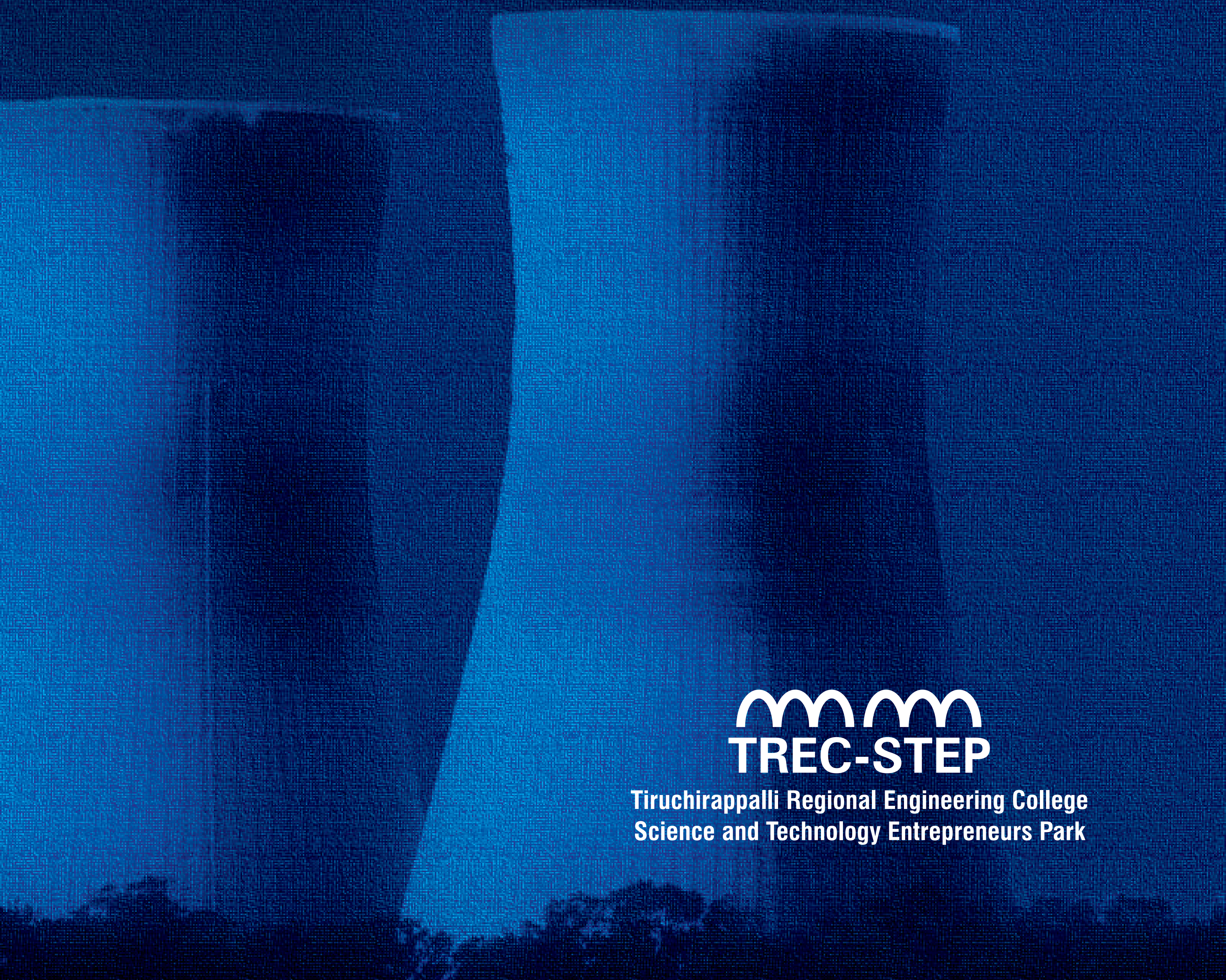
Existing Gaps and Potential for CCS and CCT Areas in the Thermal Power Industry in India



TREC-STEP
Tiruchirappalli Regional Engineering College
Science and Technology Entrepreneurs Park

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EUROPEAN UNION

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0.0 EXECUTIVE SUMMARY

The installed power generation capacity of India is 223,344 MW by the end of March 2013 of which 67.8 per cent was supplied by thermal power. India meets most of its domestic energy demand from its 293 billion tonnes of coal reserves (Ministry of Coal, 2012). The Indian power sector consumes about 80% of the coal produced in the country. As the economy continues to grow each year, energy security has become a core focus for the Indian government. As the demand for electricity is expected to rise dramatically over the next decade, coal will continue to be the dominant energy source. The Central Electricity Authority (CEA) has estimated that meeting electricity demand over the next ten years will require more than doubling the existing capacity, from about 132 GW in 2007 to about 280 GW by 2017, of which at least 80 GW of new capacity is expected to be based on coal.

A commitment was made by India to reduce its GHG emissions intensity by 20–25% by 2020 (from 2005 levels) and not including emissions from agriculture. As committed, in order to achieve this challenging goal within its overall energy growth plan, India intends to: (1) increase fuel efficiency standards; (2) adopt building energy codes; (3) increase forest cover to absorb 10% of its annual emissions; (4) increase the fraction of electricity derived from renewable sources from the current 8% to 20% by 2020; (5) increase the rate of introduction of nuclear power.

An urgent need to increase energy and electricity availability for human and infrastructure development, to increasing energy security, to address the local environment protection and pollution control; and control of greenhouse gas emissions (particularly carbon dioxide) were the key challenges facing India's power sector.

Sub-critical pulverized coal (PC) combustion power plants manufactured by Bharat Heavy Electricals Limited (BHEL) which are based on technologies licensed from various international manufacturers, have been the backbone of India's coal-power sector. As the efficiency of some stations remains poor, efforts have been made to improve the performance of the plants by renovation and life extension exercises. Additional coal-fired generating capacity is being added to the country's power sector and more is planned in an effort to meet the increasing demand and current shortages of electricity.

There is a growing emphasis on the adoption of more advanced technologies and the deployment of clean coal technologies. India's first supercritical PC power plant is already in operation and a number of large Ultra Mega Power Projects (UMPPs) are being developed. India's first 800 MW coal-fired Advanced Ultra Supercritical (AUSC) power plant which is under development with a joint effort from BHEL, Midhani, IGCAR and NTPC, would reduce the operational costs and emit less carbon dioxide than existing units. Several forms of fluidised bed combustion technology are well established within the country and their numbers are growing. Coal-fuelled IGCC technology has been developed by BHEL and a large-scale demonstration of 100MW joint venture with NTPC has been proposed

There is now a range of advanced, more efficient, and cleaner technologies for producing electricity using coal being considered. The commercial supercritical combustion technology is the best option for India in the short-to-medium term. While gasification and advanced combustion technologies will be potentially important options for the longer-term future. Oxy-fuel combustion for facilitating capture of carbon-dioxide (CO_2) is under development in BHEL. With the significant potential for cost-effective reduction of CO_2 and other emissions the Oxy-fuel combustion system is likely to be commercially available in the near future.

The main challenge facing CO_2 storage is to accurately estimate the amount of useful storage space in the Indian subcontinent. A regional study report of IEA GHG along with BGS shows that the potential for CO_2 storage in India is limited in oil, gas and coal fields as there is insufficient storage capacity. To make significant inroads into India's current and future emissions, it is clear that there is a need to quantify the realistic saline aquifer CO_2 storage capacity of India's sedimentary basins.

The country has a significant potential of generation from renewable energy sources. All efforts are being taken by the Government to harness this potential. India proposes to double the renewable energy capacity to 55,000 MW from 25000 MW now by 2017. The ministry has in the 12th plan document, projected deployment targets of 15000 MW for wind power, 2100 MW for small hydro power, 500 MW for solar power (photovoltaic and thermal). It is to be noted that India has an ambitious target of acquiring 15% of power needs, or 80,000 MW, from renewable sources by 2020.

In order to address the country's future energy requirements in an environmentally acceptable manner, assessment of India's clean coal technology choices suggests that no single technology will meet all the challenges and a portfolio of CCTs will be appropriate. CCT R&D efforts are under way for a number of technologies, undertaken by Indian researchers and technology developers, some in collaboration with overseas organisations. Commercial links have also been established between several major Indian developers and manufacturers of power generation equipment with international technology vendors. Therefore, it is essential to engage in an in-depth assessment of technology issues and rigid technology choices for long term as well as strategic planning to allow for appropriate development of the coal-power sector in India.

1.0 INTRODUCTION

The growing economy demands increasing energy needs, to feed the rapid development across its industrial and social segment. India has large reserves of coal compared to oil and natural gas. The country's economy continues to grow at 6–8% each year and the energy security has become a core issue for the Indian government. Despite the on-going efforts to diversify the country's energy mix, coal remains the dominant fuel for power generation and many industrial applications.

In spite of its poor quality, the economic and strategic benefits of coal over other forms of energy will ensure a continuing major role in the Indian economy. The largest coal consuming sector is power generation. Currently, majority of country's coal-fired boilers rely on conventional pulverised coal (PC) combustion technology with subcritical steam conditions. The efforts have also been made to improve the performance of others via renovation and life extension exercises. Additional coal-fired generating capacity is being added to the country's power sector and more is planned in an effort to meet the increasing requirements and current electricity shortages.

Adoption of more advanced technologies and the deployment of Clean Coal Technologies (CCT) are the need of the hour. The country's first supercritical PC power plant is already in operation and a number of large Ultra Mega Power Projects are being developed. Several forms of fluidised bed combustion technology are well established within the country and their numbers are growing. Coal-fuelled IGCC technology has been developed by BHEL and large-scale demonstration has been proposed.

Social and economic development in India depends on the access to modern forms of energy. Providing electricity to the people while moving to low carbon electricity generation is a social imperative. Indian electricity supply and demand are projected to increase fivefold to six fold between 2013 and 2050.

This report identifies the existing gaps and the potential to achieve higher CO_2 emission reduction in the Indian power sector and clean coal technologies needed while keeping pace with the strong growth in energy requirements that will result from a rapidly growing economy.

1.1 Energy Reserves:

1.1.1 Coal Reserves:

Even though India has extensive coal reserves and for oil and gas, the demand exceeds the domestic production which results in the country increasingly becoming a major importer. India is the third largest global producer of coal-based electricity. Coal is plentiful but of low quality, mostly being bituminous with a high inherent ash content and low heating value while relatively low in sulphur content. Similar to hard coal, reasonable quantity of lignite deposits available. The largest coal resources are mainly available in the eastern and central regions, although many centres of high power demand are in the western and southern regions. Type and category-wise coal resources of India as on 1.4.2012

Table 1: Type and category-wise coal resources of India (Million Tonnes) as on 1.4.2012 (Source: Ministry of Coal)

Type of Coal	Proved	Indicated	Inferred	Total
(A) Coking:-				
Prime Coking	4614.35	698.71	0	5313.06
Medium Coking	12836.84	11951.47	1880.23	26668.54
Semi-Coking	482.16	1003.29	221.68	1707.13
Sub-Total Coking	17933.35	13653.47	2101.91	33688.73
(B) Non-Coking:-	99617.65	128416.04	30282.09	258315.78
(C) Tertiary Coal	593.81	99.34	799.49	1492.64
Grand Total	**118144.81**	**142168.85**	**33183.49**	**293497.15**

in million tonnes (Ministry of Coal) is shown in Table 1.The plan wise demand and availability projection of coal in India is shown in Table 2.

Table 2: Planwise Demand - Availability Projection

Company	Actual 07 -08 First yr of XI PLAN	XI Plan (2011 – 12)	XII PLAN (2016 – 17)
DEMAND in Million Tonnes	550.00	731.00	1125.00
Availability (Raw Coal Production) in Million Tonnes			
CIL	379.46	520.50	664.00
SCCL	40.60	40.80	45.00
Others	39.94	118.70	346.00
Total	**497.00**	**680.00**	**1055.00**
Gap	93.00	51.00	70.00

1.1.2 Coal Quality:

Generally, Indian coals have low calorific value due to their drift origin; contain high levels of inorganic impurities. Coal ash is often bound within the coal matrix, well intermixed, making it difficult to remove beyond a certain level. The ash in Indian coals is mostly high in silica and hence, abrasive. This requires careful adoption of appropriate technology when designing power plants and special measures may need adopting. These include:

- Adequate and reserve capacity of coal and ash handling equipment;
- Adequate and reserve capacity and ruggedness of milling equipment to ensure availability, and for correct PC particle size for effective burnout;
- Provision of particulate separators commensurate with the high flue gas dust loading;
- Measures to minimise erosion
- Provision of appropriate heat transfer surface distributions (radiant: convective) in the boiler

Characteristics of typical coals supplied to Indian power stations:

- Ash content of between 25% and 55%. Impurities may include shale, stones and occasional pieces of iron;
- Moisture content between 4% and 7%, and in rainy seasons, it may increase to 18%
- Sulphur content of between 0.2% and 1%;
- Gross CV between 3100 and 5100 kcal/kg. On an average, 0.73 kcal/kg of coal is used to generate 1 unit of electricity;
- Volatile matter content usually between 20% and 30%;
- Phosphorous content generally <0.01%.

In some parts of the country, lignite is also a fuel source for thermal power generation. Lignite is not cleaned and different grades are produced solely by selective mining as different seams or parts of seams. Mostly, opencast mining has been adopted and in some cases, quality has been further compromised by the inclusion of soil and other material from the overburden during mining. To counter these effects, in 2002, the long distance transport of coal with an ash level of more than 34% was prohibited.

1.1.3 Coal Blending:

Low ash and higher CV content coals are being imported, providing the potential for economic and environmental benefits. In many situations, indigenous coals are blended with imported coals or other fuels. This can reduce overall cost by combining low cost coals with more expensive ones, but can also reduce dependence on a single source of supply. Blending is also being carried out to improve process economics, mainly to obtain optimal combustion/slagging performance of the boiler and also from environmental point of view.

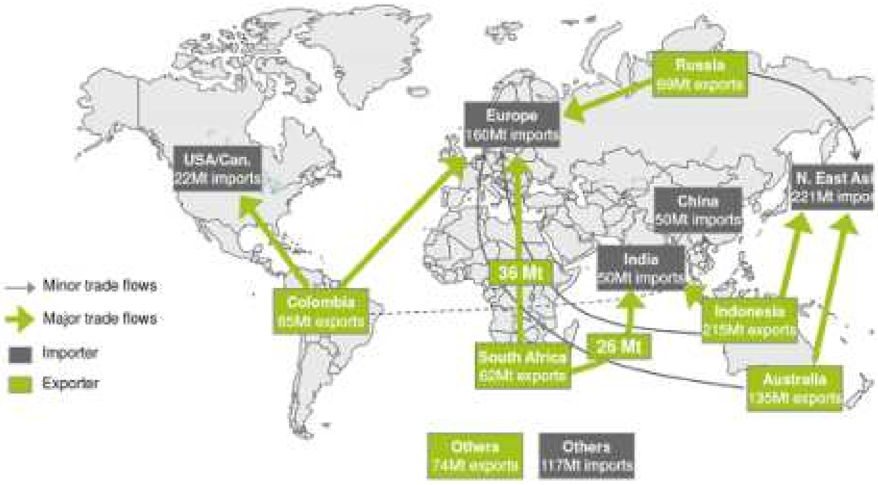

Figure 1: The global thermal coal trade on the Pacific Basin.

domestic supply, especially for use in the advanced coal-fired power plants that have begun to be introduced. In 2010, India needed to import 83 Mt of coal and this level is expected to increase rapidly, with the country poised to become the world's biggest importer after 2020.

Power consumption is projected to grow at an average rate of 3.3%/y through 2035 which means that India could well need to add at least 234 GWe of additional capacity (EIA, 2011c). On a longer-term basis, some projections suggest that a further 360 GWe to 960 GWe could be needed by 2050 compared to 2030 (IEA, 2011c). However, a combination of security of supply concerns regarding the increasing import of fossil fuels, national air quality issues and international climate change issues has resulted in a shift in emphasis as to how best to establish this additional capacity.

3.0 CURRENT AND PROJECTED FUTURE CO_2 EMISSIONS:

During 2009, annual CO_2 emissions from industrial activities (excluding land use and land use change and forestry) were 1586 Mt, of which about 70% were from coal (IEA, 2011b). Fast growth in such emissions is expected since the economy continues to grow at a significant rate with additional coal use for power and other energy-intensive sectors still representing the major increase in primary energy consumption.

Table 3: Region wise installed capacities of power utilities in India

(As on 31-03-2011)

SI.	REGION		THERMAL			NUCLEAR	HYDRO	R.E.S. @	TOTAL
No.		COAL	GAS	DSL	TOTAL		Renewable	(MNRE)	
1	Northern	32413.50	4781.26	12.99	37207.75	1620.00	15467.75	5589.25	59884.75
2	Western	49257.01	8988.31	17.48	58262.80	1840.00	7447.50	8986.93	79537.23
3	Southern	25032.50	4962.78	939.32	30934.60	1320.00	11353.03	12251.85	55859.48
4	Eastern	23457.88	190.00	17.20	23665.08	0.00	3987.12	454.91	28101.11
5	N. Eastern	60.00	1187.50	142.74	1390.24	0.00	1242.00	252.68	2884.92
6	Islands	0.00	0.00	70.02	70.02	0.00	0.00	6.10	76.12
7	All India	130220.89	20109.85	1199.75	151530.49	4780.00	39491.40	27541.71	223343.60

Captive Generation Capacity in Industries having demand of 1 MW or above, Grid Interactive (as on 31-03-2011) = 34444.12 MW
@ Renewable Energy Sources (RES) includes Small Hydro Project (SHP), Biomass Power (BP), Urban & Industria waste Power (U&I), Wind Energy and Solar Power.

3.1 CO_2 Emissions In India:

A large share of the emissions is produced by the electricity and thermal sector, which represented 54% of CO_2 in 2010, up from 40% in 1990. CO_2 emissions in the transport sector accounted for only 10% of total emissions in 2010, but transport is one of the fastest-growing sectors and there is a need to be vigilant.

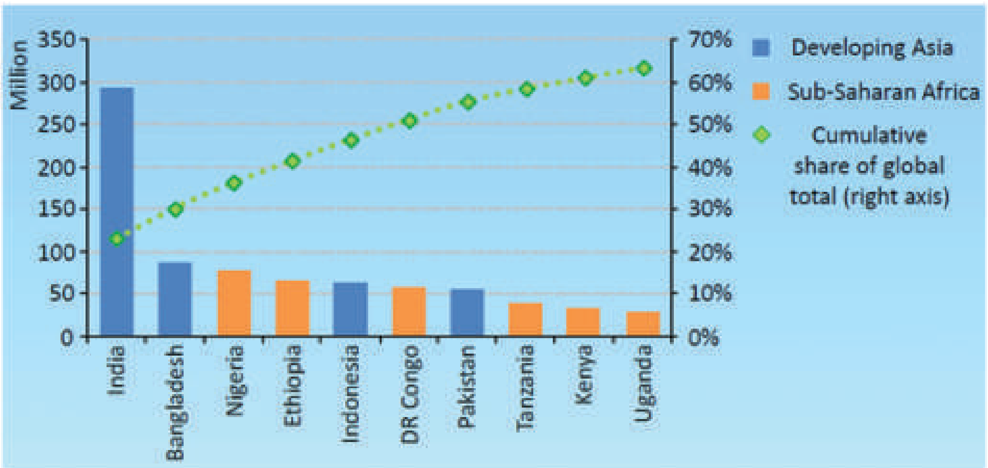

Figure 2 : Countries without access to electricity in 2010.

During 2013, 58% of electricity in India came from coal, 9% from natural gas and 5% from oil (Figure 4).The share of fossil fuels in the generation mix grew from 73% in 1990 to 85% in 2002. Since 2002 the share of fossil fuels remained fairly steady, representing 83% in 2010. Although electricity produced from hydro has actually risen during this period, the share fell from 25% in 1990 to 12% in 2010, largely due to more rapid increases in coal-fired power generation.

Figures 5 and 6 show the fuel wise and sector wise CO_2 emissions in India published in the CO_2 emissions and fuel combustion highlights of IEA 2012 edition.

The country's renewable power generation continues its strong growth reaching 23 GW in January 2012, equivalent to nearly 12% of total power capacity. Wind comprises the largest capacity with 16 GW or 70% of total renewable capacity, followed by small hydro at 14% and bagasse co-generation at 9%. Currently, solar PV with 481 MW of capacity represents only 2% of total renewable installation, but is expected to grow strongly in the medium and long term. One notable encouraging aspect of renewable power in India is the high proportion of private ownership, accounting for 86% by March 2012.

India has the lowest CO_2 emissions per capita (1.4 t CO_2 in 2010) among the BRICS countries, about one-third that of the world average. Due to the recent large increases in emissions, however, the Indian ratio is more than two times that of its ratio in 1990 and will continue to grow. In 2035, India is projected to be the world's most populous nation with 1.5 billion people. Yet according to the WEO 2012 New Policies Scenario, its carbon emissions of 2.5 t CO_2 per capita will still be substantially lower than the world average of 4.3 tCO_2 per capita in the same year.

In terms of CO2/GDP, India has sustained improvement in the efficiency of its economy and reduced the CO2 emissions per unit of GDP by 22% between 1990 and 2010 and aims to further reduce emissions intensity of GDP by 20% to 25% by 2020 compared with the 2005 levels.

4.0 NATIONAL POLICIES FOR ENERGY AND CARBON MITIGATION:

The country faces formidable challenges in meeting its energy needs and providing adequate energy to users in a sustainable manner and at reasonable costs. It has stated that it needs to maintain an 8% to 10% economic growth rate to eradicate poverty and meet its economic and human development goals. In order to deliver a sustained growth of 8% through to 2031, on a business-as-usual scenario, power generation capacity would have to increase to 778 GWe and the annual coal requirement would be 2040 Mt. Consequently the government has also declared that it must take measures to reduce the energy requirement and improve the quality of energy supply to meet its sustainable economic growth imperatives. There is certainly a focus on building up the use of renewable and, especially, nuclear, and to a lesser extent, natural gas, although coal is still expected to dominate the near- and medium-term energy mix.

India made a commitment to reduce its GHG emissions intensity by 20–25% by 2020 (from 2005 levels) not including emissions from agriculture. As committed, in order to achieve this challenging goal within its overall energy growth plan, India intended to:

- Increase fuel efficiency standards by 2011;

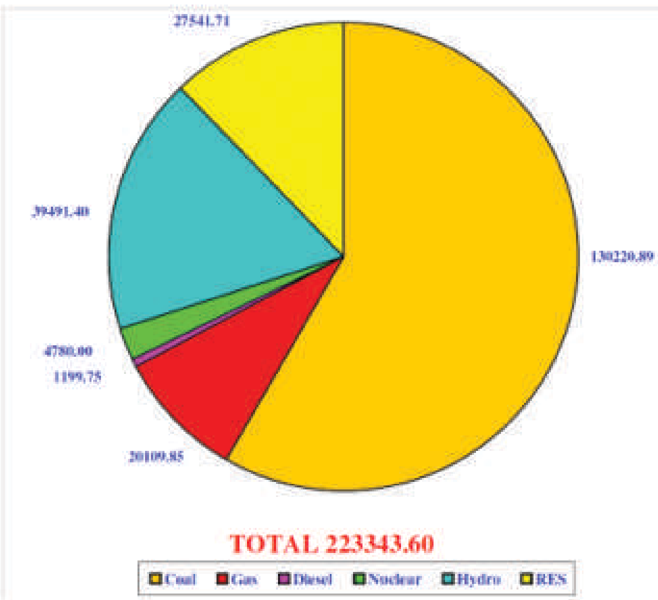

Figure 3 : Total installed capacity (MW) in India as on March 2013

- Formulate energy codes by 2012;
- Increase forest cover to absorb 10% of its annual emissions;

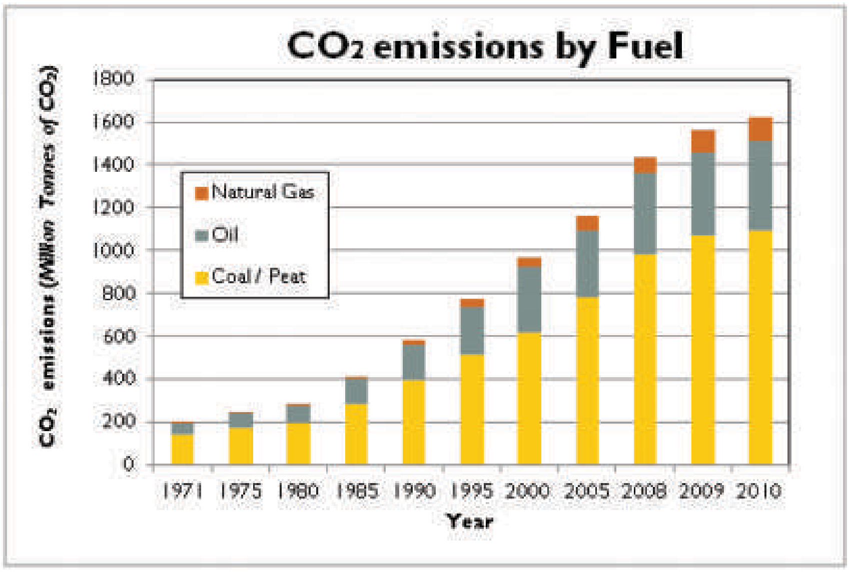

Figure 4 : CO_2 emissions by fuel in India in Million Tonnes

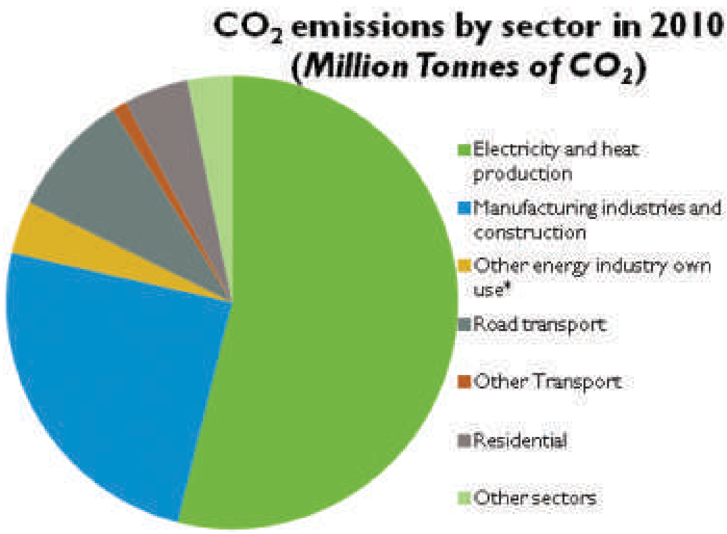

Figure 5 : Sector wise CO_2 emissions in India in Million Tonnes

- Increase the fraction of electricity derived from renewable sources from the current 8% to 20% by 2020;
- Increase the rate of introduction of nuclear power.

