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Carbon Dioxide Reduction Options in Power Generation

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Various renewable energy resources like solar, wind, hydro, biomass and geothermal are a suitable option for mitigation of climate change and reducing the carbon dioxide in the atmosphere and have been studied in detail. Advance technologies for CO_2 reduction are carbon sinks and sequestration methodologies which involves capture of carbon dioxide from the source, its utilization and disposing of into sinks as stored for long term durations.

Key Words: Carbon dioxide, Climate change, Power sector, Coal and Carbon sinks.

INTRODUCTION

Climate change (greenhouse effect) occurred as a consequences of anthropogenic activities like combustion of fossil fuels, deforestation etc. Worldwide about one third of all carbon dioxide emissions come from fossil fuels energy sources *i.e.*, thermal power plants. These liberate the highest density of CO_2 emissions in terms of mass area per unit of time, so they provide appropriate focus as a control target.

Under the business as usual scenario, carbon dioxide emissions are estimated to increase fourfold[1] during 1990-2020. From 1950 to 1999, India experienced dramatic growth in fossil-fuel CO_2 emissions averaging 5.8 % per year and is become the world's fifth largest fossil-fuel based CO_2-emitting country. Since 1990, Indian total emissions have risen[1] to 58.6 %. Fossil-fuel emissions in India continue to result largely from coal burning with India being the world's third largest producer of coal. Considering the case of the energy sector, coal contributed 87 % of the emissions and the oil fraction is 18 %. With the world's second largest population and over one billion people, India's per capita emission rate for 2000 of 0.29 metric tons of carbon is well below the global average (1.09) and the smallest per capita rate of any country with fossil-fuel CO_2 emissions exceeding 25 million metric tons of carbon.

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Various atmospheric CO_2 emissions reduction techniques which are considered under high areas of research as follows: (a) reduction in the fossil fuels consumption for energy and other applications, (b) increasing efficiency of energy conversion and utilization, (c) switching to lower carbon contents fuels for instance natural gas, fuel cell, *etc*., (d) using renewable /nuclear energy sources (*i.e.*, energy sources low at CO_2), (e) capture and store CO_2 from fossil fuels combustion, (f) enhance CO_2 sinks *e.g.* forests, soils and oceans.

The usage and application of these techniques depends on costs available, available energy resources, emission reduction targets, environmental impacts and many other social factors.

The average thermal efficiency of PC units in developing countries especially India is lower than that in OECD and developed countries. The main factors responsible for lower efficiencies in the thermal power stations are plant age, attending low design parameters, operational and maintenance related deterioration and use of poor fuel (coal) quality. Coal quality in India has been deteriorating over time along with its calorific value, ash and moisture content. It adversely effects the thermal efficiency of even the well run power plants. In India the total domestic fuels of about 59.2 % in rural areas and 35.5 % in urban areas are being met from woodfuel.

Advance technologies for CO_2 reduction are carbon sinks and sequestration methodologies which involves capture of carbon dioxide from the source, its utilization and disposing of into sinks as stored for long term durations. Carbon dioxide capture involves chemical and physical absorption, gas solid absorption, cryogenic and gas separation or removing using specialized membranes.

Potential impacts of carbon dioxide: Projections by International Energy Agency in World Energy Outlook 2000 have indicated that global CO_2 emissions would increase to 29575 and 36102 million tones in 2010 and 2020, respectively[2]. IPCC suggests that global mean surface temperature of the earth has increased by between 0.3 to 0.6 °C since the late 19th century. Giorgi and Hewitson[3] concluded that a doubling of CO_2 would increase the temperature by 2-4 °C and decrease rainfall by 10-20 % (> 1 mm day^{-1}). Carbon dioxide has already risen by 30 % since the industrial era, back[4] in 1975. Fast accumulation of carbon dioxide into atmosphere can evidently affect climate of earth rather quickly by warming earth surface. This effect is associated with absorption of long wavelength radiation much more by CO_2 than other GHGs. In particular, atmosphere of northern hemisphere will be 1 °C warmer because of anthropogenic carbon dioxide, when this contribution will have reached several billion tons corresponding to a 60 ppm increase in concentration from now[5], such an increase could take place by the year 2010.

