Low Carbon Technologies (LCT) & Carbon Capture & Sequestration (CCS) – Key to Green Power Mission for Energy Security & Environmental Sustainability

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ABSTRACT
Despite the fact that we in India have taken a giant leap forward in increasing the installed capacity from a mere 1713 MW in 1950 to over 2,54,000 MW as on date, the renewable energy sources however contribute merely 13% with total capacity of over 31,600 MW. But this contribution has a major social and economic impact on rural and remote area population. The growth of clean energy technologies for mega Power generation, such as the Solar Mega Power under Jawaharlal Nehru Solar Mission, both Solar Thermal and PV, Clean Coal Technologies, CCTs, i.e. Supercritical power plants, Integrated Gasification Combined Cycle (IGCC) and fluidized bed combustion (FBC) are key to the success Green Power Mission for India. Carbon Capture & Sequestration (CCS) is considered as the frontier Green Energy technology. CCS technology is still in the demonstration phase, and it is important that India is not left behind in this area. While there is a considerable amount of work already underway domestically, there may still be a need for research collaborations and knowledge sharing and transfer. These areas of research in CCS include development of new adsorbents, better process integration of capture equipment, and conversion of CO2 to useful products, among others. The important challenge of Energy penalty in CCS being faced world-wide, can be met through use of Concentrated Solar Power (CSP) for supplementing steam for regeneration in a MEA and other solvent based post-combustion CCS in Thermal Power Plants. Low Carbon Technologies (LCT) and Carbon Capture & Sequestration (CCS) are key factors for Energy Security Environmental Sustainability and the same are forward in this paper leading to an opportunity for course- correction in our line of thinking in Green Power.

I INTRODUCTION

(a) Green Power Technologies – Clean Coal & Renewable Energy- We are aware that the Global concern for reduction in emission of green house gases (GHG) especially CO_2 emissions are likely to put pressure on Indian Power System for adoption of improved generation technologies. Although India does not have GHG reduction targets, it has actively taken steps to address the climate change issues. It is estimated that the Green Energy Projects undertaken by Indian Power Sector will generate over 600 million Certified Emission Reductions (CERs), by 2015. Mitigation options for CO2 reduction which have been planned to be taken up by Indian Power Sector include GHG emission reduction in power sector through adoption of Co-generation, Combined cycle, Clean Coal Technologies and Coal Beneficiation. CO_2 emissions per unit of electricity generated are significantly high in India as large proportion of power generated comes from low sized, old and relatively inefficient generating units which constitute over 50% of our total installed capacity of about 2,12,000 MW. The technology up gradation through life extension of old polluting units is expected to increase the generating efficiency of these units thereby reducing CO_2 emissions.

A major thrust on CO_2 reduction on long term and sustainable basis would however come through adoption of advanced technologies of power generation like Supercritical/Ultra-supercritical power cycles, Integrated Gasification Combined Cycles (IGCC), Fluidized Bed Combustion, and Gasification Technologies and so on. In addition to Clean Coal Technologies, India is currently sitting on a gold mine of opportunities of Energy farming for Bio-diesel production, Biomass gasification for decentralized power generation and for alternative rural energy security to a large extent. The planning commission report on Bio-diesel (2003) advocates for a substitute of 20% of current diesel demand by Bio-diesel through energy farming on the available 11.2 million hectare land comprising of waste land, spare forest land and cultivation of Jatropha in rural areas and both sides of vast Railway track. This would generate a vast sink for CO_2 while at the same time reduce exhaust emission through substitute of Bio-fuels for transportation and other decentralized energy production needs.

(b) Clean coal Technologies- A beginning towards adoption of Clean Coal Technologies in the form of super critical units has already been made in the country and it is foreseen that super critical technology would almost universally be adopted for all large sized pithead units in the country. The attained efficiency gains of these technologies are likely to reduce the environmental emissions especially CO_2 significantly. Adoption

of higher parameters for super critical units after sufficient feedback and operational experience would further reduce these emissions to a great extent. A total additional efficiency of about 1.5-2% is normally achieved for adoption of super critical parameters of 246-kg/cm2 (g) and 537/565C, chosen for the first Supercritical Power Plant under planning with unit size of the order of 660 MW. Adoption of still higher parameters would further enhance the efficiency. Attempts would also need to be made to further enhance the efficiency of conventional pulverized coal fired plant by adoption of ultra super-critical parameters. The main constraint being faced for adoption of these technologies is the availability of requisite material to withstand combination of high Pressures and temperatures encountered. A consortium of several equipment manufacturers globally has pooled their resources to develop necessary materials to overcome the constraints for adoption of ultra super-critical technology.