With the recognition that coal-based power generation will remain the dominant approach within the Indian power sector for many decades, due to its large coal resource base and current overwhelming proportion of the existing capacity mix, the government is taking steps to improve the overall efficiency of coal-fired power plants by deploying higher-efficiency pulverised coal combustion technologies. It has a plan to establish up to sixteen 'Ultra Mega Power Projects', each of which will be a 4000 MWe power station comprising several large units with SC steam conditions. The Indian government intends to have these power plants built by private sector companies before 2017.

Though it is not an efficiency improvement issue, it should be noted that air pollution emissions control is focused mainly on limiting the release of fine particulates. It also intends to improve the other elements in the existing power system, such as transmission and distribution. Currently, electricity transmission and distribution losses are between 30% and 45%, which is a result of the focus on building new energy generation capacity without a corresponding emphasis on grid improvements. This problem is being exacerbated by the need to accommodate a growing level of renewable energy technology on the grid system.

In 2008, the National Action Plan for Climate Change (NAPCC) was announced, which included several measures to address global warming, including an increase in the share of renewable energy based power generation. The NAPCC also has the ambitious goal of a 1 percentage point annual increase in renewable energy growth compared to the 2010 baseline for ten years so that renewable energy will then constitute about 15% of the energy mix of India.

National Mission for Enhanced Energy Efficiency was established as one of India's eight missions under its NAPCC. The aim is to establish a market for demand-side energy efficiency improvements through policy and financial support. The overall target for this market-based approach is by 2014-15 to:

- achieve annual fuel savings in excess of 23 Mtoe;
- avoid cumulative electricity capacity addition of 19 GWe;
- ensure annual CO_2 emission reductions of 98 Mt.

As part of these objectives, the government has amended legislation so that over 710 energy-intensive businesses are required to take part in a scheme to cap energy usage as part of an energy-efficiency certificate trading scheme (Ministry of Environment and Forests, 2010).

Regarding renewable energy, although India has very significant potential, it is recognised that achieving the 2020 target will require an order-of-magnitude increase in renewable energy growth across the country during the next decade. On the basis of the current financial cost of coal-based power generation, renewable capacity is not financially viable as an alternative under Indian conditions (World Bank, 2010). About 5 GWe of such capacity is viable compared to the cost of gas-based generation, while all the intended wind, biomass, and small hydropower capacity would be viable compared to the cost of diesel-based power generation. Consequently, there is a need for strong policy measures, a proactive regulatory framework and innovative financing instruments to ensure a realistic enabling environment, if these very ambitious targets are to be achieved (World Bank, 2010). Under current planning and pricing regimes, achieving the government's goal over the next decade would require an annual subsidy of around US$1 billion.

Based on the above, the government has announced a 'coal tax' of 50 rupees (US$1) per tonne (Bloomberg, 2011). The resulting revenues will go to a National Clean Energy Fund, which will finance clean energy research and development. In addition, India has stopped subsidies for petrol and lowered subsidies for diesel and kerosene. The government has also reduced import duties on renewable energy equipment and exempted some renewable energy machinery, such as wind turbine parts, from a domestic production tax on new goods. Most states in India have implemented renewable power obligation schemes that require the electricity distribution companies to source a fixed percentage of their power from renewable sources, or buy renewable energy certificates. The Ministry for Renewable Energy is also working with the regulators to determine a suitable framework for tradable renewable energy certificates to provide a mechanism for better returns for renewable energy developers, leading to a boost for further investments in the sector.

In 2009, India unveiled a National Solar Mission. The aim is to increase the installed solar generation capacity from the 2009 level of 5 MWe to 20 GWe, by 2022, with tentative targets of 100 GWe and 200 GWe by 2030 and 2050 respectively. The intention is to provide financial incentives for leveraging domestic and foreign investments in order to encourage rapid scale-up and to drive down costs, increase and improve domestic manufacturing capability. These incentives include capital subsidies of up to 30%, low-interest loans, and feed-in-tariffs for rooftop solar projects. As a start, under the plan, the use of solar-powered equipment and applications will be made compulsory in all government buildings, as well as hospitals and hotels.

On wind power, currently 18 of the 25 State Electricity Regulatory Commissions (SERCs) have issued feed-in tariffs for wind power. These together with the renewable power purchase obligations have helped to create long-term policy certainty and investor confidence, which have had a positive impact on the wind energy capacity additions in those states. Finally, India has formed an Expert Group on Low Carbon Strategy for Sustainable Growth, with the group's recommendations adopted in India's 12th Five-Year Plan in 2012.

5.0 NATIONAL INITIATIVES FOR CCS DEVELOPMENT AND DEPLOYMENT:

In 2003, India joined the CSLF, with the Ministry of Power as the lead ministry, and it has been a member of the Asian Pacific Partnership. It signed an agreement with the USA in April 2006 to become a partner in the FutureGen zero emission power plant project. It is also an institutional partner in the Big Sky Carbon Sequestration Partnership, which involves the US DOE National Energy Technology Laboratory (NETL) and seven regional CO_2 partnerships that are designed to determine the best approaches for capturing and permanently storing GHGs.

Regarding country-specific R&D, the UK government via DECC has supported several collaborative studies. This has included two projects, one examining the introduction of advanced supercritical coal power plants with the prospect to make these CO_2 capture ready and the other providing an initial CO_2 storage assessment (British Geological Survey, 2007).The latter study was jointly commissioned by the IEA GHG R&D Programme, for which the British Geological Society (BGS) conducted a regional assessment of the Indian subcontinent to gauge the potential for CO_2 storage in geological reservoirs, which included deep saline aquifers, depleted oil and gas fields, and deep un-mineable coal fields. In addition, the study undertook some source-store matching, which considered the geographical relationship between the large point source emissions of the Indian power sector and potential geological storage reservoirs.

The peninsular region of India would be unsuitable for CO_2 storage because either basalt or crystalline basement rocks occur at the surface. It is possible that sedimentary rocks may occur beneath the basalt in some areas but imaging problems would probably prevent effective site characterisation and monitoring. The main potential CO_2 storage sites, which are not too distant from the emissions sources, are located in the saline aquifers and, to a much lesser extent, in the oil and gas fields around the margins of the peninsula, especially offshore in the Mumbai, Krishna-Godavari and Cauvery basins but also onshore in the states of Gujarat and Rajasthan. In order to determine whether there is significant realistic potential for the application of CCS, there is a need to rigorously quantify the storage capacity of the aquifers.

The impact of basalt on limiting potential CO_2 storage opportunities is significant since many of the large CO_2 emissions point sources are located in such regions. Accordingly, the National Geo-physical Research Institute of India is undertaking a co-operative CO_2 Geological Storage Research Project with the Pacific Northwest National Laboratory, USA. The aim is to develop technology for deep bed injection of CO_2 in sedimentary rocks underlying basalt foundations. Some 2000 t CO_2 will be injected at a selected site followed by monitoring and modelling of its behaviour, using a broad range of geo-physical and geo-chemical techniques.

Oil and Natural Gas Corporation Limited (ONGC) which is a Government of India undertaking, signed a memorandum of understanding with State Oil Hydro ASA of Norway to jointly develop CO_2 management projects. This has led to a project where the CO_2 released during the processing of sour gas at the ONGC plant in Gujarat will be captured and transported to a nearby depleted reservoir for EOR.

5.1 Clean Coal Initiativesin India:

The country occupies 2.4% of the world's geographical area, supports nearly 17% of its population, and yet emits less than 5% of global greenhouse gas emissions. On a per capita basis, at 1.3 t CO_2-e compared to 20–30 t CO_2-e in most developed countries, these are very low compared to the world average. However, despite such low per capita emissions, India ranks fifth in total global emissions after the USA, China, Russia and Japan and CO_2 emissions are rising rapidly.

The country's growing CO_2 emissions result from a number of factors that include a general increase in the industrial and transport sectors, as well as from the large capacity additions being made to the coal-fired power sector. The low operating efficiency of many older power plants (some of which may continue operating for a further 20 years) has contributed to this trend.

In 2003, the government approved the establishment of the National Clean Development Mechanism Authority (NCDMA) and has given host country approval to about 300 projects. In theory, the CDM should be providing an incentive for owners of inefficient power plants to invest in upgrades or replacements that reduce emissions.

5.2 Control Strategies Adopted:

As a developing country, India has initiated a number of policies and measures for the mitigation and adaptation to climate change. In 2000 alone, energy policy measures reduced CO_2 emissions growth by 18 Mt. As Indian industry is still highly energy intensive compared to developed countries, there is still considerable room for improvement. There has been a growing focus on the upgrading of existing power plants and a move towards the adoption of SC steam conditions for new build. These measures, alongside the country's IGCC development activities, confirm a commitment to concentrate (at least in the short-medium term) on a policy of limiting CO2 emissions through improving the efficiency of existing coal-fired power plants via modernisation and upgrading, and the increasing use of clean coal technologies. In the longer term, when more efficient types of plant have been established, CCS is being viewed as a possible strategy to adopt, together with novel plant designs.

The present and the proposed efforts to control CO2 emissions include:

- adoption of high efficiency thermal power generation through advances in boiler technology;
- increasing use of renewable energy sources and nuclear power;
- promotion of CCTs;
- increased R&D on coal beneficiation, gasification, CTL and IGCC;
- specific measures adopted by power companies and other major coal consumers (steel and cement manufacturers) for technology upgrades;
- R&D on CCS.

As on date, most of the coal-fired power stations operate with subcritical steam conditions and various factors limit their overall efficiency. Investing in high efficiency power plants is viewed as a first step in a carbon mitigation strategy. At present, there is a growing focus on the deployment of coal-fired plants with SC steam conditions. In the longer term, there may be the possibility of retrofitting some plants with CO2 capture technology although at present, there are only limited CCS RD&D activities taking place in India.

Even though no Indian coal-fired power plants adopts CCS technology, there is some industrial experience through the operation of a post-combustion CO2 scrubber at the Indo Gulf Fertilizer Company plant in Uttar Pradesh, where CO2 is recovered from the flue gas of an ammonia reformer using a Fluor Econamine FGSM solvent scrubber unit. This produces 150 t/d of CO2 that is utilised in the manufacture of urea.

5.3 International Collaborative Activities:

Carbon Sequestration Leadership Forum (CSLF)	Since 2003, India, with the Ministry of Power as the lead ministry, has been a member of the CSLF. The objective of participation is to develop cost effective technologies through the organisation of collaborative R&D activities. A CSLF-endorsed project examining CO2 storage in basalt rocks. The project aims to provide necessary technological understanding for the storage of a large volume of CO2 in similar geologic environments within the Indian subcontinent. Project partners are the NTPC, National Geophysical Research Institute (NGRI) of India, and PNNL of the USA
FutureGen	India was the first CSLF member to participate in the US-led FutureGen Initiative, having signed an agreement with the USA in April 2006 for partnership. Participation in the project entitles India to full membership on the FutureGen Government Steering Committee which provides guidance on the project relating to scope, design, objectives, testing and evaluation.
US-India Energy dialogue	The aim is to mobilise secure, clean, reliable and affordable sources of energy. The Dialogue is building upon the range of existing energy cooperation measures between the two countries, as well as developing new avenues of collaboration.
USAID-India Greenhouse Gas Pollution Prevention (GEP) Project	Focused on NTPC's Dadri power plant, the project improved efficiency by 1.5%, reduced coal use by 81 kt/y, and reduced CO2 emissions by >100 kt/y.
GEP Climate Change Supplement	The purpose of this agreement is to provide technical assistance support in areas that include: • promoting clean alternative fuels for pollution reduction and clean air; • facilitating the introduction of hydrogen based energy systems;

	• introducing advanced decentralised energy systems, such as fuel cells, cogeneration systems, and renewable-based cogeneration systems; • supporting institutional mechanisms such as regulatory policies that promote decentralised systems; • engaging the public in adopting clean energy technologies and systems.
The Big Sky Carbon Sequestration Partnership	The partnership's primary geologic effort is being directed towards demonstrating CO_2 storage in mafic/basalt rock formations. This is viewed as having significant long-term storage potential in several parts of the world that include India. This includes India's National Geophysical Research Institute in Hyderabad.
Asia-Pacific Partnership for Clean Development and Climate (APP-CDC)	In July 2005 the APP-CDC partnership was formed between the USA, Australia, India, China, South Korea and Japan. It is an international non-treaty agreement designed to accelerate the development and deployment of clean energy technologies.
India-IEA Collaboration	In 1998, the Indian Ministry of Power signed a MoU with the IEA for cooperation in the energy sector. India is one of only three non-member countries of the IEA with whom such a MoU has been signed. There has since been close interaction, with cooperation focusing on key areas related to energy. BHEL is a Sponsor Member of the IEA Clean Coal Centre in London. NTPC has been nominated as the Nodal Agency for representing India's interest in the GHG Programme. A major IEA GHG focus is CO_2 capture and storage and a key initial activity in partnership with India will be an assessment of the potential for CO_2 storage in the Indian subcontinent. Several Indian organisations are taking part in the study, which is being led by the British Geological Survey.

6.0 CLEAN COAL INITIATIVES IN INDIA:

In India, numerous initiatives are under way aimed at improving the economics and reducing the environmental impact associated with large-scale coal use, and progress is being made in a number of areas. Within the power generation sector, the performance of many existing plants requires improvement, although some progress has been made; R&M and LE exercises have established that considerable improvements are possible. In addition, subcritical PC units up to 500 MW are now well established in the country; the increasing adoption of larger individual capacities presents opportunities for capitalising on economies of scale. Importantly, there is also now commercial tie-up between BHEL and several international technology developers for SC boiler technology, and currently, 660, 800 MW are being installed with supercritical parameters and 1000 MW units are reportedly at the planning stage. Many existing power plants are approaching retirement and there is likely to be a significant turnover of the present fleet. In some situations, this potential for investment in substantial new capacity may also present opportunities for leapfrogging to more advanced technologies such as SC PC, CFBC and IGCC systems.

Much of the focus has been on rapid generating capacity additions via replication of existing technology rather than deployment of more advanced options. Thus, although considerable development work has been (and continues to be) undertaken in the Indian power sector, there remains significant need and opportunities for advancements in coal based electricity generation technologies in the country.

In many areas, progress towards the adoption of more advanced generating technologies has been made and, for instance, India now has a significant number of FBC based plants operating. Progress is also being made towards the application of IGCC to high ash indigenous coals. In both cases, much of this work has been undertaken by BHEL. As part of its vision for the future, the company has developed an in-house CCT roadmap covering a range of technological options.

Presently, significant generating capacity additions have been made and more will follow. There are a number of technological options available to the country's power sector, some more mature than others. The industry will therefore need to consider technologies capable of meeting its near-term objectives, but also to formulate a mechanism whereby more advanced systems can be adopted when appropriate. Thus, in the nearer term, it would be useful for a strong focus to be maintained on the deployment of high efficiency combustion technologies, whilst also engaging in a strategic R&D programme to advance and keep open key technology options. New and emerging technologies worldwide would require monitoring and their applicability on Indian context to be assessed continuously.

The recent studies conclude that the best options for new generating capacity appear to be SC PCC and CFBC. Advantages for SC PCC include high efficiency, technical maturity and relatively low cost. Advantages for CFBC include fuel flexibility, technical maturity, and relatively low emissions of SO_2 and NOx. Subcritical PCC was not considered an option on account of limited efficiency and environmental impact. More advanced technologies (such as oxy-fuel combustion) were considered as a technically immature system and relatively high costs.

6.1 Renovation and Modernisation (R&M) and Life Extension (LE) Activities:

R&M of older plants offers a number of potential advantages over new build projects. New plants can be expensive to build and involve lengthy gestation periods, whereas R&M of existing units can relatively quickly extend plant life by 15–20 years and at a lower cost. It can help recapture and/or enhance unit capacity, improve availability and efficiency, and reduce the cost of electricity. Practical experience has shown that implementation of R&M schemes can benefit Indian power plants by tackling technological obsolescence, providing low cost capacity addition, extending the life of critical equipment and components, complying with statutory and environmental norms, sustaining availability, and improving overall performance. With appropriate measures, R&M of older units has increased station output quickly and cost effectively, whilst having a positive impact on CO_2 emissions.

As part of Indian R&M exercises, a range of measures have been undertaken. Selected stations have benefited from upgraded milling and firing systems, and refurbished steam turbines, condensers, pressure parts and fans. Some have involved changes in plant design such as adoption of higher steam parameters or turbine upgrading via the addition of high efficiency blades.

LE and R&M of older power plants remains a high priority of the government. TERI has estimated that R&M of older units can improve generation by up to 30%, reduce environmental impact by 47%, and increase efficiency by 23%. R&M is not a substitute for regular Operation and Maintenance (O&M) of the plant. There is a need to improve the O&M practices and carry out regular O&M as per schedules to sustain the improvement obtained through R&M. It should be ensured by the SEBs/Power Utilities that adequate and timely O&M funds are made available to the power stations. Government of India issued the Guidelines for Renovation and Modernisation / Life Extension Works of Coal/Lignite based Thermal power Stations in October 2009.

Indian power plants are required to use power station heat rate (SHR) as a proxy for plant efficiency. The Central Electricity Authority collects data on gross electricity generation, coal consumption and average HHV. Monthly and annual heat rates are then calculated and compared with the design heat rate, or unit heat rate (UHR). Operating parameters such as fuel consumption, GCVs and gross generation are collected from each plant on a monthly basis and used to calculate the plant-specific SHR. The individual plants are then split into those with 'good performance' and those with 'poor performance'.

Under 12th Plan, life extension works have been identified on 72 thermal units of total capacity 16532 MW. This includes 30 units (5860 MW) from state sector and 42 units (10672 MW) from central sector. R&M works have been identified on 23 units (4971 MW) during the 12th Plan, out of this 11units (4050 MW) are from NTPC, 9 units (291 MW) are from NEEPCO and rest are from state sector. NTPC has undertaken remedial actions at a number of its power plants, having established an R&M Department in 1995. R&M remains an important area within NTPC as many of its units are now reaching 100,000 operating hours.

The efficiency of coal-fired power plants will tend to decrease gradually over time as components wear. Such losses may be containable if the best operating and maintenance practices can be followed. There are still a large number of older coal-fired power plants in India that could potentially be retrofitted to give major reductions (hundreds of Mt/y) in CO_2 emissions. Upgrading and efficiency improvement projects on coal-fired power plants can be taken up either on boiler side or turbine side. General boiler and turbine related technical measures taken are given below:

Turbine and related technical measures

- New rotors, modern blading, more stages
- Replacement inner casings with new stators, better sealing
- Valves, feed-water heaters, condenser refurbishments

Boiler and related technical measures

- Improved coal and air flow management, more advanced monitoring, reduction of air in-leakage
- Modern burner designs
- Upgrading of fuel milling (quality and flow)
- Redesign of heat transfer surfaces, additional area, better materials; air heater improvements; smart soot blowing

Some of the project examples are given below:

AECO Sabarmati D Station, India – Up-rating from 110 MW to 120 MW:

NASL, a joint venture of NTPC, India, and ALSTOM Power Systems GmbH, is carrying out a number of projects in India. Sabarmati has four lignite fired units. Unit D is the oldest one, opened in 1978. The project, carried out in 2003, included a turbine retrofit with new HP/IP/LP rotors, redesign of the re-heater to match the retrofitted turbine and installation of new distributed control systems. As a result, the unit has successfully operated for 5 years at 120 MW, at better than guaranteed heat rate and an average PLF of 95%.

Raichur TPS, India –Smart Wall Blowing System

Raichur Thermal PowerStation as shown in Figure 7 has 8 x 210 MW units. BHEL has installed the smart wall blowing system. The ash build-up is monitored by measurements of heat transfer rates in different zones and blowing is initiated until the local SH spray reaches desired levels. As a result, a steady SH/RH steam temperature was achieved, improved efficiency and 60% less soot blowing noticed steadily. The up gradation was disseminated in APP/USAID Best Practice Guide.

Figure 6 : Raichur TPS, India, where smart wall blowing system has been tested

6.2 Supercritical Technology:

The most cost-effective way to reduce emissions in fossil fuel power plants is to increase the plant's thermal efficiency. For example, every percentage point increase in thermal efficiency creates approximately a 2.5% reduction in CO_2 emissions. Even less CO_2 can be emitted by adding CO_2 capture and storage (CCS) system. Since more efficient coal power plants create less CO_2 per MW of power, this lowers the cost and parasitic load of CCS as there is less CO2 to capture and store.

In order to increase the efficiency of steam power plants, the basic method employed is to improve the thermal efficiency by increasing the operating pressure. As the pressure increases, the boiling temperature increases and the latent heat of vaporisation decreases. At atmospheric pressure the Latent Heat of vaporisation is 2256 kJ/kg. A further increase in pressure and temperature leads us to a point at which the latent heat of vaporisation is zero, or there is no boiling. Water directly becomes steam. This is the Critical Pressure and the Critical Temperature. For steam this occurs at 374 deg C and 220.6 bar. Conventional steam power plants operate at a steam pressures in the range of 170 bar. These are Subcritical power plants. The new generation of power plants operate at pressures higher than the critical pressure. These are Supercritical power plants or once through boilers. The operating pressures are in the range of 230 to 265 bar. Figure 8 shows the heat rate improvement for higher pressure and temperature. In the figure, the cycle efficiency with 175 bar and 538/538 deg C is base with 38% efficiency. For 241 bar and 538/566 deg C, the efficiency is calculated to be 38% x 1.0264 = 39%.

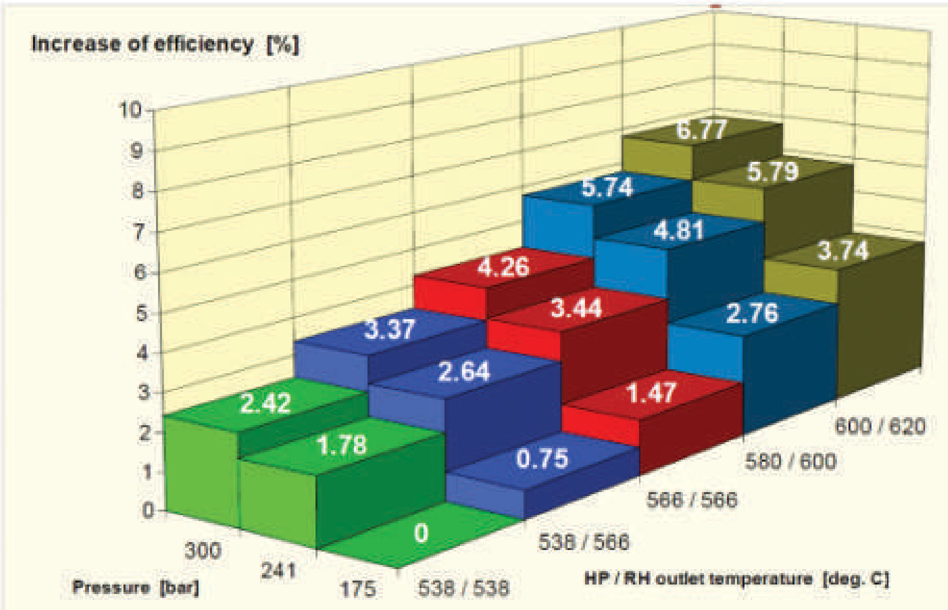

Figure 7 : Heat rate improvement (Steam parameters Vs Cycle efficiency)

The on-going government initiative is the promotion and introduction of larger thermal units (660 and 800 MW) for improved efficiency and fast capacity addition during the various Five Year Plans. A stated government objective is to adopt the latest technology in order to address environmental concerns and improve efficiency within the country's power generation sector; this will be partially achieved by the introduction of SC PCC technology. During the 11th Plan (2007-12) the government aims to deploy ten 660 MW and two 800 MW SC units, as well as pursuing its programme of UMPP projects. The steam parameters proposed for 660 MW units are of main steam conditions of 242 bar/535°C, with reheat of 565°C. Parameters proposed for 800 MW units are of main steam conditions of 242 bar /565°C, with reheat of 593°C. The adoption of SC technology offers advantages in terms of reduced coal consumption, increased cycle efficiency, and reduced emissions. A comparison of subcritical and supercritical units, in an Indian context for CO_2 reduction and efficiency improvement, is presented in Table 4.