The global atmosphere, traps an increasing amount of heat due to increased concentration of CO_2 and thus higher temperatures will result globally. This change in atmospheric temperature is of concern since even an increase of a few degrees, would leads to severe regional effects, such as prolonged droughts, crop failure, change in cropping pattern, vegetative production with increased desertification, polar ice might partially melt, resulting in ocean flooding and submergence of major portions of low lying islands and coastal areas. Problems like global warming, climate change, emergence of natural hazards like flooding, change in sea levels, are on their headway and for all these, increased concentration of carbon dioxide is held responsible. And for all this change human activities are held responsible, which mainly includes the emission of GHGs by fossil fuel combustion[5].

Energy profile in India: Electricity demand, growing at 8.7 % annually during present decade, has outstripped economic growth rate of 6.2 % and electricity consumption per person has increased[6] to 355 kWh (2001-02) from 90 kWh in 1972. A comparison with world of fossil fuels share in energy generation along with their CO_2 emission is presented in Table-1. India's energy use is mostly based on fossil fuels. Total installed capacity of country rose from only 1362 mega watt in 1947 to over 1,44564.97 mega watt presently and generation from 4.1 to over 744 billion kWh during this same period. Present installed capacity includes contributions by thermal (coal, gas and oil) 92,216.64 mega watt (64.6%); hydro 36033.76 mega watt (24.7 %) and 4,120 mega watt by nuclear (2.9 %) and remaining 12194.57 mega watt (7.7 %) by solar, biomass, wind and other renewables. Fig. 1 presents the installed capacity growth till May 2008, beginning from 1947 when India get independence. The geographical distribution of available primary commercial energy sources in country is quite skewed, with 77 % of hydro potential located in northern and north-east region of the country. India is third largest coal producing country and about 60 % energy demands are met by coal. Coal is the major source of energy production in commercial sector.

TABLE-1
FOSSIL FUELS SHARE IN CARBON EMISSION AND ENERGY GENERATION

Fuel	Share of Energy Generation (%)		Share of Carbon Emission (%)	
	India	World	India	World
Coal	55.0	20.3	69.78	41.20
Oil	30.5	41.3	26.31	42.65
Natural gas	7.0	21.1	3.90	16.12

Carbon dioxide reducing options for power generation in India: There are various technologies and process that have substantial potential to reduce GHG emissions[1] for instance, coal and biomass gasification technology, gas turbine technology, power generation with solar thermal and photovoltaic technology, fuel cells, *etc*. Clean coal technologies and renewable energy usage have been adopted by India as methods of best approach to discuss climate change. These are broadly classified as: (a) energy conservation and improvements in energy efficiency, (b) use of low carbon fuels like natural gas and hydropower, (c) promote afforestation, (d) sequestration, (e) sinks.

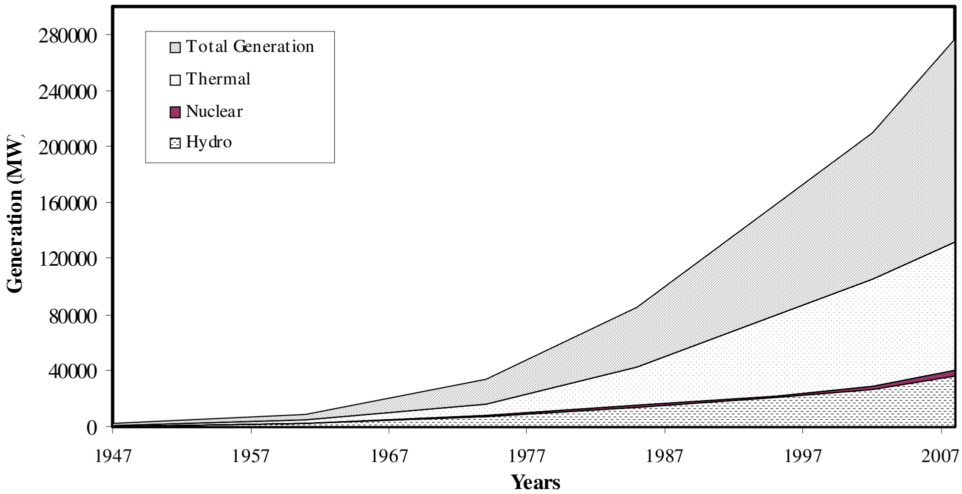

Fig. 1. Total power generation in India (1947-2008)

These options have been partially implemented and further implementations are necessary to move towards a sustainable energy future and reduce its dependency on coal fired electricity generation. Along with all these methods, further steps can be implemented for reduction of CO_2, these are research and development, information and education (for awareness), economic measures, regulatory measures and voluntary agreements. Each step offers advantages and drawback and has different effect on CO_2 reduction. Measures often interact and function in combination.