Another option for CO_2 reduction is the increased use of natural gas. This provides improvement in generation efficiency together with reduction in CO_2 emissions but would facilitate environmental pollution control only up to a certain extent. With addition of more and more generation capacity and also increasing CO_2 emissions from transport and other industrial sectors, progressive de-carbonization of generation resources may have to be adopted in certain regions/areas. Already, Natural Gas is being used in a big way in the country for power generation and GT/CCGT stations accounted for about 9.4% of total generation today. The natural Gas resource crunch being faced at present, even though there is quest for quick power generation restricts increased use of Natural gas in Combined Cycle mode, limiting it to some specific priority areas only. Research work in this area to increase the generation efficiency of Combined Cycle to an extent of 60% is already underway and this goal is likely to be realized in near future. These technologies can then be adopted as and when available. A much more efficient methodology of generating electricity from Natural gas is on the anvil and this is fuel cell technology which looks more promising source of Energy option in future.

Gasification of Coal is the cleanest way of utilization of coal; while combined cycle power generation gives highest efficiency, the IGCC is thus categorized as an environmentally benign Clean Coal Technology.

IGCC technology combines several desired attributes and are becoming an increasingly attractive option among the emerging technologies. First, IGCC systems provide high-energy conversion efficiency with the prospect of even higher efficiencies; if higher temperature turbines and hot gas clean up systems is employed. Second, very low emission levels for sulfur and nitrogen oxides have been demonstrated worldwide in such facilities as the Cool Water IGCC plant in California. Most designs for IGCC systems use cold gas cleanup including low temperature removal of SO_2 and particulate from the coal syngas, sulfur byproduct recovery, and syngas steam spray to reduce NOx formation in the gas turbine. IGCC is characterized by its potential to generate power at higher efficiency due to the possibility of coupling newer generation gas turbines with higher Turbine Entry Temperature (TET). IGCC is a superior technology due its capability to produce value added compound and fuels as well as ease of retrofitting a Carbon Capture and Sequestration (CCS) unit on an IGCC plant.

A 6.2 MW domestic coal based IGCC pilot power plant has been set up in India by Bharat Heavy Electrical Limited (BHEL), which has contributed in technology assessment of gasification of high ash Indian coals. However commercialization of IGCC needs technology demonstration at an intermediate scale of about 100 MW to address the issues regarding hot gas clean up, system optimization etc. and to establish reliability and performance on continuous operation. This would also enable to get the performance of an optimum module for air blown gasification, which in multiples would constitute a commercial size plant in the range of 300 – 600 MW sizes. Three options are possible for the demonstration plant.

(i) Retrofit to an existing gas based power plant with a coal gasifier system by utilizing the existing Power Island and operating the plant by replacing natural gas by coal gas.
(ii) Converting an existing thermal power plant to IGCC mode by installing a Gasification Island and gas turbine.
(iii) Setting up a green field IGCC plant.

Retrofit or conversion (options a, b) may be least cost options but will involve shut down of the existing power plant for carrying out modifications. In India due to acute power shortage it is not desirable to shut down any of the existing power producing capability. If appropriate financing were available, it would be preferable to set up a green field IGCC plant. This could act as a demonstration plant for generating design data for up scaling and for testing various types of coals as well as processes of gas cleaning and establish the integration between Gas Island and Power Island. A green field plant would also be a good option for human resource development and training of manpower in this field. NTPC, BHEL and APGENCO have joined hands for execution of 100 MW IGCC plant.

There is no doubt that IGCC can revolutionize the power generation scenario in India, once the commercial viability of technology with high ash coals is established for the proposed range of 100 MW plant. The success of the project will largely depend on maturity of Fluidized bed gasification technology for high ash Indian Coals.