Table 4: Reduction in CO2 Emissions in PC Boilers

	Unit	500 MW	660 MW	800MW
Parameters	Bar/°C /°C	170/538/538	246/538/565	246/565/598
Heat Rate Imp	%	Base	2.1	3.6
Coal Savings	t/yr	Base	56000	96000
CO_2 Reduction	t/yr	Base	61600	105600

The economic benefits of raising steam temperature above 635° C and the use of nickel-based alloys are being explored. The extra costs of using nickel-based alloys can probably be compensated by reduction in the amount of material required through thinner tube walls and smaller overall dimensions of both plant and site requirements. Efforts are also afoot to develop materials which can withstand high temperatures and pressures to improve thermal efficiency. However, increased live steam pressure may lower potential for improved performance due to auxiliary power consumption.

6.2.1 India's Supercritical Program:

In recent past, the focus and promotion of SC technology in India has prompted a number of developments with technology providers and recently, BHEL has entered into several important industrial alliances. A general arrangement of a steam generator is shown in Figure 9. In 2005, BHEL signed a technical collaboration agreement with Alstom, setting the basis of cooperation between the two companies on once-through boiler and pulveriser technology. In 2006, BHEL and the Siemens Power Generation Group signed a MoU on cooperation in the field of advanced power plant technology. In mid-2007, it was announced that Larsen & Toubro Ltd and MHI of Japan had agreed on a joint venture to manufacture SC boilers in India. The venture will be based in New Delhi and manufacture plants in the capacity range of 500–1000 MW.

During 2001, the CEA accorded techno-economic clearance for setting up the Barh Super Thermal Power Station at Barh in Bihar. BHEL's first OTSC boiler contract is from NTPC for BARH power station in Bihar state where BHEL is supplying two nos. of advanced coal fired once through supercritical steam generators of 660MW capacity in association with Alstom. This boiler incorporates several new and

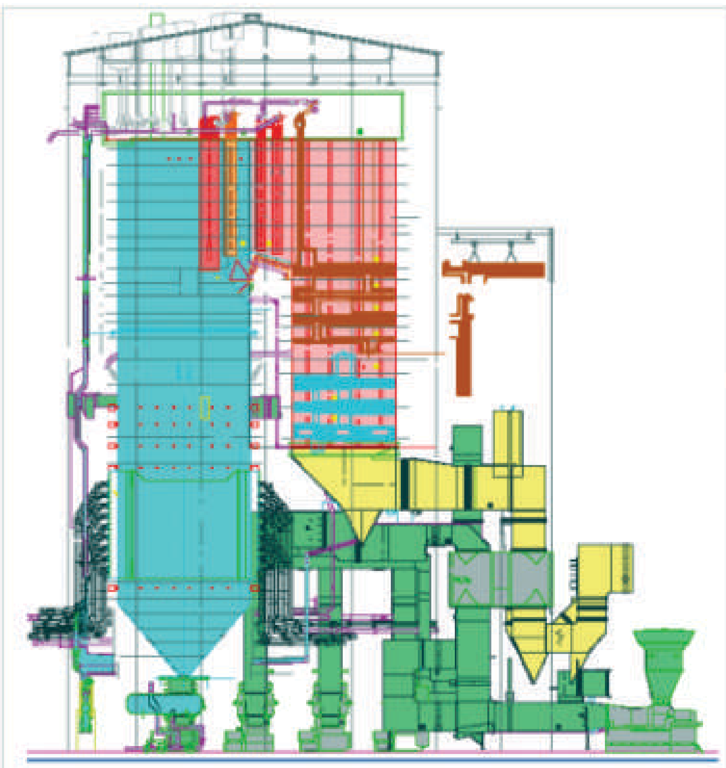

Figure 8 : General arrangement of steam generator

innovative features and is designed for higher steam parameters including sliding pressure operation. The project was identified as a Mega Power Project in the revised policy of the Ministry of Power.

The annual coal requirement would be ~10 Mt/y, to be supplied from the Amrapali block of the North Karanpura coalfields. An EPC order for coal handling plant has been awarded to Larsen & Toubro; this includes design, manufacture, supply, erection, testing and commissioning of the plant complete with civil, structural, electrical and instrumentation work. Construction will take 43 months. Land and water availability has been secured and environmental and other statutory clearances are in place. Electricity generated will be used mainly in the Northern, Western and Eastern regions of the country. NTPC recently announced that it may enlarge the project and is considering boosting capacity through the addition of either two additional 660 MW or 800 MW units. The chemical cleaning of a supercritical boiler in the pre-commissioning stage was successfully carried out at the Barh site using Di-Ammonium EDTA (ethylene diamine tetra acetate). BHEL has also developed design for supercritical boilers in the lower range of 350 MW to cater to industrial customers.

6.3 Ultra Mega Power Projects:

Ultra Mega Power Projects (UMPP) is a series of ambitious power projects planned by the Government of India. On the basis that economies of scale can produce cheaper power, as part of its drive to increase generating capacity, the Ministry of Power, CEA and the Power Finance Corporation are working together to develop a number of Ultra Mega Power Projects (UMPPs) being developed via a tariff based competitive bidding process. These projects will be awarded to developers on a BOO (Build-Own-Operate) basis. Projects will have an initial nominal capacity of ~4000 MW although to encourage more bidders to participate and introduce flexibility for increased competition, the project size has a flexibility of ±10%. Projects will also have scope for further expansion in the future. Each is expected to employ SC PCC technology, with 100% fly ash utilisation and high environmental standards.

According to the Power Finance Corporation, 16 UMPPs are envisioned. As of July 2012, 12 SPVs had been formed. Currently, two UMPPs have been commissioned. Table 5 below shows the status of the UMPPs for which special purpose vehicles (SPV) have been formed.

During 2005, guidelines for the determination of tariff through the bidding process were issued. These provided for procurement of power by distribution licensees through competitive bidding. The projects will deploy SC PC units with an individual unit size of 660 and 800 MW. Much of India's current generating fleet is based on smaller units and the introduction of large unit sizes is viewed as essential for rapid capacity addition envisaged during the 10th and 11th plans. The cost of each project has been estimated at Rs 16,000 crore.

Various domestic and international power companies and other organisations have been involved in the bidding process for the projects. For instance, overseas organisations considering bidding for the Andhra Pradesh UMP Project included Sumitomo of Japan, YTL Corporation, Bernhard of Malaysia, Khanjee Holdings of the US, China Light and Power, and Israel Electric. Indian companies involved included NTPC, Tata Power, Reliance Energy, Essar Power, GMR Energy, Larsen & Turbo, Lanco, Jindal Steel, Lanco Infratech and AES India. The Ministry of Power has adopted a central role in the development process, acting as facilitator. It is coordinating ministries and agencies involved with State governments to ensure the allotment of suitable coal blocks, that appropriate environmental/forest clearances are obtained and land is acquired, and that the necessary support from State governments and their agencies is also obtained. Furthermore, it is ensuring financial closure by financial institutions, facilitating power purchase agreements and proper payment security mechanisms with State governments and utilities, and monitoring the progress of shell companies with respect to pre-determined timelines.

Five sites based on the availability of fuel, land and water were selected by CEA. Two are pithead sites using domestic coal at Sasan and Akaltara, and three are at coastal locations at Mundra, Girye and Tadri

Table 5: List of UMPP for which SPVs have been formed

State	Plant	Owner	MW	Fuel source	Status
Andhra Pradesh	Krishnapatnam Ultra Mega Power Project	Reliance Power	3960	Imported coal	awarded
	Nayunipalli Ultra Mega Power Project	not yet awarded	4000	Imported coal	In process
Chhattisgarh	Surguja Ultra Mega Power Project	not yet awarded	4000	local coal mine	In process
Gujarat	Mundra Ultra Mega Power Project	Tata Power	4000	Imported coal	Unit 1 of 800 MW commissioned in Mar 2012; Unit 2 in May 2012, Unit 3 in Oct 2012.Unit 5 in March 2013.
Jharkhand	Tilaiya Ultra Mega Power Project	Reliance Power	3960	local coal mine	awarded
	Deoghar Mega Power Ltd, 2nd UMPP, Deoghar Disrtict	not yet awarded	4000	coal	In process
Karnataka	Tadri Ultra Mega Power Project	not yet awarded	4000	Imported coal	In process
Madhya Pradesh	Sasan Ultra Mega Power Project	Reliance Power	3960	local coal mine	Unit 1 of 660 MW commissioned on 9 March 2013. Will be fully commissioned by June 2014.
Maharashtra	Girye Ultra Mega Power Project	not yet awarded	4000	Imported coal	In process
Orissa	Sundargarh Ultra Mega Power Project	not yet awarded	4000	local coal mine	In process
	Sakhigopal Ultra Mega Power Project	not yet awarded	4000	Imported coal	In process
	Ghogarpalli Ultra Mega Power Project	not yet awarded	4000	local coal mine	In process
Tamil Nadu	Cheyyur Ultra Mega Power Project	not yet awarded	4000	Imported coal	In process. Environment clearance obtained in May 2013.
	2nd UMPP in Tamil Nadu	not yet awarded	4000	Imported coal	In process
Bihar	Bihar UMPP	not yet awarded	4000	Imported coal	In process

that will probably rely (at least partially) on imported coal. An additional pithead site in Orissa and a coastal site in Andhra Pradesh are also under consideration.

As the strategy of developing the UMPPs has progressed, the ratio of coastal to pithead projects have changed and the number of coastal projects has increased. As a result, the government is revisiting the policy of using imported coal for such projects and is examining the possibility of firing coastal sites with blends of domestic and imported coals. If this route is adopted, only two of the coastal UMPPs (Mundra and Krishnapatnam) will be fired solely on imported coal. To date, at least six coastal projects have been proposed.

Firing of blended coal is also being considered for UMPP projects at Chayyur and Nagapatnam (both in Tamil Nadu), Tadri or an alternative site in Karnataka, and Girye in Maharashtra. BHEL has examined the possibility of using coal blends at the upcoming Krishnapatnam project and confirmed the practicality of blending 20% of imported coal with indigenous supplies. The boiler would need to be designed for a pre-determined blending ratio, although BHEL will not guarantee boiler performance as this will be partially dependent on the homogeneity of the blend. The use of blends is being considered as a consequence of the anticipated cost of electricity produced, and as a response to volatility within the international coal market. Blends could offer a price advantage and help minimise fuel imports.

Figure 9 : Mundra Ultra Mega Power Project

6.4 Ultra Supercritical (USC) / Advanced Ultra Supercritical (AUSC) Technology:

In the quest for higher efficiency boilers, the trend is to go for still higher operating pressures and temperatures. The next generation of power plants will operate with steam pressures in the range of 300 bars. These are the Ultra Super Critical Power plants that operate at temperatures of 615 to 630 deg C. The steam power plant technology trend is shown in Figure 11. The Pollution level complies with United

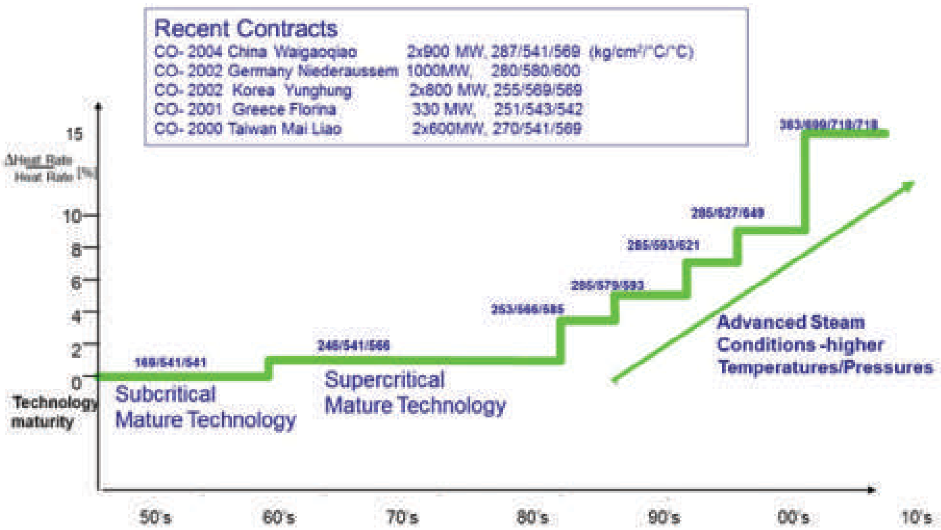

Figure 10: Steam Power Plant Technology Trends

Table 6: Status of UMPPs awarded

Name of the UMPP	Name of the SPV	Developer to whom awarded	Levelised Tariff accepted (₹ per unit of elecricity)*
Mundra 4000 MW (5x800 MW)	Coastal Gujarat Power Limited (incorporated on 10-02-2006)	Tata Power Company Limited	2.264
Sasan 3960 MW (6x660 MW)	Sasan Power Limited (incorporated on 10-02-2006)	Reliance Power Limited	1.196
Krishnapatnam 3960 MW (6x660 MW)	Coastal Andhra Power Limited (incorporated on 24-08-2006)	Reliance Power Limited	2.333
Tilaiya 3960 MW (6x660 MW)	Jharkhand Integrated Power Limited (incorporated on 02-01-2007)	Reliance Power Limited	1.77

**Note: Levelised tariff is the weighted average tariff.*
@ Worked out on levelised tariff basis.

Nations CDM (Clean Development Mechanism) standards. Several USC power plants are now achieving greater efficiencies in operation around the world, and current development interest is focused on advanced ultra-supercritical (AUSC) operations, with temperatures up to 750 deg C.

A-USC technology would form the foundation for a number of subsequent improvements. This developmental project was taken as a multi-year effort to evaluate and develop materials that allow the use of advanced ultra-supercritical (A-USC) steam cycles in coal-based power plants. These advanced cycles, with steam temperatures up to 760°C, can increase the efficiency of coal-fired boilers from an average of 35% efficiency up to 47% higher heating value (HHV). This efficiency increase will enable coal-fired power plants to generate electricity at competitive rates while reducing CO_2 and other fuel-related emissions by approximately 25%. The power plant efficiency trends with comparison with other technologies are shown in Figure 12. Higher efficiencies also reduce solid and liquid wastes, and include the additional benefit of less water consumption.

An A-USC Project consortium have been formed by Government of India that consists of NTPC, Midani, BHEL and IGCAR, which has announced their plans to build an 800 MW, 700°C plant by 2017. The consortium is working to select materials and develop welding and fabrication technologies and

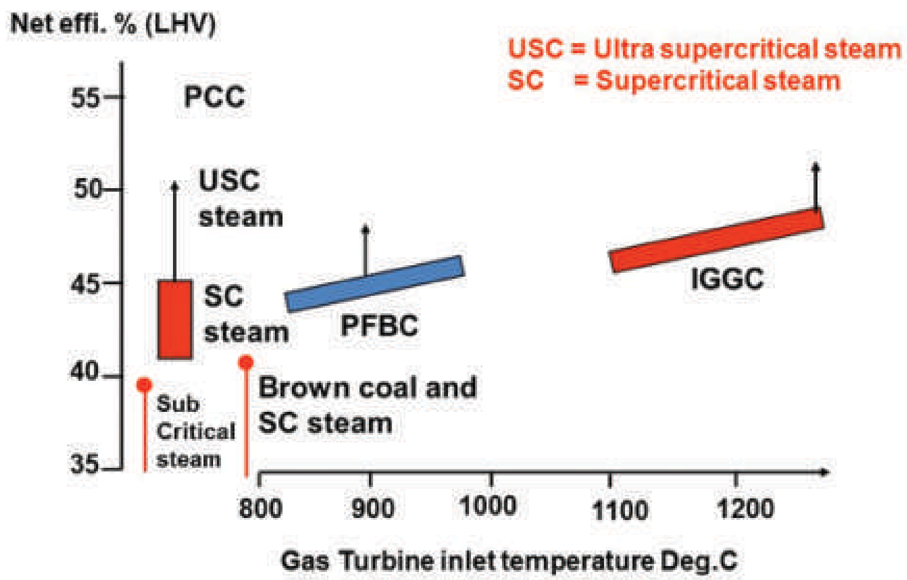

Figure 11 Power plant efficiency Trends

collaborating with national/international institutions to support the A-USC project. The project is a part of Government of India's National Technology Mission which could cost well over Rs.6000 crore. The consortium has designed and fabricated a steam loop, with plans to install it into an existing boiler and operate for two years. The preliminary conceptual design of the boiler is complete. The consortium submitted a document for 800 MW coal fired Advanced Ultra supercritical power parameters which work at pressure of 310 bar and at a temperature of 710 °C to the steering committee of the Government. The project is expected to be completed in 2018 and is likely to come up at the NTPC's Dadri complex at Uttar Pradesh. The commissioning of the plant has a time frame of 7 years from the date of sanction by the Government of India. This time frame includes 2½ years of research and development work, with the balance 4½ years devoted to actual project implementation. For developing the plant, BHEL would make the equipment while the materials testing would be done by IGCAR. Once they are satisfied, NTPC would build the plant. The plant would have five per cent more efficiency than the existing thermal plants and help in 12 per cent savings in coal, thus reducing the overall amount of carbon dioxide emission.

BHEL has installed a supercritical test facility (400 bar, 700deg.C) and tests are being carried out to collect the critical design data. BHEL has also developed Artificial Neural Network (ANN) and Computational Fluid Dynamics (CFD) models for predicting metal temperature under supercritical conditions through simulation using silver coated 180 degree heated tube in supercritical test facility. As part of the project, hot wire GTAW (Gas Tungsten Arc Welding) technology was established by Welding Research Institute, BHEL, Trichy for joining of tubes and plates of advanced materials such as Super 304H, Haynes 230, T92 and T91.

Project Design Memorandum (PDM) document for setting up and demonstration of 800 MW coal-fired plant with Advanced Ultra Supercritical (AUSC) parameters was a major stride by BHEL Tiruchi during 2012-13. The PDM submitted to the Central government was prepared in association with National Thermal Power Corporation and Indira Gandhi Centre for Atomic Research with an objective of achieving a plant efficiency of 46 percent, one of the highest so far in the world.

6.5 Pressurised Fluidised Bed Combustion Combined Cycle (PFBC)

During the late eighties, a new type of fluidised bed design called as pressurised bed was developed to further improve the efficiency levels in coal-fired plants. In this concept, the conventional combustion chamber of the gas turbine is replaced by a pressurised fluidised bed combustor. The products of combustion pass through a hot gas cleaning system before entering the turbine. The heat of the

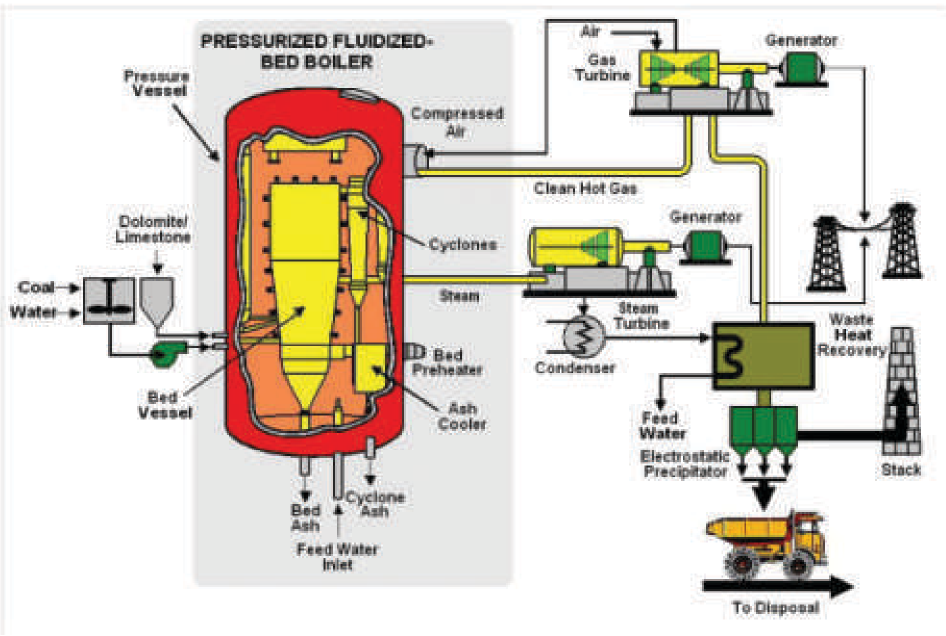

Figure 12 : PFBC Process Diagram (Tidd, USA)

exhaust gas from the gas turbine is utilised in the downstream steam turbine. This technology (shown in Figure 13) is called pressurised fluidised bed combustion combined cycle (PFBC).

The bed is operated at pressure between 5 bar and 20 bar. Operating the plant at such low pressures allows some additional energy to be captured by venting the exhaust gases through a gas turbine which is then combined with the normal steam turbine to achieve plant efficiency levels of up to 50 percent. The steam turbine is the major source of power in PFBC, contributing about 80 percent of the total power output. The remaining 20 percent is produced in gas turbines.

The PFBC plants are smaller in size than the atmospheric FBC and PCC plants of same capacity and therefore have the advantage of locating in urban areas. The fuel consumption is about 10-15 percent lower than in PCC technology. PFBC has been used only over the last few years. The development of this technology is dependent upon the compatibility of the hot gas clean-up system with the gas turbine inlet temperatures and maximum particulate size. Improvements on these two fronts would lead to greater acceptance of PFBC.

6.5.1 Status of PFBC Technology Development:

The first demonstration plant with a capacity of 130 MWe is under operation in Stockholm, Sweden since 1991, meeting all the stringent environmental conditions. Other demonstration plants were Escatron, Spain (80 MWe), TIDD station, OHIO (70 MWe), Wakamatsu (70 MWe), Grimethrope, UK (80 MWe). A 350 MWe PFBC power plant is planned in Japan and another is on order in USA (to be operated at SPORN). ABB-Sweden is the leading international manufacturer which has supplied most of the demonstration plants in the world and is now offering 300 MWe units plants.

BHEL- Hyderabad has a 400 mm PFBC operating for the last ten years and has collected useful research data. IIT Madras has taken up many studies on PFBC with BHEL grant. IIT Madras has a 300 mm diameter research facility built with NSF (USA) grant.

6.6 Fluidized Bed Combustion:

Fluidised Bed Combustion (FBC) is an alternative technology developed to raise the efficiency levels. In this technology, high pressure air is blown through finely ground coal. The particles become entrained in the air and form a floating or fluidised bed. This bed behaves like a fluid in which the constituent particles move to and fro and collide with one another. Fluidised bed can burn a variety of fuels - coal as well as other non-conventional fuels like biomass, petro-coke, and coal cleaning waste and wood. Figure 14 shows a 120 MW bubbling fluidized bed boiler.

The bed temperature in FBC is around 800-900 °C versus 1,300-1,500 °C for Pulverised Coal Combustion (PCC). Low temperature helps to minimise the production of NOx. With the addition of a sorbent into the

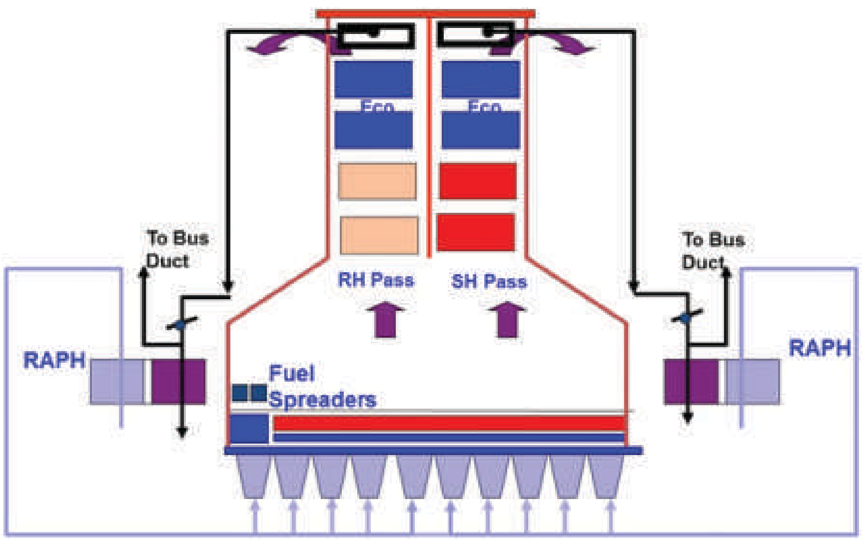

Figure 13 120 MW Bubbling fluidized Bed boiler

bed (mostly limestone), much of the SO_2 formed can be captured. The other advantages of FBC are compactness, ability to burn low calorific values (as low as 1,800 kcal/kg) and production of ash which is less erosive. Moreover, in FBC, oil support is needed for 20-30 percent of the load versus 40-60 percent in PCC. FBC-based plants also have lower capital costs compared to PCC-based plants.

FBCs are classified as bubbling and circulating beds. While bubbling beds have low fluidisation velocities to prevent solids from being elutriated, circulating beds employ high velocities to actually promote elutriation. Both these technologies operate on atmospheric temperature. The circulating bed can remove 90-95 percent of the sulphur content from the coal while the bubbling bed can achieve 70-90 percent removal.