Climate change policy: In India the electricity demand is going to increase due to population growth and rising living standard. Fig. 2 presents the installed capacity growth from possible energy sources for all the 5 year plans. Total energy demand has been estimated to be 563.21 MTOE and 723.93 MTOE respectively in 2006-07 and 2011-12. Increased economic growth and market policy in developing Asia is expected to lead to increased demand for electricity. By 2020, developing Asia is expected to consume more than twice, as much electricity as it did in 1999 along with the CO_2 emission are expected to rise at an continuous rate. Government of India has been concerned for the growth of energy consumption with the increase population through its energy mix policy as evident for the Fig. 2. Along with thermal, hydro and nuclear, an extensive growth (7.7 %) in renewable energy resources as well has been observed.

According to climate change reducing policy of the government, India is Party to United Nations Framework Convention on Climate Change (UNFCCC) and participates in international efforts to find a coordinated, equitable and effective set of actions to combat the threat of climate change. Still country's policy insists more on use of coal since its major fossil fuel for power generation.

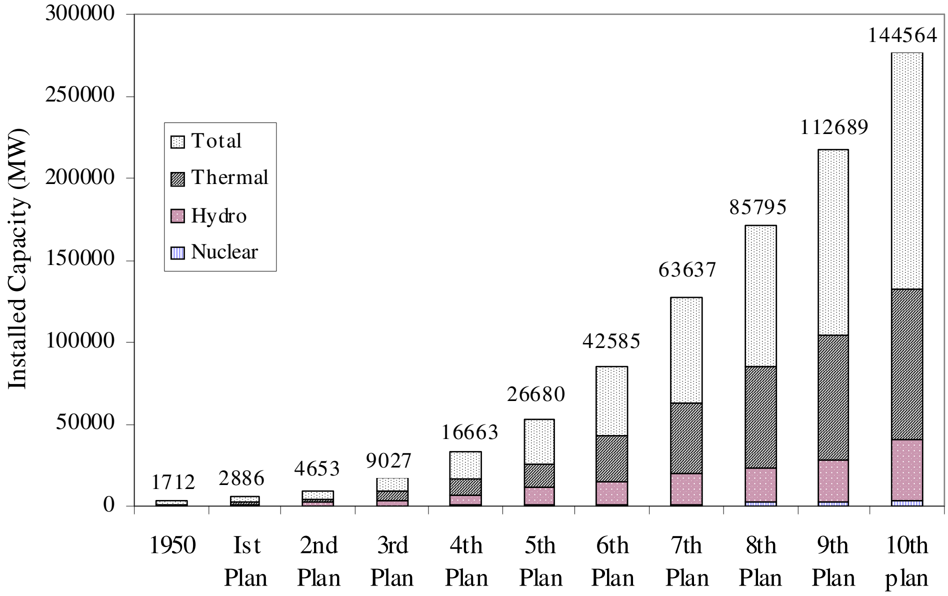

Fig. 2. Five year plan wise installed capacity growth

India recognizes the importance of reducing these harmful emissions and also places a high priority on economic development. As such, India is not a signatory to Kyoto Protocol that mandates specific commitments by countries to reduce their emissions of greenhouse gases to an average of 5.2 % below 1990 levels by 2008-2012. Nevertheless, India accepted (ratification was unnecessary) Kyoto Protocol on August 26, 2002.

Clean coal technologies (CCTs): Use of cleaner coal technologies (CCTs) can reduce the environmental impact of the increase in coal use. In India, conventional pulverized coal (PC) type of technology is used in most of the installed power generating station. An analytical study of CCTs for their energy consumption, net efficiency, CO_2 emissions and specific CO_2 reduction in relation with conventional pulverized system is presented in Table-2.

TABLE-2
ENERGY CONSUMPTION, NET EFFICIENCY AND CO_2 EMISSION OF GENERATION SYSTEMS

Technology	Energy Consumption kWh fuel/kWh_{el}	Net Efficiency (at full load)	CO_2 emissions Kg/kWh_{el}	Specific CO_2 reduction related to conventional systems (%)
Conventional hard coal-fired power plant (PC)	2.63	0.38	0.87	-
Combined cycle with PFBC	2.41	0.41	0.80	8
IGCC	2.22	0.42	0.79	9
IGCC with Hot gas cleaning	2.22	0.45	0.73	16

Power generating facilities in developing countries are often outdated and poorly maintained, but India is improving in terms of replacement of outdated and old installations by new and more efficient technologies. IGCC technology is being tried in several power stations, but still in experimental stages.