(c) Renewable Energy Technologies- By virtually all accounts, renewable energy resources will be an increasingly important part of the power generation mix over the next several decades. Not only do these technologies help reduce global carbon emissions, but they also add some much-needed flexibility to the energy resource mix by decreasing our dependence on limited reserves and overseas sources of fossil fuels. The rising stars of the renewable world-wind power and photovoltaic (PV) are on track to become strong players in the renewable energy market of the next century. We shall see an emergence of the solar wind hybrid as major power packs for decentralized power generation.

Wind power is the fastest-growing electricity technology currently available. Wind-generated electricity is already competitive with fossil-fuel-based electricity in some locations, and installed wind power capacity in India is at a respectable level of 22,000 MW. Meanwhile, PV electricity, although currently three to four times the cost of conventional, delivered electricity, is seeing impressive growth worldwide. PV is particularly attractive for applications not served by the power grid. Advanced thin-film technology (a much less expensive option than crystalline silicon technology) is rapidly entering commercial-scale production, with 25 MW of manufacturing capacity installed in the past few years.

The energy-starved developing world, which accounts for a large portion of the projected new electricity demand over the next 20 years, is considered one of the biggest markets for renewable. Many of these countries are attracted to the technologies; modular nature; located close to the user, the units are far cheaper and quicker to install than central-station power plants and their extensive lengths of transmission line. There is no doubt that R&D in the optimum mix of Solar Wind & Biomass; having proven complementary nature in providing sustainable power, will have to be pursued more vigorously than today.

In the United States, national surveys show that well over half of consumers are willing to pay more for green power, and a number of power companies are now offering this option. We in India are also committed to achieve the target of 20 - 25% Renewable by 2017, though coal is going to remain our main stay for next 2-3 decades. The issue before Indian Energy Sector today is use of high ash Indian Coal for optimum power generation with minimal environmental impact due to CO2 emission.

The power sector already started witnessing a transition from conventional power generation technologies to the green power technologies. A major thrust on CO2 reduction on long-term and sustainable basis would come through adoption of Renewable Energy Technologies and advanced Cleaner technologies of power generation like Supercritical / Ultra-supercritical Power Cycles, Integrated Gasification Combined Cycles (IGCC), Fluidized Bed Combustion / Gasification Technologies and other such green energy technologies. In the short-term, the focus is mainly on energy conservation measures and use of selected hybrid of renewable technologies like solar-wind-biomass.

II CARBON CAPTURE & SEQUESTRATION – A FRONTLINE TECHNIQUE FOR COMBATING CLIMATE CHANGE

(a) Introduction- Climate Change & Energy generation- Climate change caused by the excessive industrial emissions of greenhouse gases (GHGs) is one of the gravest challenges facing our planet today. Studies have shown that there is no single option for combating this problem, but rather, a portfolio of measures, such as the increased use of renewable energy, improved energy efficiency, adoption of Clean Coal Technologies like Supercritical Plants, IGCC and Carbon Capture & Sequestration etc. will be needed.

India is rich in coal and is the third largest coal producer in the world. Coal continues to be the dominating energy source and meets nearly 58% of total requirement of commercial energy. India has huge Gondwana (mainly Permian, 99.5%) and Tertiary (Eocene and Oligocene) coal deposits distributed in several basins located in peninsular and extra-peninsular regions of about 257 billion tons. Coal is our main stay for Power generation and would continue to be so in next 3-4 decades.

CO2 sequestration is a multifaceted aspect involving capture of carbon from atmosphere followed by transportation, injection into favorable sites and post-injection monitoring. The favorable sites for storage of CO2 must be reliable in the sense that CO2 will be stored there permanently at least for 1000 years and no leakage is preferable. In this backdrop, coal bed and saline aquifer are the most suitable storage sites where CO2 will be fixed permanently by chemisorptions and chemical reaction respectively.

Carbon Capture and Sequestration (CCS) is one among these measures, being a collection of technologies that may be able to reduce GHG concentrations beyond what would be possible using other options alone.

Carbon Capture & Sequestration would play an important role in reducing Green House Gas Emissions at the same time enabling low carbon electricity generation from Power plants. As for example CCS applied to a 500 MW unit, that emits 3 million tones of CO2 per annum, would be equivalent to:

(i) Planting over 60 million trees and allow them to grow for 10 years
(ii) Avoiding Power related emission of 3 Lac houses

CCS involves the capture of carbon dioxide, the principal GHG, from concentrated emission sources, and then transporting it to and storing it perpetually in underground geological formations, used oil wells, or other secure locations. However, several challenges must be overcome before large-scale CCS deployment becomes practical, including establishing the technical feasibility of long-term geological CO2 storage, assessing the economics of capture, transport and storage of CO2 sensitizing the Government, industry, and the common man to the potential of this technology, etc.

