier. The Indian power industry also has plans to introduce test facilities for oxy fuel combustion using indigenous coal. The National Action Plan on Climate Change has been announced to address global climate change concerns through mitigation and adaptation measures.

CO_2 sequestration research in India started in 2004 through industry and government support. The National Programme on CO_2 Sequestration (NPCS) research has been initiated from the inter-sectoral perspectives of pure and applied research with the participation of academic institutions and R&D laboratories across the country. Since carbon capture technology involves huge costs and high risk, its commercial viability cannot be ensured in the near future. As far as advancement in clean coal technology is concerned, whether IGCC or supercritical power generation cycle or oxy fuel combustion cycle will prove more effective for CCS, is yet to be determined.

Conclusions

The rise in global average temperature is the most contentious issue of our times. Innovations in technology for mitigation of CO_2 need to be made an inclusive process of the growth and development of every country. India has a unique distribution of installed electricity capacity; Coal – 52%, Oil & gas – 11%, Hydro –25%, Renewables – 9%, and Nuclear – 3%. India's policy for economic growth and sustainable development is expected to result in a relatively low carbon energy path. The National Action Plan for Climate Change has been formulated. It has identified eight action areas. The ACBCCS-2009 provided scientific awareness on CCS technology developments.

Since climate change is a global phenomenon and is posing a danger to the existence of the entire world, it requires policy and technology actions by all the nations. The Copenhagen meeting is a unique opportunity in a more than one way. Instead of fixing a uniform cap, the developed nations must come forward to check CO_2 emissions at a scale and speed greater than the developing nations. Individually each country needs to develop an approach for reducing emissions from fossil fuel use through advancements in energy technology and carbon capture research, besides the use of efficient lighting, green buildings and clean technologies such as solar and wind.

Footnotes

[1] The author was the organizing secretary

[2] ACBCCS-2009 News Flier

[3] Integrated Energy Policy, Report of the Expert Committee 2006, Government of India.