Bharat Heavy Electricals Limited (BHEL) has a bubbling fluid bed boilers test facility with a rating of 90 tonne per hour suitable for firing high ash coals (shown in Figure 15). FBC thus offers an option for burning fuels economically, efficiently and in an environmentally acceptable way. Currently, size is the only limitation of this technology. While the maximum size of a PCC-based power plant unit could be 1,300 MW, FBC has achieved a maximum unit size of 250 MW. An FBC Boiler at Jindal Steel & Power of capacity 165 t/h supplied by BHEL is shown in Figure 16. According to some estimates, FBC represents only about 2 percent of the total coal fired capacity worldwide, but is of particular interest and significance for use of those coals which are difficult to mill and fire in PCC boilers.

Figure 14 :
90 T/h BFBC Test Facility at Trichy

Figure 15 : FBC Boiler at Jindal Steel & Power

6.7 Circulating Fluidised Bed Combustion (CFBC):

Following the success of BFBC units, increasing attention is being paid for the firing of fuels with low volatile matter content in CFBC. Unlike conventional PC-fired boiler, the CFBC boiler is capable of burning fuel with volatile content as low as 8 to 9 percent (e.g. anthracite coke, petroleum etc. with minimal carbon loss). Fuels with low ash-melting temperature such as wood, and bio-mass have been proved to be feed stocks in CFBC due to the low operating temperature of 850-900° C. Figure 17shows a typical Flow diagram of Circulating fluidized bed boiler. CFBC boiler is not bound by the tight restrictions on ash content either. It can effectively burn fuels with ash content up to 70 percent.

CFBC would successfully burn agricultural wastes, urban waste, bio-mass, etc. which has low melting temperature for their ash. The low furnace temperature precludes the production of "thermal NOX" which appears above a temperature of 1200 to 1300° C. Besides, in a CFBC boiler, the lower bed is operated at near sub-stoichiometric conditions to minimise the oxidation of "fuel-bound nitrogen". The remainder of the combustion air is added higher up in the furnace to complete the combustion. With

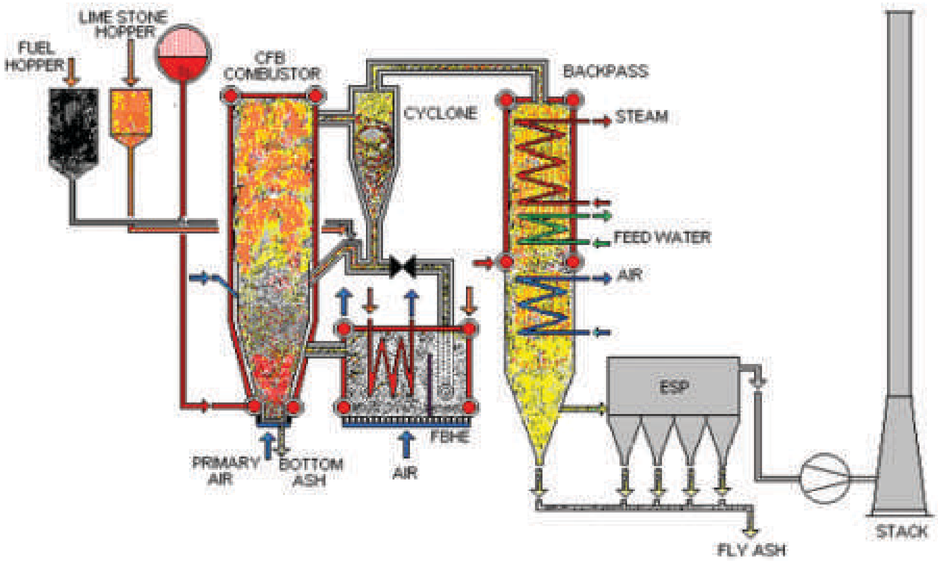

Figure 16 : Flow Diagram of Circulating Fluidized Bed Boiler

the staged-combustion about 90 percent of fuel-bound nitrogen is converted to elemental nitrogen (N2) as main product.

It is known that CFBC is a mature technology with more than 300 CFBC boilers in operation world wide ranging from 5 MWe to 250 MWe. With lime stone addition, 90 percent of the sulphur emission can be reduced. With staged combustion and with relatively low combustion temperature of 850 / 900° C, NO_2 formation is about 300 to 400 mg/Nm3 only in the CFBC boiler against 500 to 1000 mg/Nm3 in conventional PF fired boilers.

6.7.1 Status of development of CFBC technology:

Bharat Heavy Electricals Limited (BHEL) has developed circulating bubbling fluid bed boilers up to capacity rating of 150 tonne per hour for high ash coals and washery rejects (Shown in Figure 18). For units of capacity higher than 30 MW, circulating fluidised bed combustion (CFBC) technology is more economical for high ash coals and / or high sulphur coals.

Figure 17 : CFBC Test Facility at BHEL, Tiruchy

BHEL has entered into a technical collaboration agreement to make higher capacity CFBC boilers up to 250 MW. There are currently around 25 CFBC plants operating in India, based on technology supplied by BHEL/LLB, TBW, ThyssenKrupp, and Alstom/Foster Wheeler. A 2 x 125 MW CFBC units in SLPP, Surat supplied by BHEL is shown in Figure 19. CFBC plant in practice, systems have proved to be fuel flexible, have high carbon burnout (>99%), and effective in situ SO_2 and NOx control. An order for the country's biggest plant, 2 x 250 MW units for NLC (with Lurgi as process associate) is executed. Annually, this new power plant will burn 4.5 Mt/y lignite and generate 3285 million units of electricity. BHEL is currently executing an order of Lignite fired CFBC boilers of 2 x 250 MWe each for BECL, Gujarat. Figure 20 shows the increase in capacity of BHEL CFBC boilers. BHEL is currently working on the development of a high capacity CFB boiler. Figure 21 shows a design of a 500 MW CFBC boiler designed by BHEL.

During the last 20 years, improvements in refractory system designs, fuel and sorbent feed system designs, and ash extraction equipment design have been made to adequately address the initial problems encountered with these system components. To move CFBC technology to advanced steam cycle conditions, once-through boiler technology has been adopted in the designs of SC CFBC boilers. The world's largest coal-fired SC CFBC power generating unit which started operation in 2009 has a

Figure 18 BHEL supplied 2 x 125 MW CFBC units in SLPP, Surat

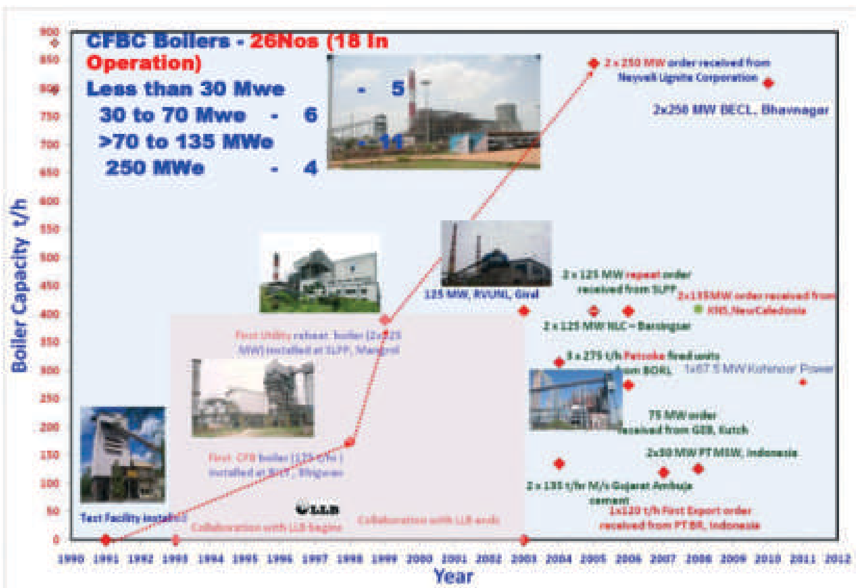

Figure 19 : The increase in capacity of BHEL CFBC boilers

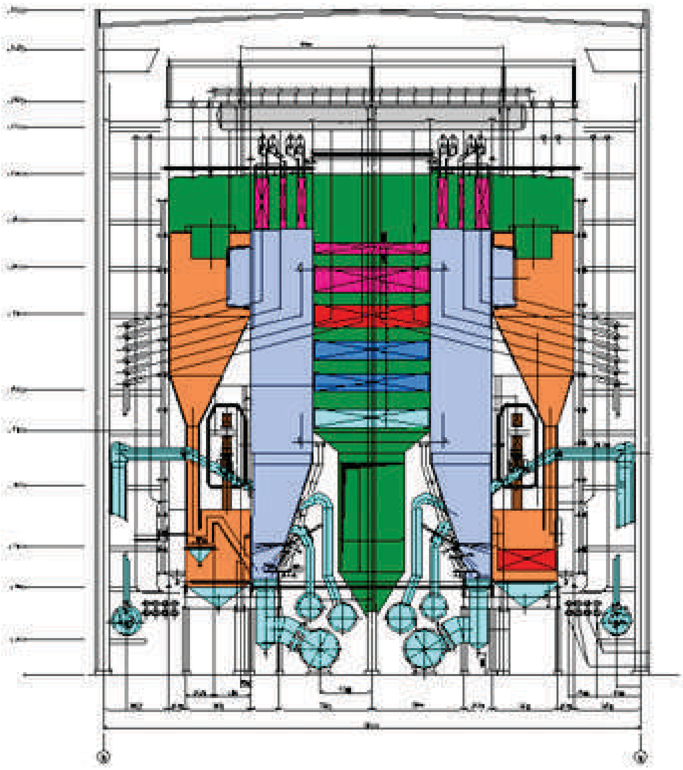

Figure 20 : 500 MW CFB design of BHEL Trichy

capacity of 460 MWe. The SC CFB unit at Lagisza power plant (Poland) uses steam parameters of 27.5 MPa/560ºC/580ºC. More coal-fired SC CFBC power plants with unit sizes of 550 and 600 MWe are under installation in South Korea and China.

Optimum design of the furnace is the key to the successful and efficient operation of a CFBC boiler. Due to the nature of fluidised-bed combustion, there is a limit to the height and depth of a CFBC furnace. Different approaches are taken to overcome the limitation to the furnace dimensions when scaling-up is done. The innovative and optimised designs enable the manufacturers to increase the size of CFBC boilers while ensure good mixing of bed material and air in the furnace and the required combustion efficiencies.

The most commonly used solid separation system in CFBC boilers is the cyclone. The development of water- or steam-cooled cyclones and the improved cooled-cyclone design have minimised refractory use and reduced the maintenance and operating costs leading to CFBC boilers with longer service life and higher availability. The use of external heat exchangers (EHE) enables the superheated and reheated steam temperatures to be adjusted, and the combustion temperature to be controlled. Therefore, with increasing boiler size, the number of cyclones are increased.

Nowadays, power generators are facing the challenge of reducing CO_2 emissions, which is likely to lead to substantial changes in the way power is produced and consumed. For CO_2 emissions control, intensive R&D is ongoing to develop and commercialise technologies for carbon capture and storage (CCS). Oxy-CFB technology is developing rapidly and will evolve as the industry gains experience and incorporates new innovations. It is expected that CFBC technology will see increasing applications in the power generation industry in the near future.

6.8 Underground Coal Gasification:

UCG is an in-situ gasification process carried out in non-mined coal seams using injection of oxidants and bringing the product as gas to surface through production wells drilled from the surface. Underground coal gasification (UCG) is a major industrial process, which converts coal into product gas. The product gas could to be used as a chemical feedstock or as fuel for power generation.

A typical underground coal gasification process is shown in Figure 22. Injection wells are used to supply the oxidants (air, oxygen, or steam) to ignite and fuel the underground combustion process. Separate production wells are used to bring the product gas to surface. The high pressure combustion is conducted at temperature of 700–900 °C, but it may reach up to 1,500 °C. The process decomposes coal and generates carbon dioxide (CO_2), hydrogen (H2), carbon monoxide (CO), methane (CH4). In addition, there are small quantities of various contaminants including sulphur oxides (SOx), mono-nitrogen oxides (NOx), and hydrogen sulfide (H2S).

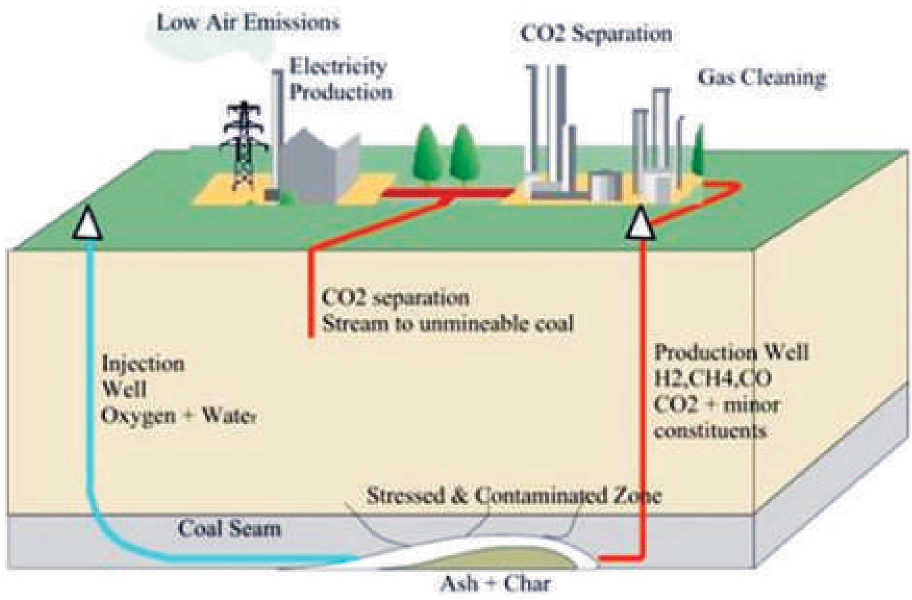

Figure 21 : The underground coal gasification process.

India has very large, deep deposits of coal and lignite that cannot easily be exploited by conventional mining methods. UCG may offer the possibility of accessing some of these reserves that would otherwise remain untapped. The UCG potential in India is given in Table 7. Recognising the significant potential of this energy source, the Hydrocarbon Vision 2025 report recommended the formation of national policy for assessment of deep-seated coal and lignite and the impact on strata conditions and hydro-geological regimes resulting from UCG.

Table 7: UCG potential in India

Un-mineable Coal Resources	210.14 Billion Tons
Un-mineable Lignite Resources	32.76 Billion Tons
Total Un-mineable Resources	242.90 Billion Tons
Percentage of Coal Amenable to UCG	30 %
Coal Reserves Amenable to UCG	72.87 Billion Tons
UCG Gas (Considering 2700 M^3/Ton)	196.749 Trillion M3
Natural Gas Equivalent	19.67 Trillion M3
Calorific Value of Produced Gas	3- 5 MJ/M3
Calorific Value of Natural Gas	38 MJ/M3

ONGC signed an MoU with Neyveli Lignite Corporation for investigating UCG projects and also proposed a joint venture with Coal India Ltd (CIL) for UCG projects. Technology support was provided by the Skochinsky Institute. ONGC also produced a UCG roadmap and carried out site selection studies of detailed geological and hydro-geological evaluation. ONGC included UGC initiative in its eleventh plan. So far, the company has studied 11 sites, out of which only five were found not suitable for UCG, five sites require additional data generation for further analysis and one site, the Vastan Mine Block, has been found most suitable for UCG. A mining exploration license (MEL) was sought for coal blocks in Bhestan basin near Surat after completing initial surveys. It is aiming to go commercial by producing about two billion cubic metres of synthetic gas per annum from the Vastan field, which has enough reserves to last for 30-40 years. A UCG facility was initiated in Gujarat and waiting to get the approval from union coal ministry.

For Lignite, which cannot be mined commercially, GAIL (India) is planning to produce synthetic gas by employing underground coal gasification technology in Rajasthan. GAIL plans to use the gas so produced to generate 70–80MW of power. It may tie up with Ergo Exergy Technologies Inc., Canada, for sourcing "in situ lignite gasification" technology for its proposed project. In 2005, GAIL signed a Memorandum of Co-operation with Ergo Exergy Technologies Inc, to explore UCG projects in India. Typically, coals of lower rank are the easiest to gasify and are better suited for UCG. Generally, a CV of at least 1000 kcal/m3 of the gas is considered a minimum requirement for firing it in a gas turbine. A higher CV can be obtained in UCG using enriched air with an oxygen content of 65% with CO_2 capture, suggesting that this could provide a technically viable option. The composition of UCG dry syn gas with and without CO_2 capture is shown in Figure 23.Reliance is also interested to set up a pilot UCG plant. Essar want to use the product gas for their proposed steel plant in Orissa.

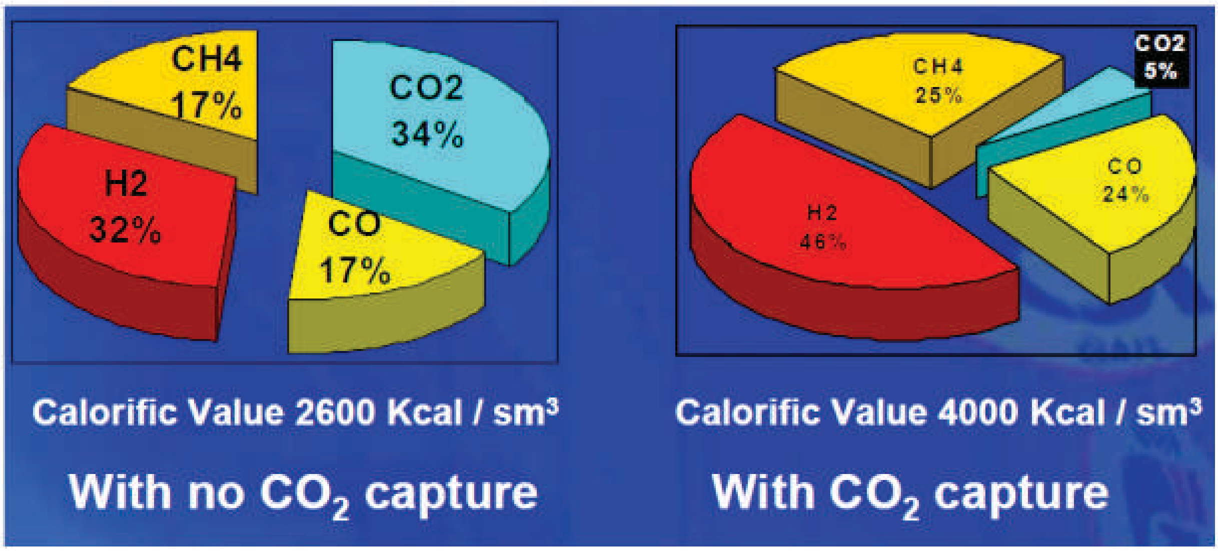

Figure 22 : Typical composition of UCG Dry Syn Gas

Neyveli Lignite Corporation (NLC) considers that the techno-economic viability of UCG under Indian conditions can be assessed only after pilot scale and has proposed the development of a pilot project, to be undertaken in collaboration with overseas partners. The proposed project would take about four years to complete. It would be carried out in three stages:

- Stage I - collection of preliminary data and pre-selection of selected lignite blocks; identification of suitable block for UCG studies;
- Stage II - preliminary exploration in the selected block; assessment of deposit characteristics, quality and reserves; carry out feasibility study for establishment of UCG and power plant;
- Stage III - establishment and undertaking of UCG pilot studies and evaluation of CV and other characteristics of gas produced.

The Ministry of Coal in February 2013 moved a Cabinet note on a policy for underground coal gasification and received comments from various ministries on the same. The Cabinet Committee on Economic Affairs (CCEA) may soon form a new policy on underground coal gasification for converting the coal seams at depths of more than 300 metres.

Coal Ministry of India has identified five number of lignite and two coal blocks, with estimated reserves of 950-million tonnes, that would be offered to private investors to undertake underground coal gasification projects. The government had issued notifications about the conditions under which private companies would be permitted to undertake underground coal gasification projects, and that these were within the ambit of the captive coal mining policy. The coal ministry has allotted two coal blocks in Talcher coalfields in Odisha Strategic Energy Technology Systems Ltd and Ramchandi block to Jindal Steel & Power Ltd with production capacity of about 80,000 barrels of oil per day per project. These are expected to commence by 2018.

6.9 Coal Bed Methane (CBM)

Coal Bed Methane (CBM) is the stored gas in coal seams, generated during the process of the coalification. It is well known that coal is formed due to bio conversion of fossilised organic matter. In the process of coal formation, anaerobic conditions lead to generation and trapping of methane in the coal seams. The pressure exerted by naturally formed water keeps the methane "absorbed" on internal surfaces of coal. Thus, coal bed gas is in mono-molecular state and not as free gas, as in natural oil/gas fields. Therefore, all coal fields of the world have coal bed methane, the only difference being the quantity of gas in individual coal seams.

Porosity plays an important role in building up methane gas reserves in the coal bed. Unlike the conventional reservoirs, in coal the methane is not compressed in the pore space (porosity) but physically attached to the coal at molecular level (micro porosity). Micro porosity makes up about 70 percent of the total porosity in coal bed and is equivalent to a conventional reservoir having 20 percent porosity, saturated with 100 percent gas. On account of this difference, coal has higher gas storage capacity than sands containing petroleum gas.

CBM is classified in three main categories: coal mine methane (CMM), abandoned mine methane (AMM) and virgin coal bed methane (VCBM). A simplified CBM well is shown in Figure 24. Methane captured during coal mining could be a significant, ecologically friendly source of energy, producing no

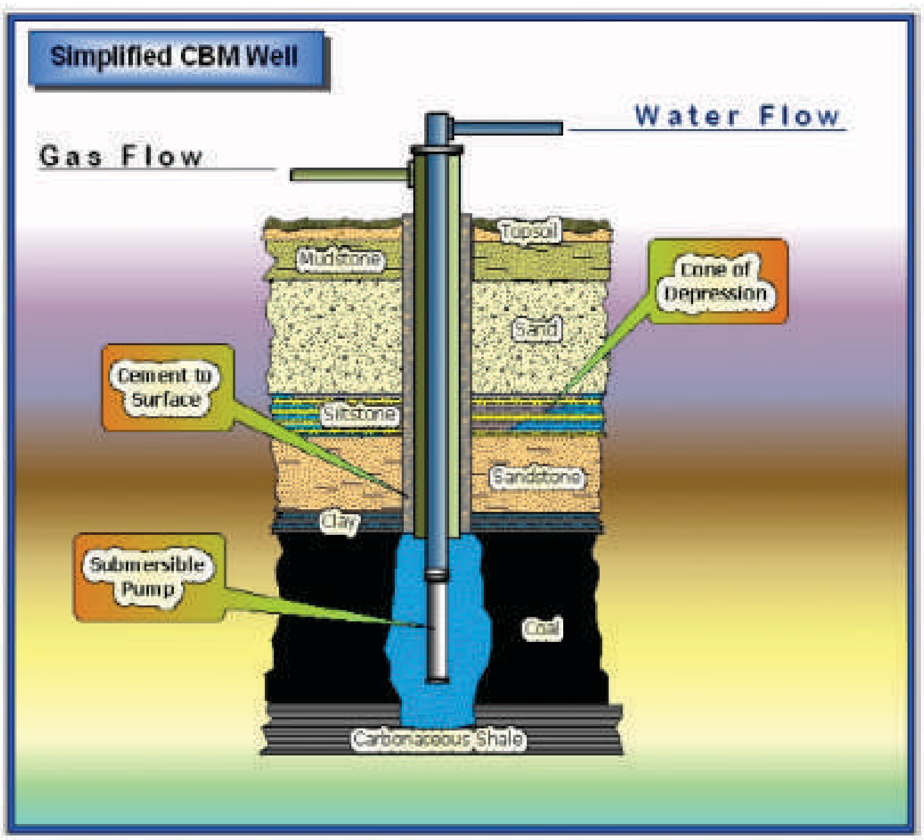

Figure : 23 A Simplified CBM Well

particulates and only about half the CO_2 associated with coal combustion. Depending on quality, methane from mines could be sold to gas companies, used to generate electricity, used to run vehicles, used as feedstock for fertilizer or methanol production, used in blast furnace operators at steelworks; sold to other industrial, domestic or commercial enterprises; or used on-site to dry coal.

Methane is a more potent green house gas and equivalent to 21 times more effect than CO_2. Thus, just burning off the captured methane (flaring) would reduce annual GHG emissions assuming that otherwise all this methane would have escaped to the atmosphere, due to the mining operations. CBM exploration and exploitation has an important bearing on reducing the greenhouse effect and earning carbon credit in preventing the direct emission of methane gas from operating mines to the atmosphere. Further, extraction of the CBM through degassing of the coal seams prior to mining of coal is a cost effective means of boosting coal production and maintaining safe methane level in working mines.

With the fourth largest proven coal reserves in the world, India holds significant prospects for exploration and exploitation of CBM. The government has identified CBM as having the potential to make an important contribution in meeting energy shortfalls. Strong support has been given to the Directorate General of Hydrocarbons in promoting and awarding a growing number of CBM blocks for exploration and development. The prognosticated CBM resources in the country are about 92 TCF (2608 BCM). The Government evolved a Policy for Coal Bed Methane in 1997 so as to utilize the country's enormous coal reserves and the methane gas trapped in coal seams. The MoPNG was to be the administrative Ministry with the Directorate General of Hydrocarbon (DGH) as the implementing agency and accordingly, an MoU was signed between the MoPNG and Ministry of Coal in September 1997.