(b) Current climate change policies and targets- India recognizes the seriousness of the threat of climate change, but is faced with the simultaneous challenge of ensuring socio-economic development which is largely linked to Energy generation in which Coal based Power generation is our main stay. Despite not having any fixed, legally binding emission reduction targets being a Non-Annex I country, India takes the issue of global warming seriously, given that the government expenditure on climate change adaptation in India already exceeds 2.6% of GDP, and that climate change is expected to have major impacts on water resources, agriculture, forests, etc. in India. To address the climate change issue, the Indian Prime Minister's Council on Climate Change released the National Action Plan on Climate Change (NAPCC) in 2008 according to which 'India is determined that its per capita greenhouse gas emissions will at no point exceed that of developed countries even as we pursue our development objectives.'

As per MOEF report 2010, the present and future CO2 emissions: India's total GHG emissions, inclusive of land use, land-use change and forestry, were 1727.71 million tonnes per annum (MTPA) of CO2 equivalent, and gross CO2 emissions were 1497.03 million tonnes. The CO2 generation per capita was 1.3 tonnes/capita per annum in the year 2007. Today the gross CO2 emission is at the level of 1602 MTPA and India's per capita CO2 emissions in 2031-32 are projected to be between 2.6 and 3.6 tonnes/capita. Around 66% of India's gross CO2 emissions came from the energy sector in 2007, with electricity generation alone accounting for almost 50% of the gross emissions. The industrial sector accounted for most of the remaining CO2 emissions, with 27% of the total emissions.

Accordingly, eight national missions for managing climate change have been set up:

(i) National Solar Mission
(ii) National Mission for Enhanced Energy Efficiency
(iii) National Mission on Sustainable Habitat
(iv) National Water Mission
(v) National Mission for Sustaining the Himalayan Ecosystem
(vi) National Mission for a "Green India"
(vii) National Mission for Sustainable Agriculture
(viii) National Mission on Strategic Knowledge for Climate Change

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The planning commission has announced the Government's interest in adding a ninth mission i.e. 'Clean Coal Technologies mission' that would include CCS.

An important portion of the NAPCC deals with GHG mitigation in India's power sector. It points out that various measures for reducing GHG emissions from power plants, such as increasing the efficiency of existing power plants, using clean coal technologies, and switching to fuels other than coal where possible, must be viewed as being complementary and not mutually exclusive. CCS is however held in the NAPCC report as not being feasible at present, and concerns have been raised about the cost as well permanence of the CO2 storage. **It has been recommended at several Forums of Ministry of Power that a better option could be carbon Capture & Sequestration (CCS) through the technologies of conversion of CO2 into multipurpose fuels.**

III PROPOSED R&D WORK

Most Indian Research and Development (R&D) activities related to CCS occur under the Department of Science and Technology (DST) of the Indian Ministry of Science and Technology. The DST set up the National Program on Carbon Sequestration (NPCS) Research in 2007, with a view to competing with other countries in this area with respect to both pure/applied research and industrial applications. Four thrust areas of research were identified under this programme, viz. CO2

Sequestration through Micro algae Bio-fixation Techniques; Carbon Capture Process Development; Policy development Studies; and Network Terrestrial Agro-forestry Sequestration Modeling as detailed in DST reports on Projects under STAC / IS-STAC. The CO2 Capture, Sequestration and Production of Multi-purpose fuels – Hydrogen, Methane and Biodiesel through Algae route through Post combustion CCS on a fossil fuel fired Plant has been successfully demonstrated at the CO2 sequestration Pilot Plant at the State Technological University of MP, the 'RGPV' installed under DST sponsorship. This pilot project revalidated the possible use of the Amine absorption system to strip the CO2 from the flue gasses but also validated the data on its efficiency for a Power Plant. A CO2 Capture of over 93% has been achieved using MEA solvent of 20% concentration and the required heat for stripping captured CO2 is 3.88 MJ per kg of recovered carbon dioxide, which is provided by the low pressure steam about 150°C and 2 bar pressure from the associated boiler of 100 kg/hr capacity. Although the stripper uses a low grade steam and some heat it contains was not used for generating power anyhow, it still causes 20% reduction of power output of Boiler. Using the water gas shift reaction and a lignite / charcoal gasifier about 18% Hydrogen is being produced in this pilot plant, paving the way to production of multipurpose fuels from captured CO2. Efforts are underway to produce Methane from the stable CO and Hydrogen so produced, in a catalytic converter. CO2 from the stripper unit is also diverted to an open Algae pond, where solar flux is concentrated using parabolic collectors and CO2 is given in a regulated manner. Algal oil was extracted from algal biomass using soxhlet extraction by two different solvents viz. hexane and petroleum ether. Hexane extracted (4.76%) more oil from the alga than petroleum ether (2.52%) by soxhlet extraction procedures.