Efficiency improvement in power generating stations: Increasing generation efficiency is major components of a broad-based energy efficiency programme carbon dioxide reduction option. This can be achieved through heat rate improvements and reduction of auxiliary power consumption in thermal power plants. Energy efficiency and emissions of environmental pollutants in thermal power stations are dependent upon the fuel used for combustion in furnace. Efficiencies in many countries including India, having PC boilers can be improved by 10 to 20 %, which can lead to a large reduction in carbon dioxide emissions[1]. Increased efficiency through generation, transmission and distribution projects should emphasize on activities as heat rate improvements, cogeneration and waste heat recovery, high-efficiency transformers and reductions in line losses associated with electricity transmission and distribution. Fig. 3 presents the decrement in CO_2 emissions with the increase of the efficiency from 26-40 %.

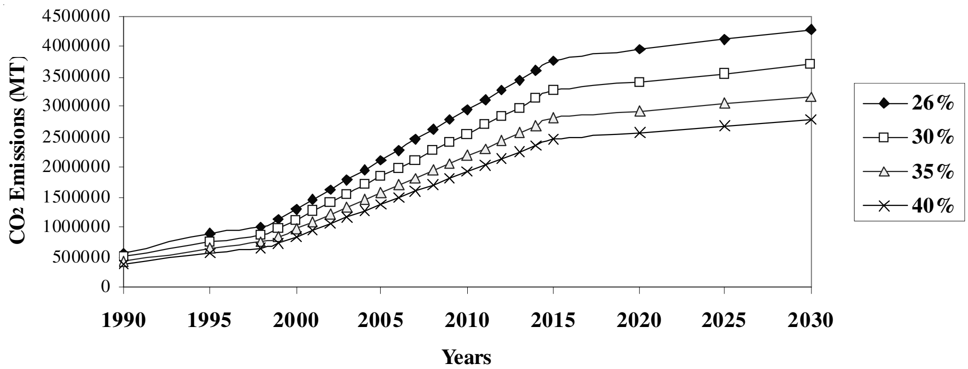

Fig. 3. Efficiency improvement in PC technology and CO_2 emissions

Average net efficiency for power generation in India, is *ca.* 26 % that means 74 % of thermal energy produced is lost in production and distribution[7]. Production and distribution improvements can be done by T&D upgradation, to improve the delivery of electricity from power stations to the end user. Reduction of CO_2 emissions from energy end use and transportation can be met by reducing energy demand at stationary sources and transportation fuels use. And if these power stations work at design efficiency, increase in aggregate power output will be more than 15 % employing 12 % decrease in CO_2 emission per kWh of energy generated and similar observation have been reported by Kumar and Sinha[8].

Also fuel switching from coal to other fuels of less carbon intensity, decreases CO_2 emissions per unit of energy consumed by as much as 43 % when switching from coal to natural gas[9].

Renewable energy as a tool for mitigation of climate change: Renewables have the capacity to replace fossils for reducing the greenhouse gases emissions. According to government policy, it is suggested and targeted that there would be 10 % power generation in India by renewables. Major issues due to which generation from renewable energy sources is facing setback in India are resource variability is site specific, load uncertainty, system selection/sizing-incomplete assessment of options, most renewables are promoted by individual technologies/component suppliers, system analysis/load forecasting, software/modeling support is required.

The country possesses renewable energy sources in abundance. Potential capacity is estimated to be 126,000 MW. The largest source (79000 MW) including ocean, thermal, tidal/wave power. Solar energy is also available in abundance and intensity, which needs to be tapped.

Similarly waste to energy options are open to be explored. Waste can be urban, agricultural, animal residue or industrial waste, Indian waste is rich in organic content.

Carbon dioxide sinks: Disposal of carbon dioxide into sinks can be the best mitigation option. Carbon dioxide sinks are biosphere sinks (oceans, forest and soils), geosphere sinks (oil reserves, coal beds, depleted oil and gas reservoirs and deep aquifers) and material sinks (durable wood product, chemicals and plastics). These CO_2 sinks are grouped on the basis of nature; location and ultimate fate of carbon dioxide[10].