CBM blocks were carved out by DGH in close interaction with MOC & CMPDI. Till date, four rounds of CBM bidding rounds have been implemented by MOP&NG under the CBM policy resulting in award of 33 CBM blocks which covers 17,200 sq.km out of the total available coal bearing areas for CBM exploration of 26,000 sq.km. Exploration under CBM policy has been undertaken by national and international companies. Total prognosticated CBM resource for awarded 33 CBM blocks, is about 63.85 TCF (1810 BCM), of which, so far, 8.92 TCF (252.8 BCM) has been established as Gas in Place (GIP). List of CBM blocks awarded are given in Table 8. Major players in this sector are Arrow Energy, Gas Authority of India Ltd. (GAIL), ONGC, Great Eastern Energy Corporation, BP Exploration, Reliance Energy Ltd, Reliance Natural Resources Ltd, GeoPetrol and others.

Depending on the location, estimates suggest that methane content is between 3–16 m^3/t coal. For instance, in the Jharia coalfield, the gas content is estimated to be between 7.3 and 14.9 m^3/t within a depth range of 150 to 800 m. In the Damodar Valley, gas contents of between 6 and 15 m^3/t have been noted. Important potential CBM areas of 2000 km2 (containing coal reserves of 37.31 Gt) are spread over Jharia, Raniganj, East and West Bokaro, North Karanpura and Sohagpur. However, there are several coal/lignite areas not yet fully investigated that potentially, could hold a further 2500 billion m^3.

A CMM demonstration project is being implemented jointly by Bharat Coking Coal Ltd (BCCL) and CMPDI in the former's Sudamdih and Moonidih mines. Further areas for CBM development are in the Jharia and Raniganj coalfields and the Damodar Valley where there is a high density of coal seams and a large number of operating and disused coal mines. However, as in other potential locations, this will be largely dependent on techno-economic aspects.

In spite of its obvious attraction, CBM projects are likely to be capital intensive and may require additional support from mechanisms such as the CDM. It is hoped that the project will provide an impetus to private sector involvement and international cooperation in the CBM sector in India. Specific project objectives include the uptake of CBM as a local energy source, reduced global greenhouse gas emissions, and increased understanding of the issues surrounding CBM and CDM, and the building of institutional capacity in this sector. Key deliverables include data on CDM potential of CBM projects in India, and costs involved in the development of CBM projects. Even though the current confidence level of such resources is low, and a recovery factor of 40% is applied, there is still an expected production potential of 90 Mm3/d or 22.5 GW.

Commercial CBM production has started from 1 block since 14th July 2007, which contributes about 0.25 MMSCMD of CBM production. Four more CBM blocks are expected to start commercial production in near future. The total CBM production is expected to be around 4MMSCMD by end of 12th plan.

Table 8: CBM blocks awarded

Sl. No.	Coal Field / State	Block Name	Consortium (Participating Interest)	Date of Signing Contract	Awarded Area (Sq. Km.)
CBM-I Round					
1.	Raniganj East / West Bengal	RG(E)-CBM-2001/1	EOL (100)	26.07.2002	500
2.	Bokaro / Jharkhand	BK-CBM-2001/1	ONGC (80) & IOC (20)	26.07.2002	95
3.	N. Karanpura / Jharkhand	NK-CBM-2001/1	ONGC (80) & IOC (20)	26.07.2002	340
4.	Sohagpur East / M.P.	SP(E)-CBM-2001/1	RIL (100)	26.07.2002	495
5.	Sohagpur West / M.P.	SP(W)-CBM-2001/1	RIL (100)	26.07.2002	500
				Total Area:	**1930**
On Nomination Basis					
6.	Raniganj North / West Bengal	Raniganj North	ONGC (74) & CIL (26)	06.02.2003	350
7.	Jharia / Jharkhand	Jharia	ONGC (90) & CIL (10)	06.02.2003	85
8.	Raniganj South / West Bengal	Raniganj South	GEECL (100)	31.05.2001	210
				Total Area:	**645**
CBM-II Round					
9.	South Karanpura / Jharkhand	SK-CBM-2003/II*	ONGC (100)	06.02.2004	70
10.	North Karanpura / Jharkhand	NK(West)-CBM-2003/II*	ONGC (100)	06.02.2004	267
11.	Sonhat / Chattisgarh & M.P.	SH(North)-CBM-2003/II	RIL (100)	06.02.2004	825
12.	Barmer / Rajasthan	BS(1)-CBM-2003/II*	RIL (100)	06.02.2004	1045
13.	Barmer / Rajasthan	BS(2)-CBM-2003/II*	RIL (100)	06.02.2004	1020
				Total Area:	**3227**
CBM-III Round					
14.	Raj Mahal / Jharkhand	RM-CBM-2005/III*	ARROW(35)-GAIL(35) -EIG(15)-TATA(15)	07.11.06	469
15.	Birbhum / West Bengal	BB-CBM-2005/III*	BPE (100)	16.11.06	248
16.	Tatapani Ramkola / Chattisgarh	TR-CBM-2005/III*	ARROW(35)-GAIL(35) -EIG(15)-TATA(15)	07.11.06	458
17.	Mand Raigarh /M.P.	SP(N)-CBM-2005/III*	ARROW(40)-GAIL(45) -EIG(15)	07.11.06	634
18.	Sohagpur /M.P.	SP(N)-CBM-2005/III	GEO(10)-REL(45)-RNPL(45)	07.11.06	609
19.	Singrauli / M.P.	SR(N)-CBM-2005/III	COALGAS(10)-REL(45) -RNPL(45)	07.11.06	330
20.	Kothagudem / Andhra Pradesh	KG(E)-CBM-2005/III	GEO(10)-REL(45) -RNPL(45)	07.11.06	750
21.	Barmer / Rajasthan	BS(4)-CBM-2005/III	GEO(10)-REL(45)-RNPL(45)	07.11.06	1168

Sl. No.	Coal Field / State	Block Name	Consortium (Participating Interest)	Date of Signing Contract	Awarded Area (Sq. Km.)
22.	Barmer / Rajasthan	BS(5)-CBM-2005/III	GEO(10)-REL(45)-RNPL(45)	07.11.06	739
23	Godavari / Andhra Pradesh	GV(N)-CBM-2005/III	COALGAS(10)-DIL(40) -ADINATH(50)	07.11.06	386
				Total Area:	**5791**
CBM-IV Round					
24.	Raj Mahal / Jharkhand	RM(E)-CBM-2008/IV	ESSAR OIL LIMITED (100)	29.07.10	1128
25.	Talchir / Orissa	TL-CBM-2008/IV	ESSAR OIL LIMITED (100)	29.07.10	557
26.	IB Vlley / Orissa	IB-CBM-2008/IV	ESSAR OIL LIMITED (100)	29.07.10	209
27.	Sohagpur / MP & Chhattisgarh	SP(NE)-CBM-2008/IV	ESSAR OIL LIMITED (100)	29.07.10	339
28	Satpura / Madhya Pradesh	ST-CBM-2008/IV	DART ENERGY(80)-TATA POWER(20)	29.07.10	714
29	North East / Assam	AS-CBM-2008/IV	DART ENERGY(60)- OIL INDIA(40)	29.07.10	113
30.	Mannargudi / Tamilnadu	MG-CBM-2008/IV	GEECL (100)	29.07.10	667
				Total Area:	**3727**
Relinquished CBM-II Blocks					
1.	Satpura / M.P.	ST-CBM-2003/II	ONGC (100)	06.02.2004	714
2.	Wardha / Maharashtra	WD-CBM-2003/II	ONGC (100)	06.02.2004	503
3.	Barmer-Sanchor / Gujarat	BS(3)-CBM-2003/II	ONGC (70)&GSPCL(30)	06.02.2004	790

** Relinquishment proposed by Operator*
Note: Name of Arrow Energy has been changed to Dart Energy

6.10 Coal-To-Liquids:

Coal-to-Liquids (CTL) is a process of liquefying coal and this process has been successfully used in several countries, particularly in South Africa. Conversion ratios for CTL are generally estimated to be between 1-2 barrels of oil per tonne of coal. Coal-to-Liquids is a technology based on the liquefaction of coal using basic approaches i.e., direct coal liquefaction (DCL) and indirect coal liquefaction (ICL). Figure 25 shows the schematic diagram of direct and indirect coal liquefaction process. CTL is one of the more reasonable approaches for alternative liquid fuels, having already been technically and commercially established.

Direct coal liquefaction (DCL) is the basic process that dissolves coal at high temperature and pressure. Addition of hydrogen and a catalyst causes "hydro-cracking", rupturing long carbon chains into shorter, liquid parts. The added hydrogen also improves the H/C-ratio of the product.

Indirect coal liquefaction (ICL) involves a complete breakdown of coal into other compounds by gasification. Resulting syn-gas is modified to obtain the required balance of hydrogen and carbon monoxide. Later, the syn-gas is cleaned by removing sulphur and other impurities capable of disturbing further reactions. Finally, the syn-gas is reacted over a catalyst to provide the desired product using FT-reactions

One of the commercial scale ICL Plants currently in operation is by Sasol in South Africa, shown in Figure 26, Which produces about 160,000 bbl/d of liquid fuels. The Sasol process is based on Fischer-Tropsch (FT) liquefaction process. Sasol uses both the low – temperature FT process (fixed bed gasification and

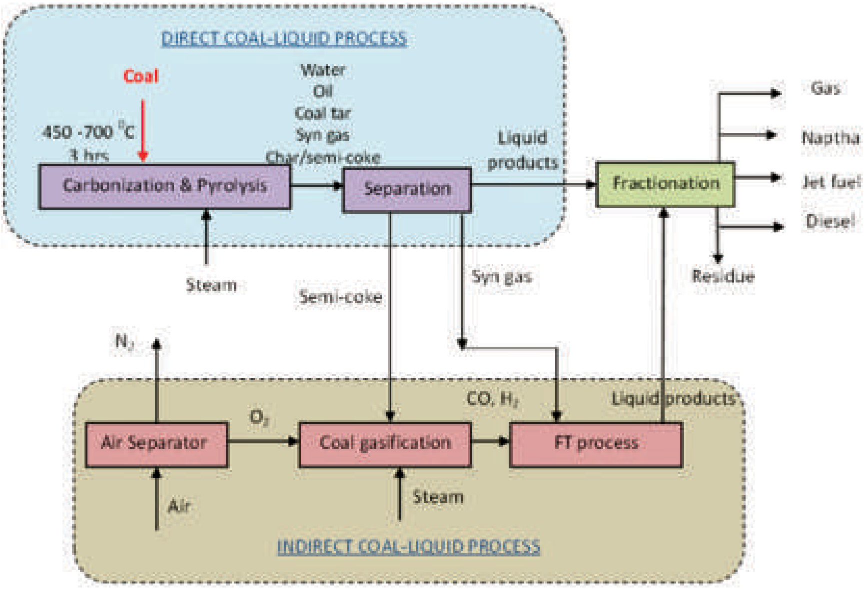

Figure 24 : The schematic diagram of direct and indirect coal liquefaction process

Figure 25 : SASOL's Secunda CTL Plant operation in South Africa

slurry phase FT), and the high temperature (HTFT) process incorporating fluidized bed gasification, and Sasol Advanced Synthol technology.

India's rapidly-expanding economy is increasing demand for transport fuels and the import of crude oil and other products has risen sharply in recent years. Potentially, the country's extensive coal resources could support a new coal-to-liquids sector, helping to minimise dependence on imports. India currently imports over 70% of its oil needs, yet has 92 billion tonnes of proven coal reserves. Liquid fuel production from coal is not a new idea, but its development has been constrained by low oil prices.

Several CTL projects are being considered in India. Coal India Ltd and Oil India Ltd plan a $2.5-billion project based on direct liquefaction of 3.5 million tonnes of low-ash, high-sulphur Assam coal to produce about 2 million barrels of diesel and naphtha. Endorsed by the finance ministry's investment commission, the Tatas and Sasol of South Africa are promoting a large $8-billion indirect liquefaction project using Sasol's gasification technology to convert high-ash, open-cast mined coal into 80,000 barrels per day (bpd) of liquid products, which can then be refined to produce diesel, naphtha, jet fuel, LPG and base oils (lubricants). About 1-1.4 billion tonnes (bt) of extractable open cast coal mining reserves will be needed to produce the annual coal requirement of 28-31 MT. Reliance Industries has also put forward an $8-billion proposal for an indirect liquefaction pithead plant using Mahanadi coal to produce 80,000 bpd of synthetic oil products. Reliance plans to use US technology, and has requested the allocation of three coal blocks with 1.6 bt of reserves in the Talcher region. While CTL projects may make commercial sense given current high oil prices, there are some concerns about the benefits of converting a solid primary fuel, which is the dominant source of electricity production, into a liquid primary energy resource. Furthermore, the volatility of oil prices dramatically affects the commercial viability of CTL plants. Hence, companies are demanding government subsidies and incentives to maintain commercial viability. However, specific incentives just for CTL would promote distortions.

The CTL era in India really kick started when, in 2008, Ministry of Coal (MoC) offered three Captive Coal Blocks in Orissa for CTL Projects and issued guidelines for allotment of these blocks. There was a tremendous response to this offer and as many as 28 companies, including several prominent Private and Public Sector Companies submitted a total of 22 applications, either solely or as Consortium. Finally, two companies, Jindal Steel & Power Ltd (JSPL) and Strategic Energy Technology Systems Ltd. (SETSL), a Tata –Sasol Joint Venture emerged as the successful applicants. While the Ramchandi block was awarded to JSPL, Tata-Sasol JV got the North of Arkhapal Block for CTL Projects. A total investment of about US $ 18 billion is expected in these two awarded blocks with combined production potential of 160,000 bbl/d of synthetic liquid fuel.

Jindal Steel and Power in March 2013 signed a pact with Lurgi for roping it in as the technology partner for Coal to Liquid project without any investment participation from Lurgi. JSPL's subsidiary, Jindal Synfuels, would develop the project in Odisha's Angul district at a total cost of Rs 55,000 crore. JSPL had envisaged producing 80,000 barrels of liquid petroleum products. Using Lurgi's technology, three products can be produced methanol, gasoline and high-speed diesel. CTL technology is expected to bring cleaner fuel for transportation, reduce greenhouse emission through CCS and contribute greatly to the energy basket of our country.

6.11 Hydrogen From Coal

Fuel cell is a reverse of hydrolysis. A fuel cell consists of an electrolyte sandwiched between an anode and cathode. The anode and cathode form the electrodes of the fuel cell. In a typical fuel cell shown in Figure 27, fuel is fed continuously to the anode (negative electrode) and an oxidant (often oxygen from air) is fed continuously to the cathode (positive electrode). The electrochemical reactions take place at the electrodes to produce an electric current through the electrolyte, while driving a complementary electric current that performs work on the load. Fuel cells are in the early stages of development as an efficient power generation system. The comparison of power overall efficiency vs. plant capacity of fuel

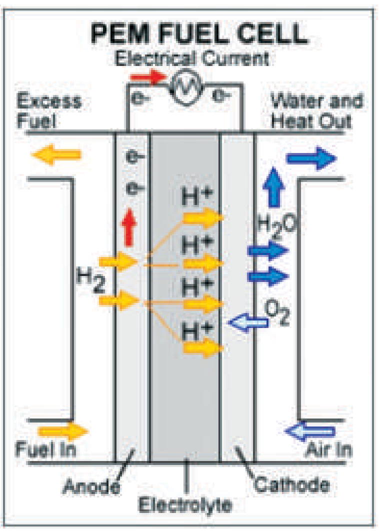

Figure 26 : Schematic of a PEM fuel Cell

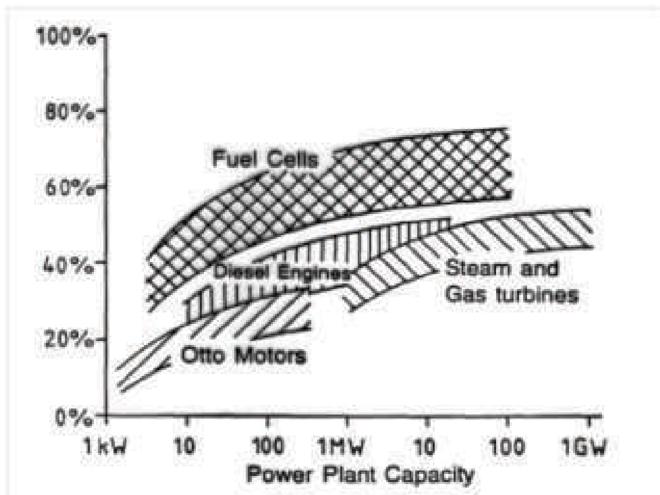

Figure 27 : Comparison of power overall efficiency vs. plant capacity of fuel cells

cell is shown in Figure 28.Use of fuel cells in power generation promises to greatly reduce greenhouse gas emissions through its relative efficient operation (when compared to conventional technologies).

Figure : 28 Fuel Cell Lab at BHEL

India tends to move towards a hydrogen economy and investigative efforts are under way both within the country and through overseas collaborative arrangements. In 2004, as part of its Ministry of Non-conventional Energy Sources, India established a National Hydrogen Energy Board. The Board has been tasked with providing guidance in the country's preparation and implementation of a National Hydrogen Energy Road Map. This will create a policy framework and provide the basis for coordinated development on all aspects of a hydrogen economy, including production, storage, distribution, safety, standards and applications. Part of this will consider the production of hydrogen from coal via gasification. At present there are many R&D projects under way in different institutions across India and it is anticipated that there will be significant interaction and liaison between the organisations involved. Several of the R&D groups are actively engaged in fuel cell research and in the longer term, biomass and coal gasification as a route to hydrogen will be considered.

India is also involved in overseas efforts and is participating in the US-led FutureGen project, a major component of which is the production of commercial grade hydrogen from coal. It is also a partner and founding member of the International Partnership for the Hydrogen Economy (IPHE). This provides a mechanism for organising and coordinating multinational R&D programmes that advance the transition to a global hydrogen economy.

BHEL has established a fuel cell and renewable energy systems lab in Corporate R&D, Hyderabad which has a 1.2 KW fuel cell test station (Figure 29). It is studying the various aspects of air Hydrogen PEM Fuel Cell Stack.

6.12 Biomass Co-firing

One of the methods of reducing environmental impacts is increasing the fraction of renewable and sustainable energy in national energy usage. Most of the control methods are expensive and therefore increase production costs. Among the less expensive alternatives, co-firing has gained popularity with the power producers.

Biomass co-firing consists of burning biomass along with coal in coal-fired power plants. Typical biomass co-milling and firing in PC boilers is shown in Figure 30. Co-firing can play an important role in increasing the use of biomass in power generation and reducing greenhouse gas (GHG) emissions because only a relatively modest incremental investment is needed to retrofit existing coal plants or build new co-fired plants. Compared to power plants burning 100% biomass, co-firing offers several advantages, including lower capital costs, higher efficiency, improved economies of scale and lower electricity costs due to the larger size and the superior performance of modern coal power plants.

Co-firing technologies include: 1) direct co-firing, using a single boiler with either common or separate burners (i.e. the simplest, cheapest and most widespread approach); 2) indirect co-firing, in which a gasifier converts solid biomass into a gaseous fuel; and 3) parallel co-firing, in which a separate boiler is used for biomass, and its steam generation is then mixed with steam from conventional boilers.

The net electric efficiency of a co-fired coal/biomass power plant ranges from 36-44%, depending on plant technology, size, quality and share of biomass. While a 20% co-firing (as energy content) is currently feasible and more than 50% is technically achievable, the usual biomass share today is below

5% and rarely exceeds 10% on a continuous basis. A high biomass share means lower GHG emissions. However, high biomass shares involve technical issues, such as securing sufficient biomass, as well as potential combustion problems, such as slagging, fouling (which reduces heat transfer) and corrosion. With the use of high ash Indian coals, the slagging problem can be minimised. The overall cost of co-firing is sensitive to the plant location, and the key cost element is the biomass feedstock.

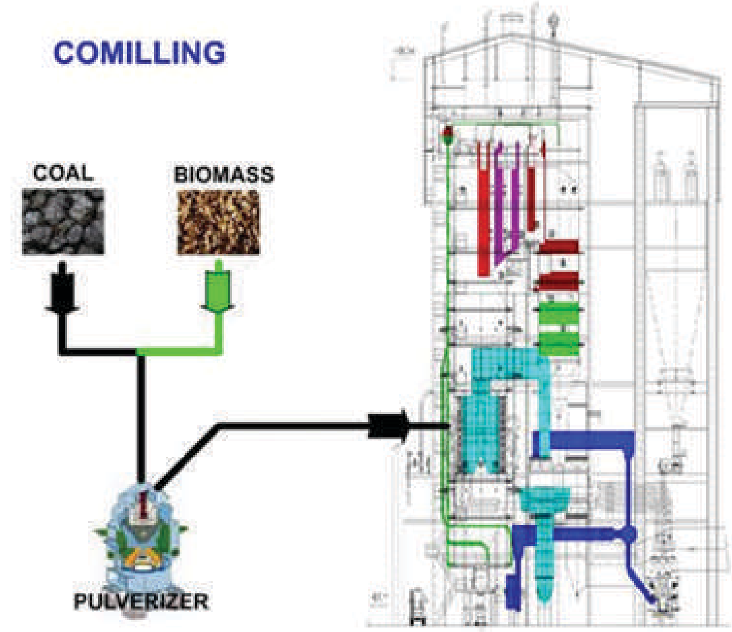

Figure 29 : Typical co-milling for co-firing in PC boilers

Co-firing biomass in coal-fired power plants offers advantages with respect to using biomass in power plants. Advantages include higher efficiency (i.e. modern coal power plants are more efficient than smaller-scale dedicated biomass power plants), lower sulphur emissions (due to biomass combustion), lower costs (due to the larger size of coal power plants) and no need for continuous biomass supply because the plant can burn coal if biomass is not available. However, the use of two different fuels increases the complexity of power generation from both a technical and regulatory point of view.

Biomass feedstock includes forestry and agriculture residues (e.g. sugar cane bagasse), animal manure, wastes such as sawdust or bark from the timber industry, waste wood and dedicated energy crops (e.g. short-rotation coppices). The sources vary greatly between countries, depending on their local natural endowments, their industrial potential and their biomass energy use.

Biomass co-firing offers a comparatively low-cost way to reduce greenhouse gas (GHG) emissions. As the combustion of biomass is considered carbon neutral (i.e. the CO_2 released in the process is withdrawn from the atmosphere by photosynthesis during the plant's growth), co-fired power plants release less net GHG emissions than conventional power plants. The cost of the precluded emissions is relatively low because the incremental investment costs for retrofitting or building new co-fired power plants is modest in comparison with other options to reduce power generation emissions. If combined with carbon capture and storage (CCS) technologies, biomass co-firing results in negative GHG emissions (i.e. net removal of CO_2 from the atmosphere), also referred to as "biogenic carbon sequestration". It is estimated that 1-10% biomass co-firing in coal power plants could reduce CO_2 emissions from 45 million to 450 million tonnes per year by 2035, if no biomass upstream emissions are included.

Biomass co-firing can reduce the net GHG emissions of coal plants; other polluting emissions deserve a specific assessment. Co-firing typically reduces sulphur dioxide, which leads to acid rain, and other harmful emissions as compared to coal, but the extent of such reductions depends strongly on the specific biomass feedstock, plant technology and operation.

Technical barriers to co-firing include the local availability of large amounts of quality biomass, as well as the cost of collection, handling, preparation and transportation, in comparison with the relatively low cost of coal. From a technical point of view, the risk of slagging, fouling, erosion and corrosion associated with the use of biomass can be countered by choosing appropriate co-firing technologies and feedstock.

A memorandum of understanding that the BHEL, Tiruchi, has signed with TREC-STEP (Tiruchirappalli Regional Engineering College - Science and Technology Entrepreneurs Park) provides for pilot-scale testing of oxy-fuel combustion and biomass co-firing with European Union funding. BHEL and TREC-STEP team was deputed to Germany, UK, Netherlands and France for benchmarking in the field of carbon capture and storage, and clean coal technologies as part of the project.

The pilot scale demonstration of biomass co-firing with Indian coal was done by BHEL in June, 2013. In the study, the existing solid fuel evaluation test facility (SFBTF shown in Figure 31) was retrofitted with a new feeder system for biomass and water wall panel fabricated was installed inside the SFBTF furnace to study the effect of the ash deposition. The fuels tested were rice husk and wood pellets as shown in Figure 32. The co-milling trials for biomass co-firing have been carried out with wood pellets, Julie flora and rice husk. Firing trials were carried out with 20% weight biomass and PC 80% wt. The results were compared with the baseline test conducted with Singareni coal .

Figure 30: Biomass co-firing pilot scale demonstration test facility in BHEL, Trichy

Figure 31 : Wood pellets and rice husk tested in BHEL, Trichy

Based on the trials it was established that upto 20% biomass can be co-fired in a thermal power plant successfully without any fouling or reposition problems.

7.0 CARBON CAPTURE:

Carbon Capture and Storage (CCS) involves capturing carbon dioxide (CO_2) from large industrial emission sources, and then transporting it and storing it in a suitable underground geological formation.