R&D in the area of carbon sequestration need to be directed and country's policy need to be dovetailed with the research. Stress needs to be given towards fixation and conversion of CO2 into useful products, building materials etc., rather than transportation and storage.

The simulation study has shown that if the technology of CO2 Capture Recycling & Sequestration in applied on a 500 MW Coal based Thermal Power Plant with 30% capture we will get benefits like:-

(i) Levelized Cost of Electricity or LCOE on a long term basis calculated through simulation exercise for retrofitting would be Re. 1.05 per kWh. The energy penalty for 30% abatement would be 25%, if CO2 is compressed and disposed. The total efficiency drop for 100% abatement is from 38.5% to 29.3%, i.e., 9.2%. The Loss in generation due to use of steam in MEA process would be 15000 kWh/hr. The Capital cost would be Rs. Over 1.50 Cr. per MW.

(ii) The simulation study further revealed that in a Thermal Power Plant, if a slip stream of the Flue gasses is recycled then a 30% reduction of CO2 would be achieved by direct abatement and recycle would result in a decline of fuel consumption by at least 7% and thereby reducing the CO2 emissions by about 10% due to use of CO as fuel, thereby overall reduction of CO2 by about 40% in the most cost effective manner. Thus the Net emission reduction when the Recycled CO2 is used in tandem with abatement would be 40% or down from 0.9 kg CO2/kWh to 0.54 kg CO2/kWh on a retrofitted Thermal Plant.

(iii) Simulations also showed the energy penalty for CO2 capture from 500 MW flue gas from coal-fired power plants to be 0.01572 kWh/g mol CO2.

(iv) A full scale plant on a 500 MW Pulverized Coal Fired Unit would require a CCS plant of 510 tones /hr capacity as shown below:

Efforts are underway to set up a CO2 Capture & Sequestration plant on an actual Coal Thermal Power plant through consortium approach. A scheme of retrofitting of existing 500MW Unit with CO2 Capture & Recycling of CO is being discussed with NTPC, TOSHIBA and BHEL and the broad outline of the same would be as under (Fig. 1:

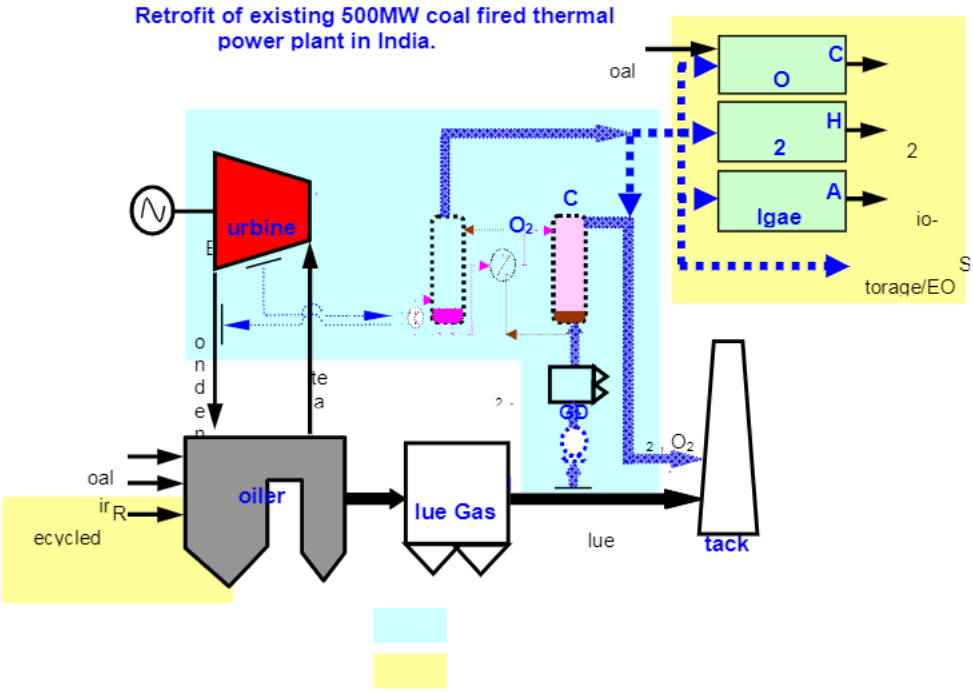

Fig. 1: Schematic of Demo Project – CO2 Capture Plant

The pilot unit of this impact project is considered an important milestone in CO2 Capture Technology for fossil fired power plants. The size of the plant is selected well above lab scale unit so as to produce appreciable moles of CH4 and H2. This Project is expected to resolve certain frontline issues in CO2 sequestration such as Energy intensive process optimization in terms of cost of generation and development of effective Catalyst for Methane, Hydrogen and Biodiesel recovery through Algae route.

IV NEW APPROACH – USE OF SOLAR FOR REDUCING ENERGY PENALTY

The thermal plants in India have a thermal efficiency of 35% and an emission ratio of 0.90 kg/kWh of CO2 emissions as published by CEA. The reduction of 20% intensity would translate to a decrease by 0.20 kg/kWh of CO2 emissions to 0.70Kg/kWh emissions by 2020. This decrease is possible by a combination of abatement and recycling measures.

However, the CO2 reduction by an Amine system of 30% CO2 capture would mean an Energy penalty of about 25% including about 15% for compression and pumping to deep reserves like mineral rocks, gas hydrates and ocean. In any case the Energy penalty in our case where CO2 Sequestration is considered a far more appropriate option than CO2 storage the Energy penalty still remains at level of 10- 12%. This can be further reduced to a level of 4-5% if Solar Thermal device is used for production of steam for MEA solvent regeneration and stripping of CO2. This can be demonstrated only after establishment of pilot scale CO2 Capture and Sequestration plant integrated with Concentrated Solar Power for carrying out System Optimization studies.

DST is being approached for funding this project to AISECT University in MP where a Center of Excellence in Energy & Environment is on the anvil.

Figure 2 below gives scheme of implementation of CO2 Capture & Sequestration Plant through integration of steam for stripping from Solar Thermal Plant.