Buildup of CO_2 in the earth's atmosphere is presently only occurring at a rate of 1.8 ppmv/year (14.0 Gt CO_2/year) due to several, natural carbon dioxide sinks which work to remove the gas from the planet's atmosphere. The sinks, which remove gases from the atmosphere, are generally natural processes that have a limited capacity[11].

Oceans as sink: Oceans absorb CO_2 from the atmosphere because the concentration of CO_2 in the atmosphere is greater than that in the oceans. This difference in 'partial pressure' of CO_2 results in the gas being absorbed into the world's oceans. The amount of CO_2 which can be taken up by the oceans in a given year is a function of wind speed, air and water temperatures and concentration gradients and is therefore difficult to determine accurately. Similarly, the absolute amount of CO_2, which the oceans will be able to absorb, is currently a matter of debate. The best estimates of the ocean sink are that the oceans are absorbing 7.4 Gt CO_2/year (0.9 ppmv/year)[12].

Forests as sinks: Forest sequesters carbon for a finite time periods, which allow the implementation of more permanent options for avoidance of GHGs emissions and stabilization of climate change. Slowing deforestation and planting trees will increase the planet's terrestrial biomass sink, also slowing CO_2 buildup in the atmosphere. Globally forests, grasslands and other land-based plants are currently absorbing an estimated 5.5 Gt CO_2/year (0.7 ppmv/year). Total forest area in India is $63,300 \times 10^3$ ha having deforestation rate of 274×10^3 ha year^{-1}. Out of the total land available for forestation (*i.e.*, 53200×10^3 ha) about 10640×10^3 ha can be considered for energy plantation. Trees growth in the forest serves as an important means to capture and store atmospheric CO_2 in vegetation, soil and forest products. Further in India, wasteland available for forestation is quite large, *i.e.*, 30×10^6 ha. Energy plantation can be used for power generation in three general applications for instances: (i) co-firing in fossil fueled fired power generation facilities, (ii) cogeneration in agriculture and forestry processing facilities, (iii) stand alone grid connected biomass-based power stations, which consider energy plantation feed stocks and agriculture residue like bagasse, wood waste, rice hull, *etc*.

Though non-conventional fuels like biomass, hydro, solar, *etc.* can replace coal based power generations to an extent but they are expensive to establish and operate one hand while their net life cycle CO_2 emissions are negligible or zero on the other hand which provide them a superior position above fossil fuels like coal.

Brown *et al.*[13] have grouped forest mitigation activities into three categories: first category includes activities that avoid the release of emissions from carbon stock (forest conservation and protection); second includes activities that stores carbon (afforestation, reforestation and agro forestry) and third category involves substituting the use of carbon intensive products and fuels with sustainable harvested wood products and wood fuel (*e.g.* substitution of wood for steel or concrete and bio-electricity for electricity generated from fossil fuels combustion). Sathaye *et al.*[14] have suggested afforestation (short and long rotation) regeneration and protection of forest as a possible and fastest way to reduce carbon emissions. The potential was estimated to be of order of 1 Pg C $year^{-1}$ in 2010 or enough to offset a large portion of annual GHGs emission from this sector during 1990s.

The reason for forests as increased sink is that increased levels of atmospheric CO_2 have acted to 'fertilize' plant matter, causing their increased growth. Forests allow bio-chemical conversion of carbon dioxide into useful product for long-term storage. Regeneration of forests on abandoned farmLand in northern hemisphere may also be contributing to the capacity of this sink.

Emissions of CO_2 from coal combustion can also be reduced by CO_2 capture and sequestration. The CO_2 may be stored in aquifers, oil and gas fields or on the ocean floor. These technologies have great potential and have been studied in depth by the IEA Greenhouse Gas R&D Programme[15].

Conclusion

Reduction measures can be improved many-folds with a combination of two options *i.e.*, using low carbon fuels in efficient systems for power generation and enhanced growth of sinks (*e.g.*, forests). Also CO_2 emissions reductions cannot be achieved with in a short span of time, since clean coal technologies, renewable energy sources and sinks have their own times to reduce CO_2 from atmosphere.

Nomenclature

GtC: Giga tons of Carbon; PgC: Pico gram carbon; Ppmv/year: parts per million volume per year; ha $year^{-1}$: hectare per year.

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