7.1 CO_2 Capture Technologies:

Where fossil fuels are burnt for electricity, there are three techniques shown in Figure 33 to remove the CO_2 — post combustion capture, pre-combustion capture and oxy-fuel combustion. In which, Pre-combustion and oxy-fuel combustion are less mature technologies.

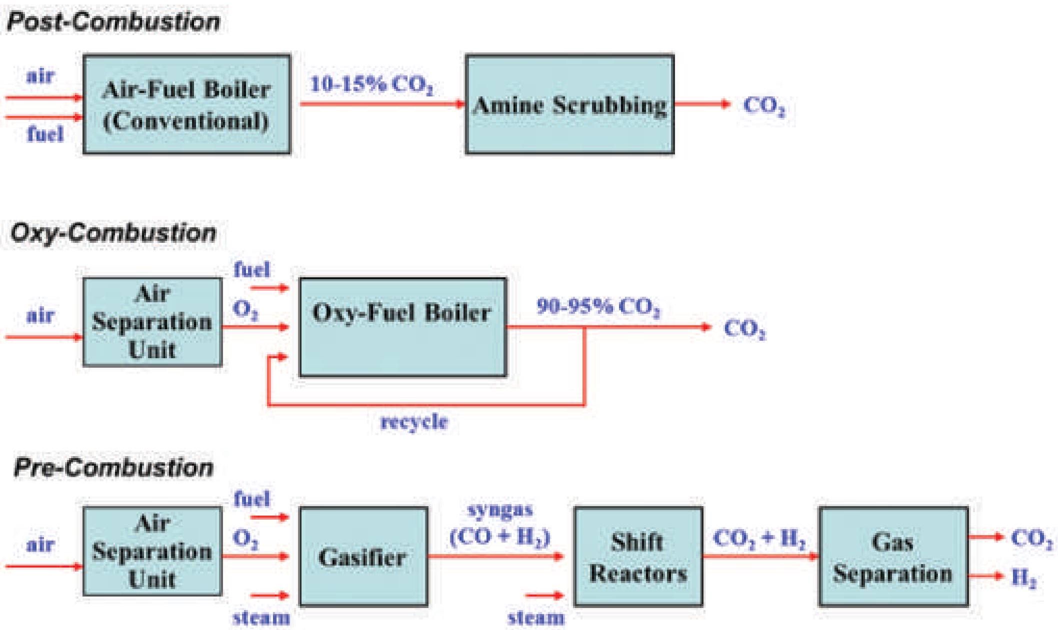

Figure 32 : CO_2 Capture Techniques

Post-combustion capture (Figure 34) is the method that would be applied to most conventional power plants. Here the CO_2 is removed after burning the fossil fuel by capturing or 'scrubbing' it from the exhaust or 'flue' gases. The technology is well understood and is currently used in other industrial applications, but not at the same scale as would be required in a commercial-scale CCS power station.

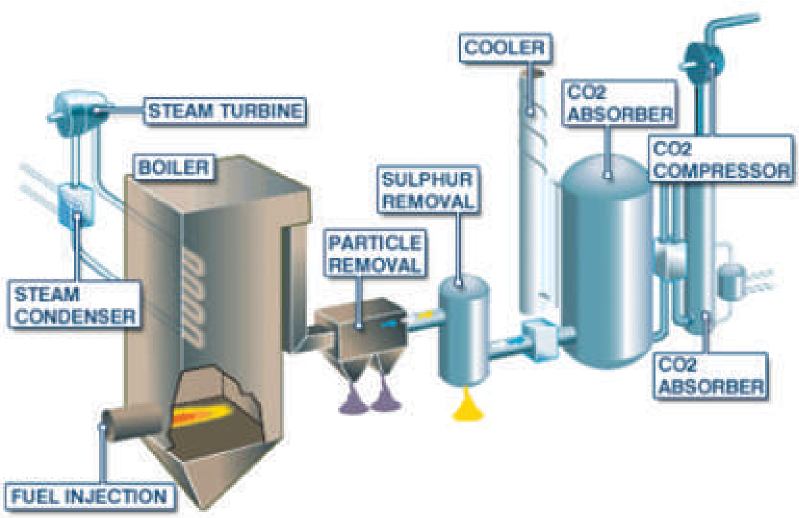

Figure 33 : Post Combustion Capture

Pre-combustion capture (Figure 35) is a method in which the fossil fuel is partially oxidized, for instance in a gasifier. The resulting syn-gas (CO and H2O) is shifted into CO_2 and H_2. The resulting CO_2 can be

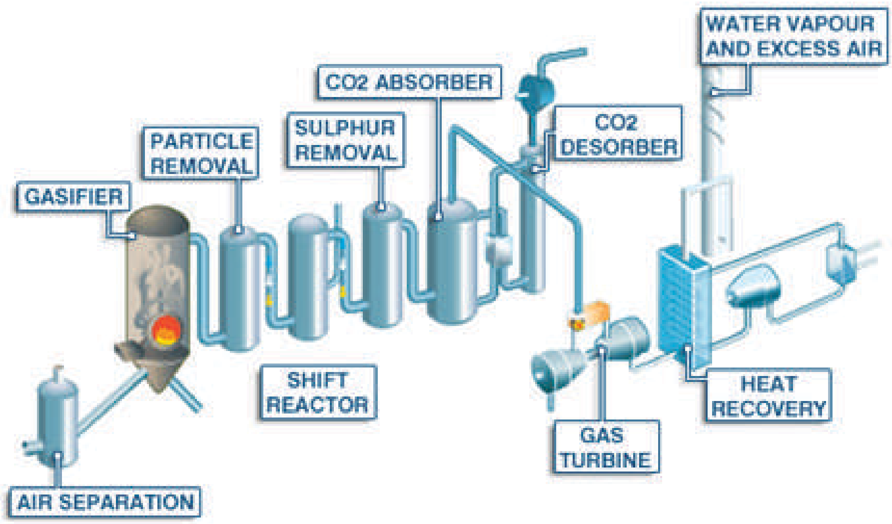

Figure 34 Pre-Combustion Capture

combustion chamber. The result is an almost pure carbon dioxide stream that can be transported to the sequestration site and stored. The technique is promising, but the initial air separation step demands a lot of energy.

An alternate method under development is chemical looping combustion (CLC) shown in Figure 37. Chemical looping uses a metal oxide as a solid oxygen carrier. Metal oxide particles react with a solid,

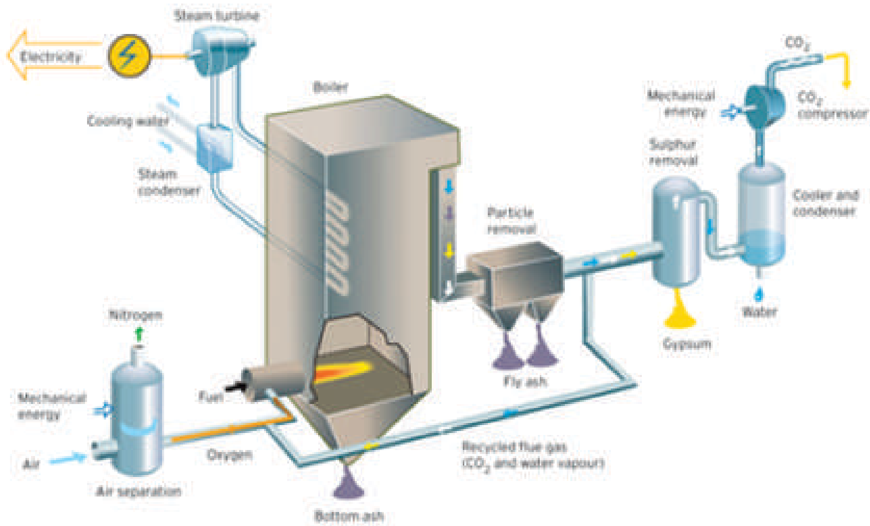

Figure 35 : Oxy Combustion Capture

liquid or gaseous fuel in a fluidized bed combustor, producing solid metal particles and a mixture of carbon dioxide and water vapour. The water vapour is condensed, leaving pure carbon dioxide, which

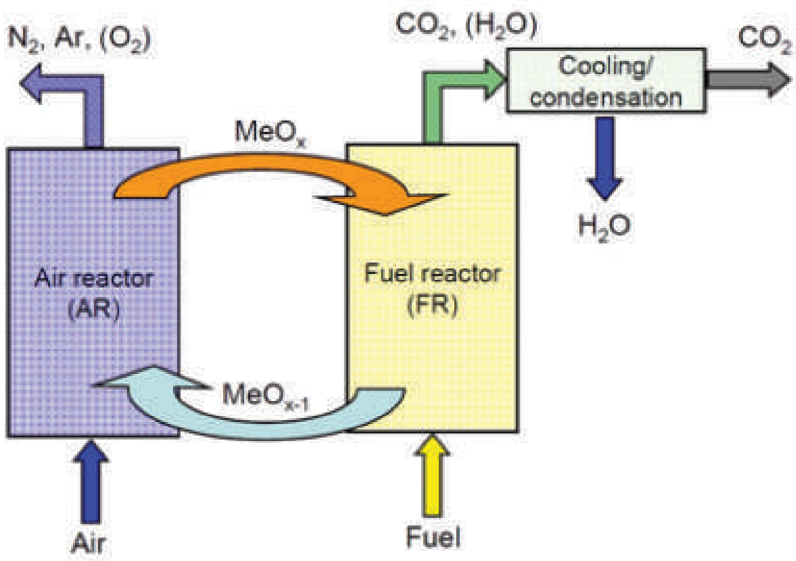

Figure 36 : Concept of Chemical Looping Combustion

blown gasifier operating at high pressure. The concept is shown in Figure 38. The raw gas thus produced is cleaned of most pollutants (almost 99 percent of its sulphur and 90 percent of nitrogen pollutants). It is then burned in the combustion chamber of the gas turbine generator for power generation. The heat from the raw gas and hot exhaust gas from the turbine is used to generate steam which is fed into the steam turbine for power generation.

The main subsystems of a power plant with integrated gasification are:

- Gasification plant
- Raw gas heat recovery systems
- Gas purification with sulphur recovery
- Air separation plant (only for oxygen blown gasification)
- Gas turbine with heat recovery steam generator

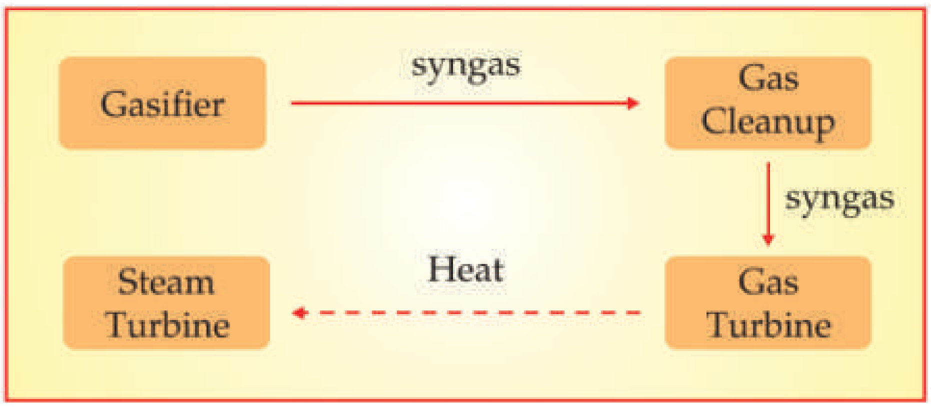

Figure 37 : Coal Gasification within the IGCC Concept

- Steam turbine generator

The feedstock which is fed into the gasifier is more or less completely gasified to synthesis gas (syn-gas) with the addition of steam and enriched oxygen or air. The gasifier can be fixed bed, entrained or fluidised bed. The selection of the gasifier to achieve best cost efficiency and emission levels depends upon the type of fuel.

In the gas purification system, initial dust is removed from the cooled raw gas. Chemical pollutants such as hydrogen sulphide, hydrogen chloride and others are also removed. Downstream of the gas purification system, the purified gas is reheated, saturated with water if necessary (for reduction of the oxides of nitrogen) and supplied to the gas turbine combustion chamber.

The IGCC technology scores over others as it is not sensitive with regard to fuel quality. Depending on the type of gasifier, liquid residues, slurries or a mixture of petcoke and coal can be used. In fact, the IGCC technology was developed to take advantage of combined cycle efficiency of such low-grade fuels. Figure 39 shows a simplified flow diagram for an IGCC process.

IGCC technology is also environment friendly. In IGCC, pollutants like sulphur dioxide and oxides of nitrogen are reduced to very low levels by primary measures alone, without down-stream plant components and additives like limestone. The low NOx values are achieved by dilution of the purified syn-gas with nitrogen from air separation unit and by saturation with water. The direct removal of sulphur compounds from the syn-gas results in the effective recovery of elemental sulphur, yielding a saleable raw chemical product. Gasification and gas cleaning are extremely effective filter for

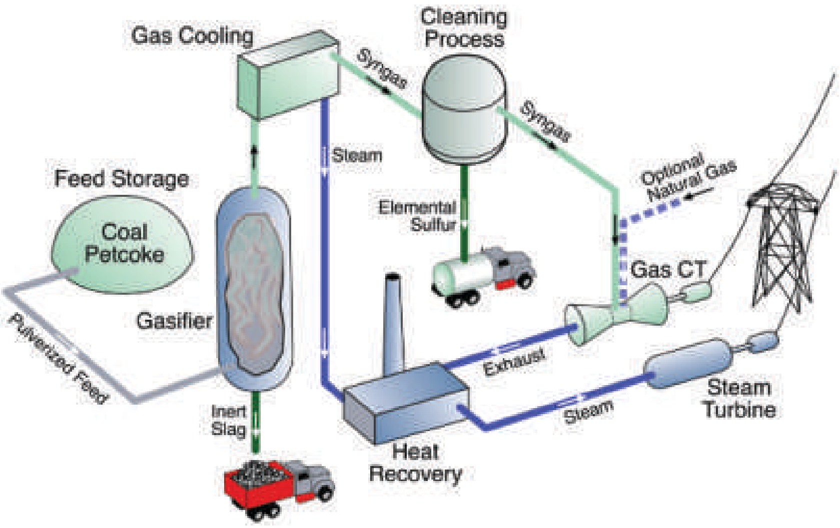

Figure 38 : A simplified flow diagram for an IGCC process

contaminants harmful to both gas turbines as well as environment. The IGCC technology is not only environment friendly, but also efficient in power generation (up to 50 percent) and an expensive option.

Some companies claim that they have found an answer to the cost issue with a new technology for producing methanol. They believe that fitting this system, which produces methanol at twice the rate of conventional methods, on the back end of the gasifier units on an IGCC plant can cut the capital cost by 25 percent. The technology achieves this saving by reducing the number of gasifiers the IGCC plant needs - provided the full capacity of the power station is not required for base load running. This enables the operator to make full use of the gasifers, which account for 50-60 percent of the cost of an IGCC and become prohibitively expensive under part time operation. When power is not required, they can be switched to methanol production. This provides the additional fuel to meet full power output at time of peak demand.

The additional benefits may not make an IGCC unit competitive with a combined cycle gas turbine (CCGT) plant where there is adequate supply of natural gas. However, a 500 MW unit could compete with traditional coal-fired technology. The biggest difficulty may arise in securing a long-term purchase contract for methanol that will allow the plant operator to keep the gasifiers in continuous operation.

Gasification based power generation is perceived by many as a complex and expensive technology. However, recent experience in both developed and developing countries reinforces its relevance to power generation. The continuing research on gasification projects in several areas is aimed at reducing emissions, reducing capital cost and increasing process efficiency. Turbines with higher efficiencies and operating temperatures are being developed. In India, in particular, the IGCC technology is of great relevance as we do not have huge reserves of hydrocarbons. Since coal is available, more project developers can go in for coal-based IGCC plants.

The merits of advanced clean coal combustion technologies over pulverised fired conventional combustion are enlisted in Table 9.

7.2.1 BHEL's Coal Gasification and IGCC Programme

IGCC development in India has been undertaken from the 1980s and extensive studies were carried out by BHEL. Fluidised bed gasification is considered to be the most suitable form in terms of process efficiency, economics and environmental impact within the Indian context. The BHEL IGCC development

Table 9: Merits of Advanced Coal Combustion Systems

Parameters	Conventional pulverised fired	Super critical pulverised fired	PFBC /CFBC	IGCC	Hybrid Cycle (Gasification in combustion)
Maturity of technology	Completely proven and commercially available with guarantees	Substantially proven and commercial plant available with guarantees	Substantially proven and commercial plant available with guarantees	Mainly demonstration plant operational where coal is the fuel source	Still at R&D stage
Range of units available	All commercial sizes available (common unit size in the range 300-1000 MWe)	All commercial sizes available	Upto 350 mw sizes available	250-300 MWe, currently limited by the size of large gas turbine units available	Demonstration plant proposed at around 90 MWe
Fuel flexibility	Burns a wide range of internationally traded coals	Burns a wide range of internationally traded coals	Will burn a wide range of internationally traded coals, as well as low grade coals efficiently; best suited for low ash coals	Should use a wide range of internationally traded coals, but not proven; Not really designed for low grade, high ash coals	Should use a wide range of internationally traded coals; designed to utilise low grade, high ash coals efficiently
Thermal efficiency (LHV)	Limited by steam conditions around 41% with modern designs	At least 45% now possible and over 50% subject to successful materials development i.e. further R&D	Around 44% possible, some increases likely with further R&D and/or with supercritical steam cycle	Around 43% currently possible, but over 50% possible with advanced gas turbines and further R&D	Around 43% should be obtainable, but over 50% possible with advanced gas turbines and further R&D
Operational flexibility	Can operate at low load, but performance would be limited	Can operate at low load, but performance would be limited	Can operate at low load but performance would be limited	Realistically could only operate at base load	Design suggests would have reasonable performance at low load
Environmen-tal Performance **CO_2 (g/KWH)** **SO_2 (mg/KWH** **NOx (mg/KWH)**	830 600 600	- - -	810 585 585	460 150 300	- - -
Availability	Proven to be excellent	Proven to be good	Limited experience	Demonstration so far not satisfactory	Not yet demonstrated

programme has been executed in three main phases:

- Phase 1 – assessment and operation of a 150 t/d pressurised moving bed gasifier as part of a 6.2 MWe combined cycle plant. Located at Tiruchirapalli in Tamil Nadu, this was the first IGCC facility to operate in India and the first in Asia to fire low Btu syn-gas in a gas turbine;
- Phase 2 – an 18 t/d coal capacity Process and Equipment Development Unit (PEDU) was constructed and operated;
- Phase 3 – based on the data and experience from the PEDU plant, a PFBG of 165 t/d coal throughput capacity (for 42% ash coal) was designed and retrofitted to the existing 6.2 MWe IGCC plant. BHEL also designed and installed a hot gas cleanup system, using a granular bed filter. This was fitted to a 6 t/d PFBC unit. A view of the BHEL IGCC development facility at Tiruchirapalli is shown in Figure 40.

The on-going development programme has resulted in significantly improved process reliability and performance. Improvements have been made to areas that include gasifier refractory lining, ash extraction systems, cooling devices, and air distribution systems. IGCC development has been aided by the fact that all major process components, including gas and steam turbines and HRSGs, have been

Figure 39 : BHEL IGCC development facility at Tiruchirapalli – CCDP 6.2 MWe

based on standard BHEL products and were designed and manufactured in-house.

Development activities for the proposed demonstration plant are continuing. An uninterrupted run on the Tiruchirapalli test rig was successfully completed, using >100 t of Singareni coal with an ash content >40%. Gasification was carried out at temperatures between 950 and 1050°C. In total, >4000 hours of air blown pressurised gasification operation have been achieved. Operational experience has resulted in a number of process improvements that have enhanced operation and increased reliability. The performance of the plant is shown in Figures 41 and 42.

With the experience gained from pilot plant and demonstration studies, BHEL now intends to establish a 100–125 MW IGCC National Commercial Demonstration Project, based on the air-blown PFBG process. The IGCC plant will be engineered and installed by BHEL and owned and operated by NTPC. There are also proposals to follow the demonstration with the construction of a 400 MW commercial-scale plant. If natural gas costs continue to stay at high levels, the feasibility of an IGCC based project would be increased.

The technical feasibility of upgrading the 6.2 MWe CCDP of the BHEL to 100 MWe has been satisfactorily

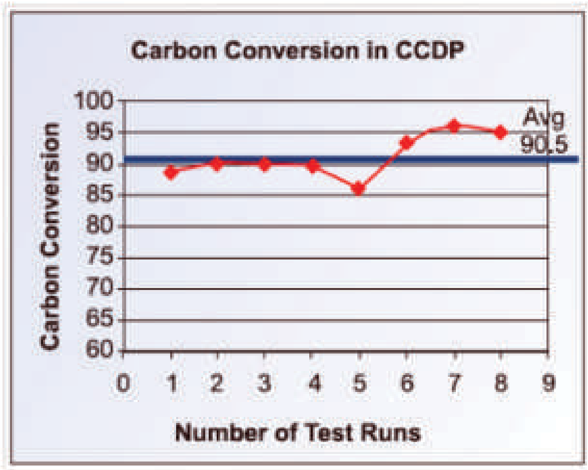

Figure 40 :
Carbon Conversion for the CCDP Gasifier

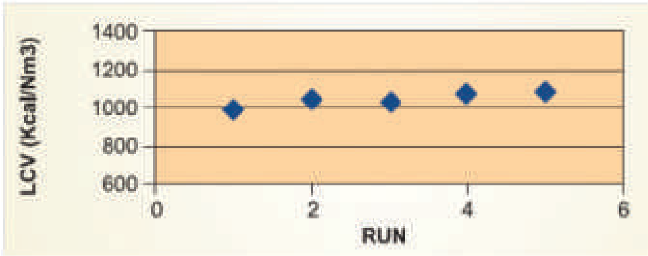

Figure 41 :
Calorific Value of the Syn-gas of the CCDP Gasifier

established, a detailed project report may be prepared jointly by BHEL and NTPC for setting-up the first 100 MWe IGCC demonstration plant in the country. The talks between the two companies have progressed. Discussions have been held on parameters and the plant design is already developed. The plant is planned at Dadri in Uttar Pradesh.

7.2.2 Reliance Gasification and Project:

During 2007, it was announced that Reliance Industries intended to construct a 1000 MW petcoke-fuelled IGCC power plant in Jamnagar. The proposed plant will also produce hydrogen for petrochemical production. The plant investment is of Rs 100 billion and be commissioned within a three-year period. Reliance Industries Limited (RIL) has selected Phillips 66's E-Gas Technology for its planned gasification plants at Jamnagar in May 2012. Phillips 66 will license its E-Gas™ Technology to Reliance and provide process engineering design and technical support relating to the gasification technology process area. Reliance's Jamnagar site is the largest refining complex in the world, with an aggregate refining capacity of 1.3 million barrels of oil per day. The planned gasification plants at Jamnagar will be among the largest in the world and will process petroleum coke and coal into synthesis gas utilizing the E-Gas Technology. The synthesis gas will be used as feedstock for a new chemical complex and will fuel the refinery's existing gas turbine power generation units.

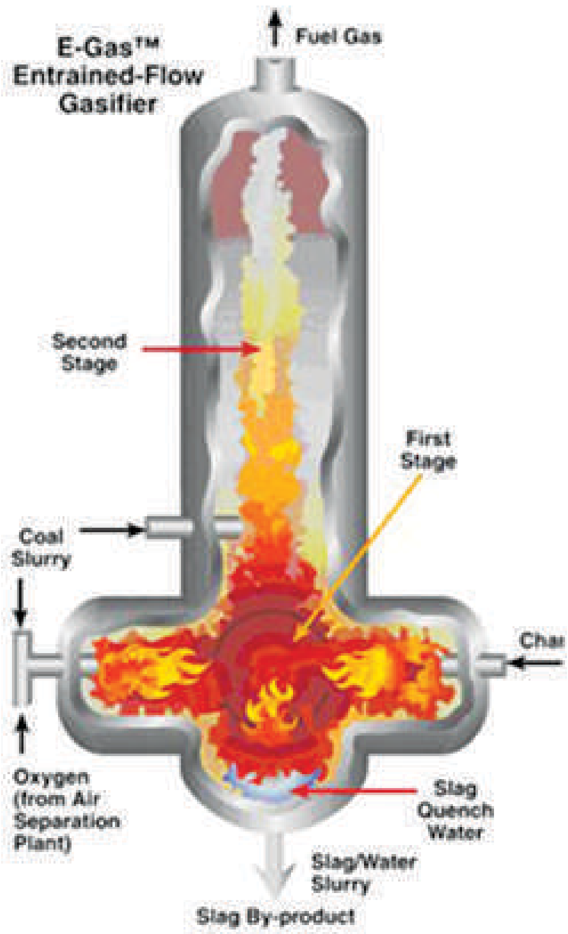

Figure 42 : ConocoPhillips' E-Gas™ Coal Gasifier Technology (source: ConocoPhillips)

The E-Gas™ coal gasifier shown in Figure 44 is a pressurized, up flow, entrained slagging design with a unique two-stage operation. Wet crushers produce slurries from the raw feed coal/petcoke. About 75% of the total slurry feed is fed to the first (or bottom) stage of the gasifier through mixer nozzles, along with 95% pure oxygen. This stage involves highly exothermic oxidation reactions and operates at typically 1425 °C and 400 psig. Ash in the coal melts and exits through a tap hole at the bottom of the gasifier into a water quench, forming an inert vitreous slag product.