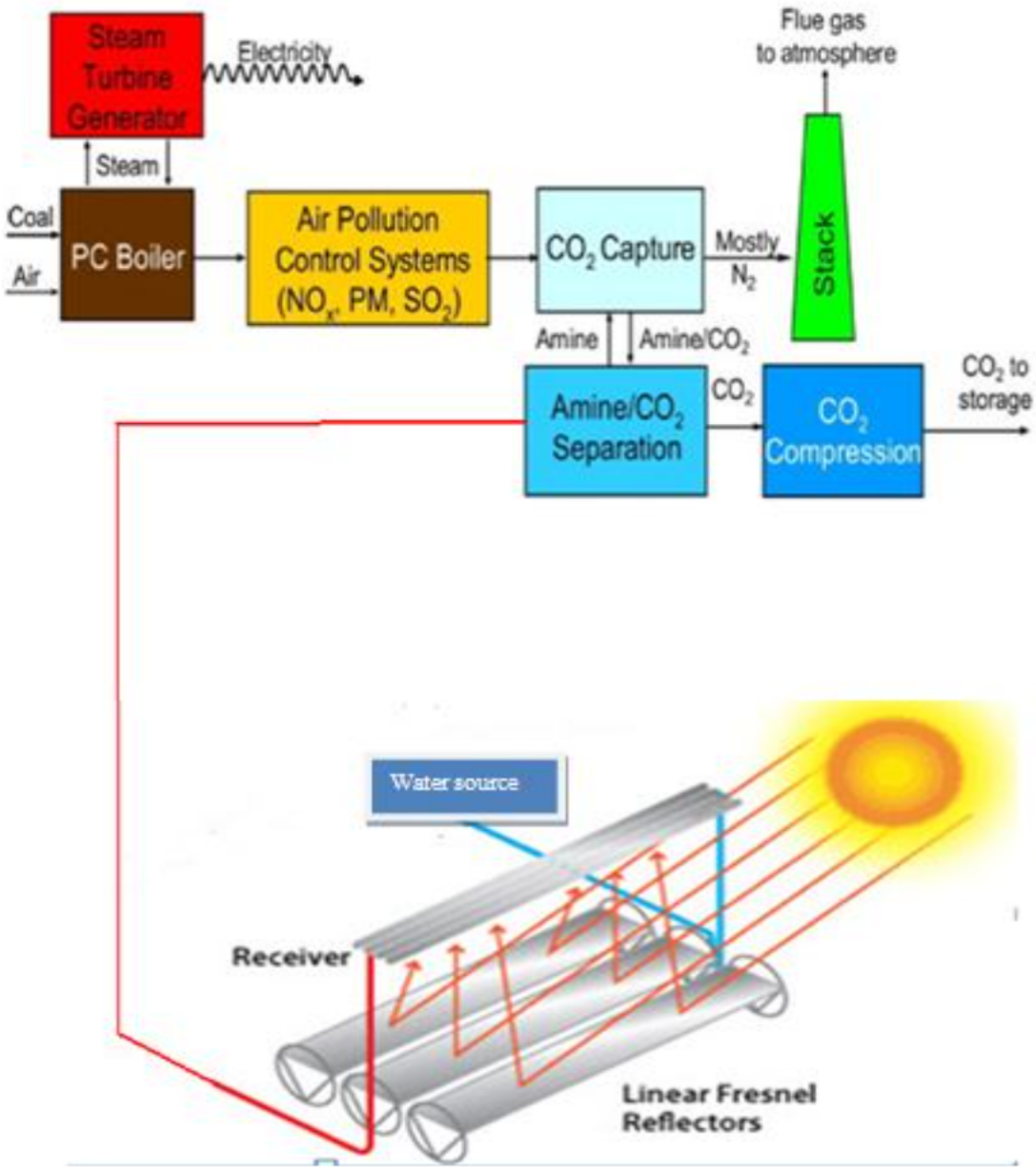

Fig: 2 - Scheme of implementation of CO2 Capture & Sequestration Plant Through integration with Solar Thermal at AISECT University

V CONCLUSION

Low Carbon Technology Vision for India together with Strategies, Challenges & Opportunities in Green Power for Energy Security Environmental Sustainability are put forward in this paper covering Low Carbon Technologies (LCT) and Carbon Capture & Sequestration (CCS) as key factors for Energy Security Environmental Sustainability.

By virtually all accounts, renewable energy resources as LCT's will be an increasingly important part of the power generation mix over the next several decades. Not only do these technologies help reduce global carbon emissions, but they also add some much-needed flexibility to the energy resource mix by decreasing our dependence on limited reserves and overseas sources of fossil fuels. Under the International Energy Agency (IEA) Energy Technology Perspectives 2012 (ETP 2012) 2°C Scenario (2DS), CCS contributes one-sixth of CO2 emission

reductions required in 2050, and 14% of the cumulative emissions reductions between 2015 and 2050 compared to a business-as-usual approach, which would correspond to a 6 °C rise in average global temperature.

Carbon capture and storage (CCS) will be a critical component in a portfolio of low-carbon energy technologies if we undertake ambitious measures to combat climate change. At the current trends of increasing global carbon dioxide emissions by energy sector and the dominant role that Coal continue to play in primary energy consumption, the urgency of CCS deployment is very important

The power sector already started witnessing a transition from conventional power generation technologies to the green power technologies. A major thrust on CO2 reduction on long-term and sustainable basis would come through adoption of advanced technologies of power generation like Supercritical / Ultra-supercritical Power Cycles, Integrated Gasification Combined Cycles (IGCC), Fluidized Bed Combustion / Gasification Technologies, Renewable Energy Technologies, Bio-fuels, other such green energy technologies. In the short-term, the focus is primarily on energy conservation measures and use of selected hybrid of 'renewable' like solar-wind-biomass. The LCT plus CCS Technologies are forward in this paper which may lead to an opportunity for course-correction in our line of thinking in Green Power.

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