Hot synthesis gas (syn-gas) from the first stage then enters the second (top) stage where the remaining slurry feed is injected. Endothermic gasification and devolatization reactions take place at 1040 °C, resulting in the formation of some hydrocarbons in the product gas and the production of char, which are both recycled to the first stage where they are readily gasified. The product gas exits the gasifier at 1040 °C and is cooled in a fire-tube cooler to 600 °C, generating saturated steam. Particulates and chlorides are removed from the cooled syn-gas in a wet scrubber and char is recycled to the gasifier. Although not coal fuelled in RIL, its construction and operation will help increase practical experience within the country.

7.3 Oxy- Fuel Combustion:

Oxy-fuel combustion is the best option for power generation with CO_2 capture. It can be simply described as a process that eliminates nitrogen from the oxidant or combustion by burning the fuel in either nearly pure oxygen or a mixture of nearly pure oxygen and a CO_2-rich recycled flue gas (RFG) resulting in a product flue gas from the boiler containing mainly carbon dioxide and water vapour. Burning of fuel with pure or nearly pure oxygen is typically applied to high temperature processes such as reheating furnaces or glass tank furnaces; whereas for steam generation applications such as pulverised coal boilers, lower combustion temperatures are necessary. Therefore, fuels are burned with a mixture of CO_2-rich recycled flue gas or steam (to act as diluents replacing nitrogen in order to moderate the temperature) in addition to the oxygen from an air separation unit. In the current design of the oxy-fuel combustion for pulverised coal fired boilers, the CO_2-rich recycled flue gas is used as the diluents.

The combustion products (or flue gas) consist mainly of carbon dioxide and water vapour together with excess oxygen required to ensure complete combustion of the fuel. The flue gas exiting from the boiler will also contain other components such as reactive and inert components derived from the fuel such as SOx, NOx, fly ash, trace metals, etc., any inert components from the oxygen stream supplied (Ar, N2), any inert components from the air in-leakage (N_2, Ar, H_2O).

In general, there are four components for the oxy-fuel combustion process:

1. Air separation unit (ASU), which provides oxygen for combustion;
2. Combustor, which can be either a boiler, or a furnace, or a turbine;
3. Integrated emissions control;
4. Product recovery train (PRT), which produces a product CO_2 stream.

Even though oxy-fuel combustion is economically competitive with alternative technologies, there is a perception that post-combustion is 'easier' and that pre-combustion is also seeing heavy R&D investment and is being promoted strongly. However, several utilities are making or planning significant investments in oxy-fuel technology with large-scale testing and plant demonstration. Indeed, oxy-fuel combustion may have an advantage in that it does not use chemical reagents such as the amines used in post-combustion capture.

It was also recommended that the next generation of boilers should be developed to operate at the conditions found in oxy-coal firing since there is significant potential for reduction in boiler size and cost – it was estimated that oxy-fuel combustion could reduce required heat transfer area by as much as 50% compared with air firing. Some gaps in the knowledge of this technology were

- Optimum recycle ratio
- Carbon burnout

- Ash formation, slagging and fouling
- Fine particulates, SO_3, trace metal emissions
- Radiative heat flux measurements
- Start-up and shut-down procedures

The techno-economic studies reviewed had revealed that oxy-fuel combustion was a cost-effective method of CO_2 capture. More important, the studies indicated that oxyfuel combustion was technically feasible with current technologies, reducing the risks associated with the implementation of new technologies and also for retrofit application.

Establishment of 400 KW Oxy-Fuel combustion test rig at BHEL, Tiruchirapalli is in progress with the objective to study the suitability of Indian coals while using this technology for PF combustion and change in boiler efficiency. The proposed 400 KW Oxy Fuel Pilot plant in BHEL is shown in Figure 45. It is expected that Oxy-Coal combustion at higher oxygen concentration increases boiler efficiency and depending on the level of oxygen enrichment in gas entering boiler, the concentration of CO_2 reaches 55-60% with significant reduction in NOx emissions. The technical challenges include investigation of flame stability, heat transfer, level of flue gas clean-up for CO_2 and corrosion due to elevated concentrations of SO_2/SO_3 and H_2O in flue gas.

7.4 Post Combustion Capture Technology

In the case of coal-fired thermal power plants in India, the focus at present is on the control of SOx and

Figure 43 : 400 KW Oxy Fuel Pilot Plant in BHEL

NOx. The new generating unit will be equipped with three types of emission control equipment, namely Bye-pass Over Fire Air (BOFA) and Selective Catalytic Reduction (SCR) for reducing NOx and Flue Gas Desulphurization (FGD) for reducing SO_2.

7.4.1 Nox Control Technologies

7.4.1.1 Separated Over Fire Air (SOFA) System:

Higher NOx reductions are achieved by increasing the separation of the over-fire air ports from the primary combustion zone and increasing the air velocity through the ports. This technique is known as SOFA. NOx reductions of 40 to 60 % can be achieved with this arrangement. Figure 46 shows the SOFA system arrangement.

7.4.1.2 Bypass Over Fire Air (BOFA) System:

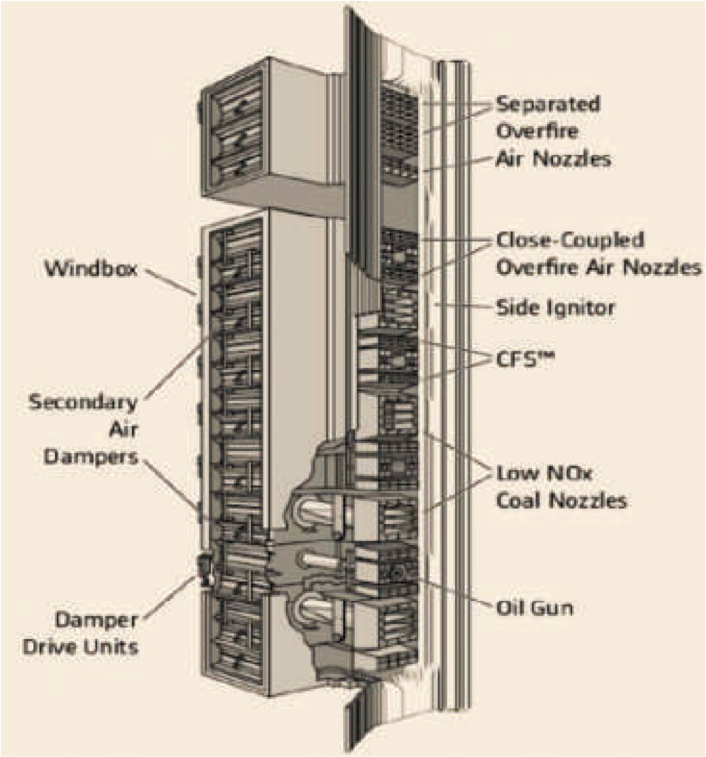

Figure 44 : Separated Over Fire Air (SOFA) Arrangement System

When nitrogen and oxygen in the air combine during combustion at higher temperature, NOx is produced. BOFA aims to change and optimize combustion of coal so as to suppress formation of NOx during the combustion process and reduce NOx emission. BOFA works by forcing air into the higher section of the boiler by the fans. This causes coal to burn at a lower temperature and in turn reduces the amount of NOx produced. The 'over fire' air which is injected into the boiler above the main burner mixes with the tails of the flames and this increases the area available for NOx levels to be reduced. BOFA systems combine with other low-NOx burner systems reduces the NOx emission in the flue gas to a lower level. Figure 47 shows the "Bypass Over Fire Air (BOFA) System" to reduce NOx emission by about 40%.

7.4.1.3 Selective Catalytic Reduction (SCR) Technology:

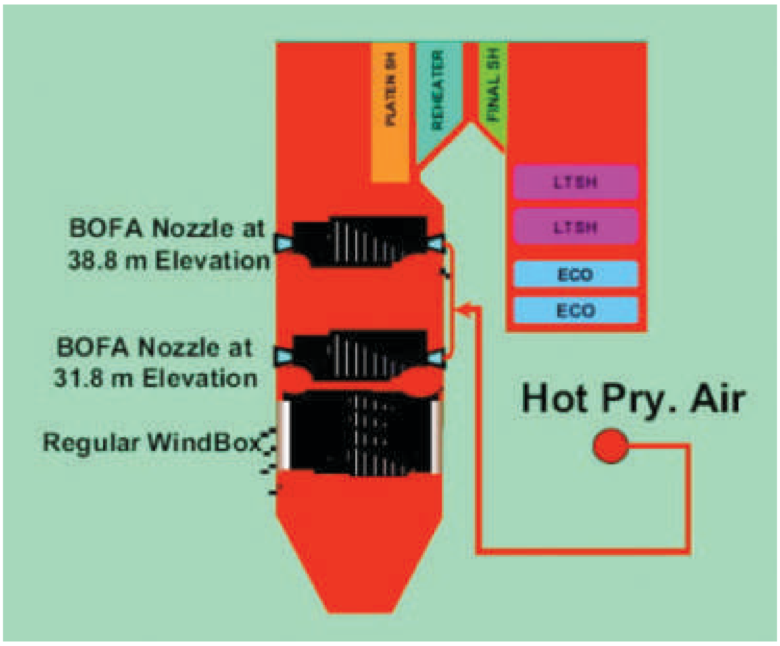

Figure 45 : Development of "Bypass Over Fire Air (BOFA) System" to reduce NOx emission by about 40%

The technique is preferred as the Best Available Control Technology as it is superior to several other primary and secondary NOx control measures available today. The NOx reduction efficiency through SCR technology is more than 95%. In the SCR technology, stoichiometric quantities of ammonia (NH_3) are injected into the flue gas over a catalyst at temperatures ranging from 300° C to 400° C to reduce NOx into harmless nitrogen and water. The reduction occurs even in the presence of large excess of oxygen (O_2) as follows:

$4\,NO + 4\,NH_3 + O_2$ à $4\,N_2 + 6\,H_2O$

$2\,NO_2 + 4\,NH_3 + O_2$ à $3\,N_2 + 6\,H_2O$

7.4.2 Particulate Emission Control Technology

The state-of-the-art particulate control technology is the application of fabric filters (bag houses) and electrostatic precipitators (ESPs). An electrostatic precipitator (ESP) is an integral part of coal based thermal power plant to control particulate emissions. The emission level from the power plant depends on the stable operation of boiler and efficient functioning of ESPs. The ESP unit of a thermal power plant is shown in Figure 48.

BHEL has unmatched expertise in dust precipitation in utility and industrial boilers including AFBC and

Figure 46 : Electrostatic Precipitator in a Thermal Power Station

CFBC boilers, co-generation plants, pulp and paper mills, cement and steel industries. BHEL ESPs are designed for as low as 20 mg/Nm^3 emission rate, operate at collecting efficiencies as high as 99.98+% and can be used for gas flow rates of up to 37,00,000 m^3/hr. BHEL offers complete turnkey solutions from problem analysis and design to erection and commissioning including carrying out feasibility studies for ESP installation in existing plants and rendering assistance in carrying out renovation work on existing precipitators.

BHEL Fabric Filters can filter the finest particulate matter from flue gases for a variety of applications before they are released into the atmosphere. Fabric Filters offer several advantages including compact design and can be used to achieve emission levels of 10 mg/Nm^3 or less. The bag filter system is being used in Mahagenco India, Koradi TPS, Unit-5 (40 mg/Nm^3), ISPAT SIDEX, Romania (20 mg/Nm^3), Koniambo Nickle, New Caledonia (30 mg/Nm^3).

7.4.3 Flue Gas Desulphurisation (FGD) Technology

An FGD plant removes sulphur dioxide (SO_2) contained in the untreated flue gas discharged from a coal, oil or other carbon-derived fuel fired boilers. FGD plants are also very efficient at removing particulate matter. Furthermore, FGD plants produce useful by-products, such as gypsum, which can be recycled into gypsum board or building cement. Thus FGD plants play an important role in improving the environmental performance of power stations and refineries whilst also producing useful products which can be sold in the market.

Limestone is injected into an absorber which scrubs the flue gas. The limestone slurry contacts with the flue gas and absorptive removal of sulphurous acid gas occurs, inducing the subsequent production of gypsum ($CaSO_4 \cdot 2H_2O$) through use of the oxidation air sparger. Particulate matter in the flue gas are also captured and removed in the absorber leading to a double environmental benefit and a cleaner flue gas stream which is then emitted to atmosphere via the plant stack.

SO_2 Absorption Chemical Equation:

$SO_2 + CaCO_3 + ½ O2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + CO_2$

The Figure 49 is a representative process flow of a single tower flue gas desulfurization (FGD) plant featuring a Double Contact Flow Scrubber (DCFS) designed absorber.

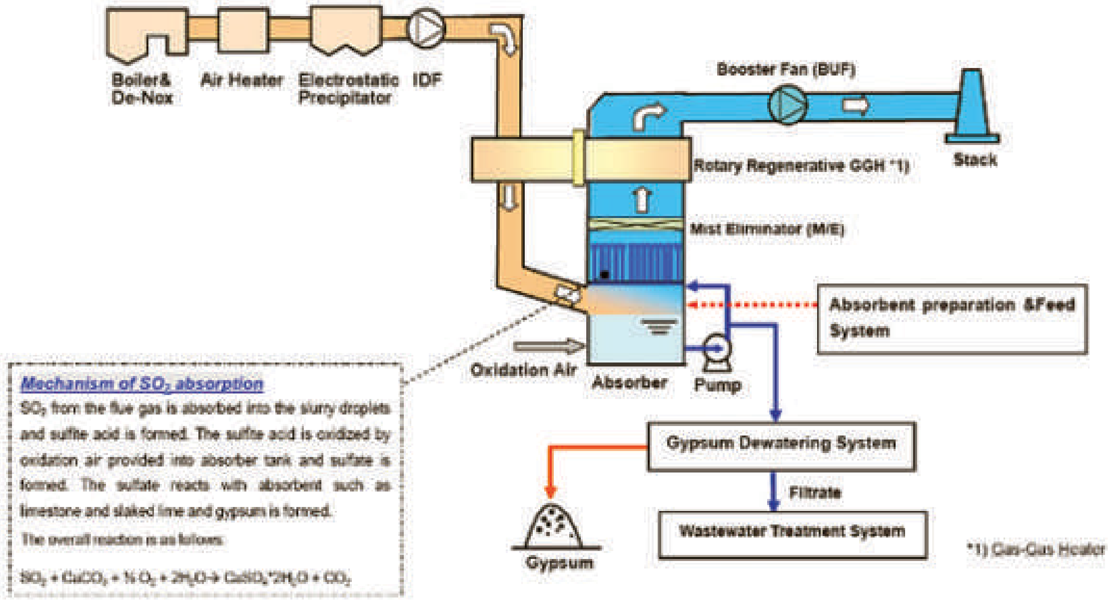

Figure 47 : Schematic process flow of FGD system (courtesy: MHI)

While Indian coals have low sulphur, in imported coal sulphur is higher. In the National Ambient Air Quality Standard revised in November 2009, Industrial and Residential areas are combined and the ambient air standard norms for SO_2 are reduced. With the growing concern for environmental pollution in the country, Central Pollution Control Board, Ministry of Environment and Forests, is expected to stipulate stringent control regulations towards Sulphur Di Oxide (SO_2) emissions for power plants.

CEA has advised power project developers that for all new power plants, provision of space for FGD plants has to be included and in future, these power plants would be required to install FGD systems. Further, it is expected that some of the upcoming power projects including Ultra Mega Power Projects would be set up in coastal areas utilising imported coal having high sulphur content and they may have to install FGD systems. These coastal projects would require FGD systems mostly based on seawater FGD technology. In all the upcoming/on-going 660 /800 MW Projects, space provisions are made to install FGD at later date. Therefore, FGD retrofit is a distinct possibility in future of BHEL designed plants. To this effect, BHEL has entered into a License Agreement with Mitsubishi Heavy Industries Ltd. (MHI), Japan - a leading supplier of FGD Systems, for acquiring FGD system technology, finding application in fossil fuel power plants. The FGD systems will be engineered and manufactured at the Ranipet unit of BHEL in Tamilnadu. The tie up is utilized to commission a FGD unit for 660 MW power plant at Vindhyachal. Some of the other FGD Projects are Saint Gobain Glass India (Semi Dry), Trombay Unit 8 X 250 MW (Sea Water) & NTP Bongaigaon 3x250 MW (Wet Lime).

7.5 POST COMBUSTION CAPTURE TECHNOLOGIES

Post-combustion capture refers to the removal of CO_2 from power station flue gas prior to its compression, transportation and storage in suitable geological formations, as part of carbon capture and storage.

Post-combustion capture is an end-of-pipe technology offers some advantages as existing combustion technologies can still be used without radical changes on them. This makes post combustion capture easier to implement as a retrofit option (to existing power plants) compared to the other approaches. This aspect is of special importance for the large number of new PF plants being installed in India. Therefore, post-combustion capture may probably be the first technology that shall be deployed. A number of separation technologies could be employed with post-combustion capture. These include: (a) adsorption; (b) physical absorption; (c) chemical absorption; (d) cryogenics separation and (e) membranes

Main categories of post combustion capture technologies:

7.5.1 PCC using Chemical Solvents:

Gas containing carbon-dioxide is cooled to 40-60°C and forced through an aqueous alkaline solvent such as amine (MEA or MDEA). The CO_2 in the gas chemically reacts with the solvent and binds to it. The flue gas is washed and sent out of the system with 80-95% of CO_2 removed. The CO_2-rich solvent is sent to a 'regeneration vessel', where the CO_2 is desorbed from the solvent because of elevated temperature (100-140°C) and pressure. The regenerated solvent is then re-circulated back for capture.

Figure 43 shows a pilot Scale system for CO_2 absorption from flue gas and Syn-gas under development in BHEL.

Figure 48 : Pilot Scale development of CO_2 absorption from flue gas and Syngas in BHEL

Regeneration of the solvent requires thermal energy input to maintain the high temperature, leading to an energy penalty. Furthermore, nearly 1.5 tons of low pressure (50 psig) steam needs to be extracted per ton CO_2 for the capture process, which can reduce the overall power generation. For post-combustion use, it is important to remove SOx and NOx from the flue gas to very low levels before attempting carbon capture, since these impurities bond to the solvents irreversibly, reducing its absorptive property for CO_2 and increasing the risk of solid formations in the amine solution. It also results in excess consumption of chemicals to regenerate the solvent and produces high waste streams.

7.5.2 Physical Solvents:

The method is by means of physical absorption of CO_2 to the pressurized solvent. The physical solvents are Rectisol and Selexol. The absorbed gas is removed from the solvent when pressure is released. Physical solvents are applicable for gas streams with high CO_2 concentration – i.e., for IGCC or oxy-fuel systems.

7.5.3 Solid sorbents:

Solid sorbents, such as sodium, calcium, and potassium oxides, carbonates (limestone/dolomite), and lithium-based sorbents, can be used cyclically as wet absorption systems to selectively remove CO_2 from flue gas streams. The gas-rich solids can then be either moved into a different reactor for regeneration, or switched between absorption and regeneration modes in a batch-wise manner.

A significant advantage of solid sorbents is that they can be operated at a wide range of high temperatures (with maximum temperatures greater than 600°C), thereby reducing the energy penalty paid by conventional solvent systems for lowering the flue gas temperatures. However, solid sorbents need further development to reduce their cost, increase their absorption capacity, and increase chemical and mechanical stability for long periods of cycling.

7.5.4 Pressure Swing Adsorption:

Adsorptive materials, such as molecular sieves (such as zeolites) or activated carbon, are pressurized and depressurized in a cyclical manner. Certain kinds of gases are adsorbed to the material under high pressure; these adsorbed gases are then released under low pressure. Unlike absorption processes, adsorption processes are less selective and they are generally used for purifying syn-gas or for H_2 separation.

7.5.5 Membranes:

Specially manufactured membranes can allow selected gases to permeate through them, driven by a pressure difference across the membrane. The nature of the material determines the gas selectivity, with polymeric membranes being more common. Currently, polymeric membranes are used for separating CO_2 from natural gas in industrial processes. Membranes also have a higher energy penalty when compared to standard absorption processes, with a lower percentage of CO_2 removed. However, a hybrid membrane-absorbent system is now being considered for flue gas recovery. Such a hybrid system increases contact surface area between the flue gas and absorbents, resulting in a more compact system and less operational problems associated with conventional absorbent systems. Another future option is the 'facilitated membrane', where embedded chemicals in the membrane can facilitate the transport of gases through the membrane.

BHEL has developed in-house membrane contractor system with hollow fibre membrane which has shown very good CO_2 capture (>95%) from flue gas. The hollow fibre is used as contacting surface. The schematic diagram of membrane contactor for CO_2 absorption and desorption for continuous operation is shown in Figure 50.The pilot scale plant for testing of 1 T/day CO_2 capture membrane plant is under development by CTI/BHEL.

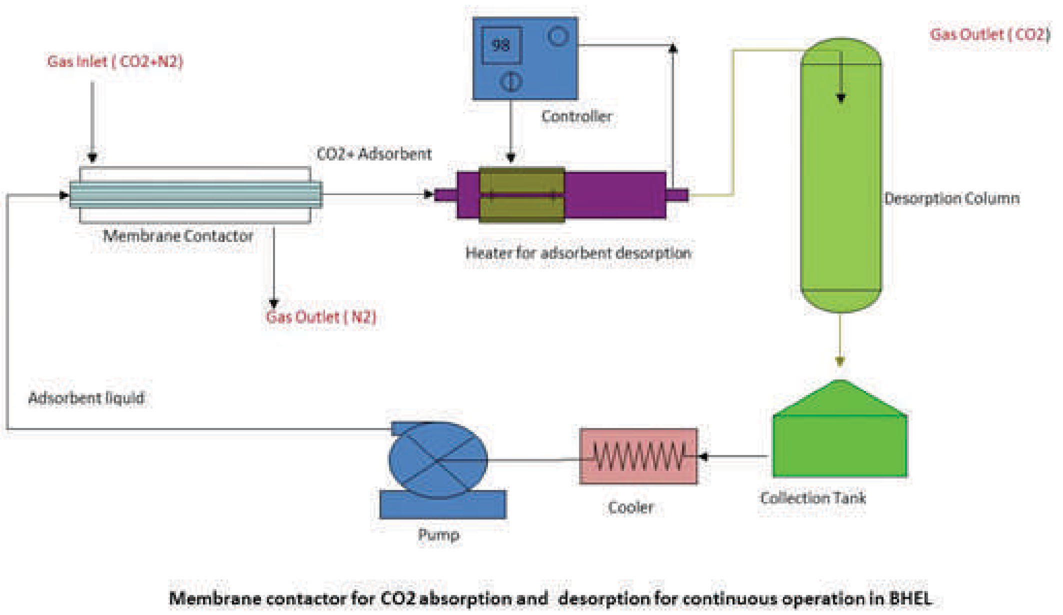

Figure 49 : Scheme of pilot scale testing of membrane contractor in BHEL

7.5.6 Cryogenic Liquefaction/Distillation:

Similar to standard cryogenic oxygen production, gas streams with relatively high initial CO_2 concentration (80-95%) can be purified further (up to 99.9% CO_2 purity) by liquefying the gas and distilling it in columns. This method could be applicable to oxy-fuel combustion flue gas streams, for syngas that has already been water-gas shifted, and for further purifying CO_2 streams from post-combustion capture. Ultra-pure CO_2 streams may be necessary to avoid two-phase flow conditions during pipeline transport.

7.5.7 Micro Algal Removal of CO_2:

Numerous studies have been carried out to determine the ability of microalgae to capture high CO_2 concentrations present in flue gas by micro-algal photosynthesis. In addition to CO_2 removal, the algae can later be turned into biodiesel and other useful by-products. Laboratory scale studies in academic institutions are in progress in India to quantify the efficacy of microalgae based carbon sequestration at industrial scale and determine under which conditions carbon capture and sequestration by micro algal photosynthesis is economically attractive when compared with other means of carbon capture and sequestration.

8.0 CO_2 STORAGE:

Figure 51 shows the CO_2 capture and storage process. One main challenge facing CO_2 storage is to accurately estimate the amount of useful storage space in a given region. We also need to be able to reliably predict and model the behaviour of the CO_2 in the storage reservoir in the short, medium and long term. It will be necessary to develop effective monitoring systems to monitor storage security (such as potential leakage) and to provide us with more data to enhance predictive models.

CO_2 can be stored in three main ways:

- in deep ocean water - ocean storage
- in the form of mineral carbonates - mineral storage
- in deep geological formations - geological storage

Storage in geological formations is currently considered the most technically viable and environmentally secure option.

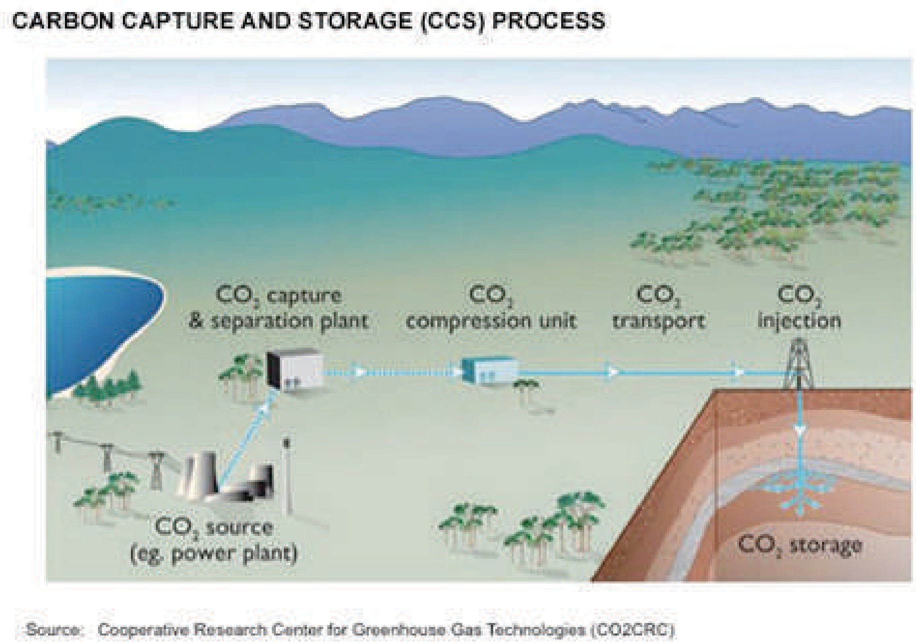

Figure 50: CO_2 storage process

8.1 Ocean Storage

Ocean storage means the transportation of CO_2 via pipelines or ships and injecting it into the deep waters or sea beds. The viability of ocean storage has not yet been demonstrated on a large scale, although there has been some theoretical, laboratory and modelling studies. The environmental impact of ocean storage are enormous and the cost for storage may be more.

Presently understanding of long term impact on deep ocean ecosystems is very limited. The ocean has already absorbed about 50% of the total anthropogenic carbon emissions over the past 200 years, and it is already losing its alkalinity. It is quite clear already that further increase in CO_2 levels in the ocean adversely affects marine biology. Furthermore, public perception is against ocean storage, in contrast with geological storage. Hence, ocean storage currently may not be an option for storing CO_2 from power plants.

8.2 Mineral Storage

Mineral storage is the fixing of CO_2 to alkaline and earth-alkaline oxides that are present in natural silicate mineral rocks to form carbonates and silica. This chemical reaction is the most permanent method for storing CO_2, as it is an exothermic reaction. The technology for mineral carbonation is not yet mature to allow for a proper assessment of costs and performance; nonetheless, there is interest in mineral storage because the vast quantities of silicate mineral rocks present in the Earth's crust are more than enough to permanently store all of CO_2 that can be generated by fossil fuel reserves.

8.3 Geological Storage

The method of Injection of CO_2 in deep rock formations below the Earth's surface – i.e., geological storage – is becoming an important option for storing CO_2 captured from power plants. CO_2 can be injected into geological formations such as oil and gas reservoirs, deep saline aquifers, un-mineable coal beds, basaltic volcanic rocks and deep water-saturated mineral rocks. Prior to its injection, the gaseous CO_2 has to be compressed into a dense, high pressure, 'supercritical' state, which has rather unfamiliar properties, being as dense as a liquid but flowing like a gas. The geological options for CO_2 storage are shown in Figure 52.

The Earth's sub-surface already has plenty of carbon stored in it as coal, oil, gas, oil-rich shales, and carbonate rocks. So, in some sense, geological storage can be considered as returning the carbon back underground after utilizing its stored chemical energy for human activity.

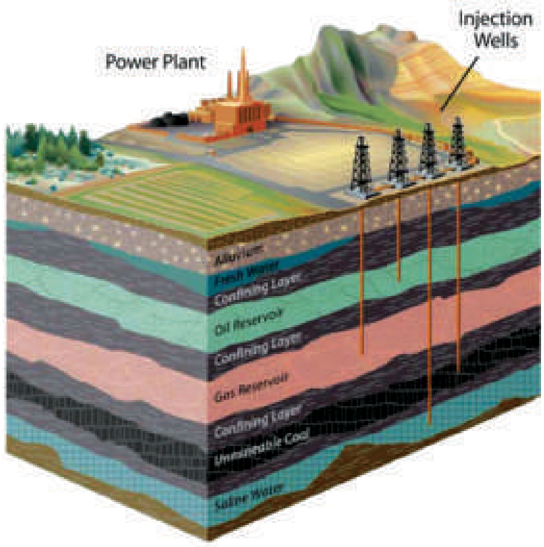

Figure 51 :
Geological options for CO_2 storage

8.4 Risks of Storage

Improper or leaky geological storage involves global risks, such as release of CO_2 that will accelerate the impact of global climate change, and local risks, such as CO_2 leaking into groundwater and local ecosystems that affect humans and local terrestrial systems . The global risk of CO_2 leakage is minimal because it is expected that geological storage, if done correctly and properly monitored, can store 99% of the injected CO_2 for over 100 years or more. Local risks include sudden release of CO_2 because of injection well failures or up abandoned wells, and slow leaks through undetected faults, fractures or wells. In the former case, sudden CO_2 release can be detected and stopped quickly using current technology. In the latter case, slow leaks could affect drinking water aquifers, soils, and local terrestrial ecosystems (if in low-lying areas with little wind). Careful location and design of storage sites, combined with effective monitoring of CO_2 migration (CO_2 sensors, seismic surveys, etc.) should be implemented and early detection of leaks & remediation techniques are necessary to stop or control these slow leaks.

8.5 Potential CO2 storage sites in India

It is to be noted that much of Peninsula India is unsuitable for CO_2 storage because basalt or crystalline basement rocks occur at the surface as shown in Figure 53. It is possible that sedimentary rocks may occur beneath the basalt in some areas but imaging problems would probably prevent effective site characterisation and monitoring.

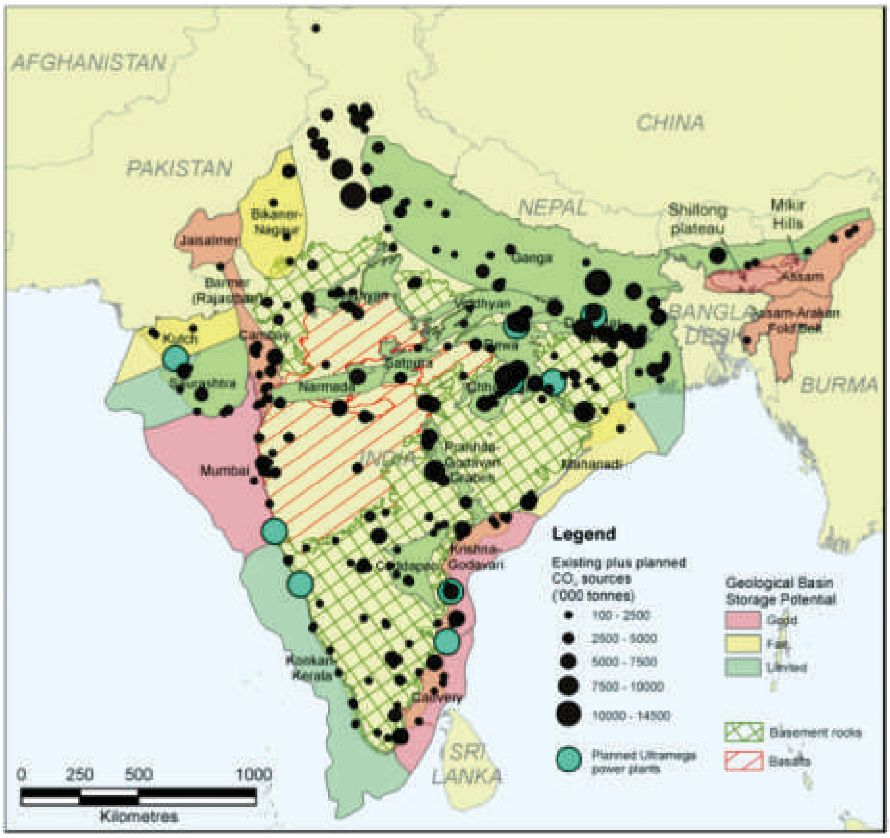

Figure 52 : Geographical relationship between existing and planned CO_2 sources and sedimentary basins in India

The country has the fourth largest recoverable coal reserves in the world. However, much of this coal is easily mined and will be used as fuel. This means that the potential for CO_2 storage on coal at depths above 1200 m could be severely constrained. An indicative calculation of IEAGHG suggests that the potential could be of the order of 345 Mt of CO_2 nationally in the major coalfields, and none of the coalfields are estimated to have the capacity to store >100 Mt of CO_2.

Oil and gas fields so far found in three areas: Assam and the Assam-Arakan Fold Belt, the Krishna-Godavari and Cauvery Basins, and the Mumbai/Cambay/Barmer/Jaisalmer basin area. The total storage capacity in oil and gas fields is estimated to be between 3.7 and 4.6 x 109 t of CO_2. Many Indian oil and gas fields are relatively small in CO_2 storage terms. Only a few fields, e.g. the Bombay High field, offshore Mumbai, are thought to have ample storage capacity for the lifetime emissions of a medium sized coal-fired power plant. However, some of the recent offshore gas discoveries may have potential as CO_2 storage sites in the future.

There is significant CO_2 potential in the saline water-bearing sedimentary rocks in the oil and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan. There may also be saline aquifer CO_2 storage potential in Assam and possibly in Cachar, Tripura and Mizoram, although this is distant from most of the main emission sources in India.

As shown in Figure 53, the geographical relationship between the major existing and planned sources of CO_2 in India and areas containing the sedimentary basins considered on the basis of this first-pass assessment to have good, fair and limited storage potential. The basins rated as good are the hydrocarbon bearing basins, so they also contain all the potential in oil and gas fields. It may be seen that sources in the NW of peninsula India and along the SE coast have good nearby storage potential. The good potential in NE India, in Assam and the Assam-Arakan fold Belt, appears to be stranded relative to most of the major sources.

It was estimated that the total storage capacity of India's major coalfields and oil and gas fields is <5 Gt CO_2, none of the fields have the capacity to store the lifetime emissions of a single UMPP being currently planned in India. As there is insufficient storage capacity in oil and gas fields and coal fields to make significant inroads into India's current and future emissions, it is clear that there is a need to quantify the realistic saline aquifers CO_2 storage capacity of India's sedimentary basins. This would require the use of oil and gas exploration data and might best be approached on a basin-by-basin basis, starting with the most strategically placed basins, as it is a time-consuming and resource-intensive process. If the saline aquifers are found wanting, export of CO_2 by ship, perhaps to the Middle East, would be the only remaining alternative for CCS in India, unless the basalt storage concept can be advanced into a mature technological option.

9.0 ALTERNATIVE CARBON MITIGATION DEVELOPMENTS

The country has major and ambitious plans to build up its various alternatives to fossil energy use as part of its carbon mitigation initiative. There has been a visible impact of renewable energy in the Indian energy scenario apart from contributing 12.5% in the national electric installed capacity. During the 11th Five Year Plan there has been an addition of 14660 MW taking the total installed renewable energy capacity to 24915 MW, with the wind power contributing over 10,000 MW. Renewable energy has also provided basic lighting services to over 5000 villages. India's renewable energy programme is driven primarily by private sector investment.

Renewable energy has a central place in India's National Action Plan on climate change with National Solar Mission as one of the key missions. Further, India is perceived as an excellent country for developing Clean Development Mechanism (CDM) projects. Currently renewable energy projects constitute a large share (789 projects out of 938 projects) in the registered CDM projects.

The targets for India's 11th Five-Year Plan was to add 12.4 GWe of grid-connected renewable power by March 2012,although most of this is in the wind sector, as outlined below Table 10. The major achievements in the renewable energy sector in the 11th plan period are

- Under National Action Plan on climate change, Jawaharlal Nehru National Solar Mission (JNNSM) was launched which aims to install 20 GW solar power by 2022.
- 10260 MW of grid-interactive wind power capacity has been created
- 2014 MW of biomass power including sugar cogeneration and waste to energy projects has been created.
- 1419 MW of small hydro power capacity has been added.

Table 10: Plan-wise growth of Renewable Power Generating Capacity

Sector	Cumulative Capacity in MW		
	Beginning of 10th Plan (April 2002)	Beginning of 11th Plan (April 2007)	Beginning of 12th Plan (April 2012)
Wind	1628	7092	17352
Small Hydro	1434	1976	3395
Bio Power	389	1184	3225
Solar	2	3	941
Total	3453	10255	24914

The country has significant potential of generation from renewable energy sources. All efforts are being taken by Government of India to harness this potential. India proposes to double the renewable energy capacity to 55,000 MW from 25,000 MW by 2017. The ministry has in the 12th plan document, projected deployment targets of 15000 MW for wind power, 2100 MW for small hydro power, 500 MW for solar power (photovoltaic and thermal). India has an ambitious target of acquiring 15% of power needs, or 80,000 MW, from renewable sources by 2020.

9.1 Energy Efficiency

The Bureau of Energy Efficiency is an agency of the Government of India, under the Ministry of Power created in March 2002 under the provisions of the nation's 2001 Energy Conservation Act. The Energy Conservation Act provides a legal framework to embark on this national energy efficiency drive, including the setting up of a Bureau of Energy Efficiency (BEE) to co-ordinate and implement the activities. The agency's function is to develop programs which will increase the conservation and efficient use of energy in India.

India's energy-intensive industries will be part of the initiative to streamline their operational efficiency through the use of technologies such as introducing building management systems, low energy lighting, energy optimising technologies, and energy-efficient appliances in order to reduce their emissions to pre-determined levels. The potential annual CO_2 savings through such initiatives have been estimated at 310 MtCO_2-e.

9.2 Bio-fuel Power

The estimated annual amount of surplus biomass materials in India is about 150 Mt, which could be used to generate some 16 GWe of power. However, to date, there is about 3.3 GWe of installed capacity of biomass plant. Biomass gasifier based 1.2 MW power plant has been commissioned in Madhya Pradesh and installation of 50 biomass gasifier and combustion based power projects with cumulative installed capacity of 8.54 MW to meet the captive demand for electricity and thermal applications are under installation in different states.

Agricultural waste and other woody matter are used as fuel to generate electricity in bio mass based power plants. There are over 1250 MW of biomass based power plants but more than half of these units are not able to operate continuously with biomass fuel because of high fuel cost and low power tariff.

9.3 Hydropower

The installed capacity of hydropower projects is over 2.7 GWe, with an additional 900 MWe at various stages of implementation. The potential for small hydropower projects, each up to 25 MWe capacity, is some 15 GWe and, at present, about 300 MWe per year is being introduced, with 70% coming through the private sector. The aim is to double the current growth rate in the next two to three years. With a view to ensure accelerated development of the hydro power, a New Hydro Policy has been announced by the Government.

Though hydroelectric power is one of the cleanest and most environment-friendly sources of energy, it too has the capability to alter or damage its surroundings. Among the main problems that have been demonstrated by hydroelectric power is significant change in water quality. In some cases due to the nature of hydroelectric systems, the water often takes on a higher temperature, loses oxygen content, experiences siltation, and gains in phosphorus and nitrogen content. Hydropower plants can be impacted by drought. When water is not available, the hydropower plants can't produce electricity.

9.4 Solar Power

India is densely populated and has a high solar area potential, an ideal combination for using solar power in the country. There are two basic kinds of systems :(1) Photovoltaic (PV) uses sunlight to generate electricity and (2) Thermal solar uses sunlight to heat water. The focus will be on PV systems while validating the technological and economic viability of various solar applications, for rural, urban and industrial locations, including grid and non-grid systems. In view of the large target for 2022,

Figure 53: 5 MW SPV power plant at Gajner, Rajasthan

progress from 2010 onwards has been slow. 25.1 MW was added in 2010 and 468.3 MW in 2011. By the end of March 2013 the installed grid connected by photo-voltaic had increased to 1686.44 MW, and India expects to install an additional 10,000 MW by 2017 and a total of 20,000 MW by 2022.

The country has launched Jawaharlal Nehru National Solar Mission with an objective of developing 22,000 MW of solar capacity by 2022 covering both solar photovoltaic and thermal. The cost difference was being covered by different forms of subsidy and cross subsidy. Under the Off-grid and Decentralized Solar Applications Scheme of Jawaharlal Nehru National Solar Mission, the Ministry provides a subsidy of 30% of the project cost limited to Rs. 57,000 per kWp for installation of solar water pumps having solar photovoltaic module capacity up to 5 kWp. On a more positive note, some large applications have been proposed, and a 35 sq.km area of the Thar Desert has been set aside for solar power projects, which if taken up completely could accommodate between 700 and 2100 GWe capacity. Figure 54 shows a 5 MW SPV power plant at Gajner, Rajasthan.

Government of Tamil Nadu has recently unveiled its new Solar Energy Policy which aims at increasing the installed solar capacity from the current approximate of 20 MW to over 3000 MW by 2015.The solar park is coming up in a joint venture of the INDarya Green Power Pvt Ltd and the Tamil Nadu Government's industrial development arm, TIDCO. Engineering major L&T is set to bag a Rs 2,100-crore engineering, procurement, construction order for a 300 MW solar power plant coming up in Tamil Nadu. A 300 MW solar park would typically call for an investment of about Rs 3,000 crore. The project developers do not intend to get into electricity generation. The idea is to develop a solar park in a modular fashion — 300 plants of 1 MW each.

BHEL commenced manufacturing of Solar Photovoltaic cells and modules from 1983. The Solar Cells and Solar PV Modules are manufactured in the state of the art manufacturing line at Bangalore. The Indian Space Research Organisation (ISRO) has deployed BHEL's space-grade solar panels and lithium-ion batteries. BHEL has planned to set up an integrated manufacturing facility for ingots to wafers, cells and panels using crystalline photovoltaic technology. BHEL Hyderabad unit is set to launch a solar power driven steam turbine with the steam generated through solar power. BHEL promotes the use of solar energy and BHEL Corp R&D is also developing a system for tracking the sun to produce increased power output from the solar panels mounted on it to make solar energy cheaper.

PV is also projected to continue its current cost reductions for the next decade and be able to compete with fossil fuel. Land is a scarce resource in India and per capita land availability is low. The amount of land required for utility-scale solar power plants—currently approximately 1sq.km for every 20–60 megawatts (MW) generated—could pose a strain on India's available land resource. Analysis shows that India can make renewable resources such as solar, the backbone of its economy by 2050, reining in its long-term carbon emissions without compromising its economic growth potential.

9.5 Wind Power

India is now the fifth largest wind power producer in the world. Wind energy is a successful and fast growing sector. As on July 2013, the installed capacity of wind power in India was 19500 MW, mainly spread across Tamil Nadu (7134 MW),Gujarat (3,093 MW), Maharashtra (2310.70 MW), Karnataka (1730.10 MW), Rajasthan (1524.70 MW), Madhya Pradesh (275.50 MW), Andhra Pradesh (200.20 MW), Kerala (32.8 MW), Orissa (2MW), West Bengal (1.1 MW) and other states (3.20 MW).Figure 55 shows a wind farm in Muppandal, Tamil Nadu. The wind power sector has plans to add up 3000MW every year.

Figure 54 : Wind farm in Muppandal, Tamil Nadu.

10.0 COAL AND CLEAN COAL RELATED R&D IN INDIA:

Various public and private sector organisations are engaged in coal related R&D in India. Their activities and areas of interest are examined in the following section.

10.1 Bharat Heavy Electricals Limited (BHEL)

Bharat Heavy Electricals Limited maintains an active presence in all major areas of the Indian power sector, including coal-fired generation. Overall, the company’s investment in R&D is amongst the largest in the Indian corporate sector. Products developed in-house during the last five years contributed 19.3% (₹.9643 Crores) to company revenues in 2012-13. In recent years, significant coal related programmes have been undertaken. 385 patents /copyrights have been filed during 2012-13. Most major clean coal technologies have been addressed and projects have been undertaken in the areas of AFBC, CFBC, PFBC and IGCC.

This organisation currently operates a number of R&D facilities, laboratories and research programmes. This includes a Coal Research Group, engaged primarily in the development of equipment and systems aimed at the deployment of clean coal technologies. It also operates a Combustion Studies Group and IGCC Development Programme. The R&D Group is involved in the development of FBC/CFBC processes; PFBC based combined cycle power plants, and development work on PCC-fired boilers. The IGCC Programme remains at the forefront of IGCC technology development in India.

10.2 Central Fuel Research Institute (CFRI)

Central Fuel Research Institute operates under the auspices of the Council of Scientific & Industrial Research and is a research organisation that undertakes fundamental and applied R&D work on Indian energy resources, particularly coal and lignite. Core competencies include coal science, beneficiation, carbonisation, combustion and co-combustion, gasification and IGCC, liquefaction and waste management. Projects have been undertaken in a number of coal related areas that include quality assessment of coal resources, CBM, improved washery design and operation, coal blending for steel making operations, coke oven design, coal tar processing, and fly ash utilisation.

The Institute has a number of sections engaged in coal related studies that include Departments of Carbonisation, Coal Preparation, Environmental Management, Fuel Science, Power Generation and Gasification. Studies carried out by the latter have included investigations into the relationship between coal characteristics and gasifier design and performance, and the development of methodology for technology scale-up.

10.3 Tata Energy And Resources Institute (TERI)

This institute was established in 1974 and headquartered in Delhi; TERI also operates several regional centres (in Bangalore, Goa, and Guwahati) and maintains an overseas presence in Japan, Malaysia, Russia and the United Arab Emirates. It has also set up affiliate institutes: TERI'NA (Tata Energy and Resources Institute, North America) and TERI'Europe based in London.

TERI maintains a strong focus on sustainable development and undertakes reporting and studies related to a range of energy related issues, particularly within an Indian context. It also facilitates research, training and demonstration projects. Coal related areas of activity have included fly ash handling and utilisation, gasifier producer gas cleanup, and CBM. TERI also reports on issues such as global warming and the CDM, carries out coal market studies, and undertakes a wide range of energy related projects.

10.4 Neyveli Lignite Corporation, Centre For Applied Research And Development (CARD).

In recent years, with funding from UNIDO, CARD has been upgraded to become a centre for excellence in lignite related technology known as the Lignite Energy Research Institute (LERI). This has the aim of providing technical support to ensure the application of the latest technologies for minimising the environmental effects associated with lignite mining and utilisation. LERI incorporates a number of departments focused on analysis, energy and environment, lignite treatment, and new products. Facilities include an FBG pilot plant and a reactor for gasification studies. The overarching aim is to pursue R&D programmes aimed at diversifying lignite uses, waste utilisation, and the monitoring of environmental impact. R&D projects are under way examining the use of fly ash composites for road building, development of activated carbons from Neyveli Lignite, utilisation of power plant bottom slag, and underground lignite gasification and its application for power generation purposes.

10.5 Central Power Research Institute (CPRI)

Several Indian organisations are heavily involved in R&D activities focused on the power generation sector. This invariably means that a strong focus is maintained on coal-fired power generation. Alongside BHEL's on-going activities in the power sector, are such organisations as CPRI. This was set up in 1960 by the government (as a National Laboratory) to operate as a centre for applied research in electrical power engineering and assist the electricity industry in product development and quality assurance. The Institute's headquarter is in Bangalore and its other units are at Bhopal, Hyderabad, Nagpur, Ghaziabad, Thiruvananthapuram and Raichur.

CPRI has made significant contributions to the power sector through improved processes developed for planning, operation and control of power systems. It undertakes in-house R&D and carries out sponsored research projects from manufacturers and power utilities. Numerous products resulting from the Institute's activities have been developed and licensed. A range of specialised test facilities, some focused on energy and environmental issues, is maintained. Clientele of CPRI include manufacturers of power equipment from within India and overseas. Expert consultancy services are also offered in the areas of Remaining Life Assessment and Life Extension studies of coal-fired power plants.

10.6 Centre for Power Efficiency and Environmental Protection (CENPEEP)

This Centre is an NTPC initiative, set up to improve the performance and reduce the environmental impact of India's coal-fired power plants. A major aim is to reduce the emission of classic pollutants and CO_2 per unit of electricity generated by improving plant efficiency. This is being achieved through the demonstration and dissemination of improved technologies and practices to different state electricity utilities. CenPEEP receives USAID technical assistance to promote its aims and has established several regional centres. Areas of activity include power plant maintenance optimisation, improvement in ESP operations, utilisation of coal ash, improvement of power plant performance in both state and private sectors, and greenhouse gas mitigation. NTPC Energy Technology Research Alliance is a recent development by NTPC.

10.7 Central Mining Research Institute (CMRI) In Dhanbad

CMRI is one of the national laboratories of the government's Council of Scientific and Industrial Research which was established in 1956 to undertake a range of R&D activities in the field of coal mining. Its main objective is to provide scientific and technical input to the Indian mineral industry with a view to optimising mining technology for improved safety, economy, conservation and environmental management. The Institute has a number of departments focused on areas that include geo-mechanics and mine design and operation. An important area of activity is the minimisation of environmental pollution and degradation created by mining and associated industrial activities.

The Department of Fuel and Mineral Engineering deals with the beneficiation and handling of coal and minerals, offers consultancy and testing services to the country's coal and mineral industries. The department has coal characterisation equipment that includes unique pilot-scale test facilities. Areas of activity have included development of coal cleaning processes such as heavy medium cyclones, froth flotation, oil agglomeration, and flocculation. Current research is focused on cyclone designs, coal crushing and performance analysis of coal crushing circuits, coal beneficiation, froth flotation reagents, carbonisation, coal-oil and coal-water mixtures, FBC modelling, and spontaneous combustion.

11.0 SUMMARY

Coal will remain the backbone of the country's energy sector for many years. As the economy continues to grow, energy security has become a core focus for India. The burgeoning economy requires increasing amounts of electrical energy to meet the rapid development taking place.

The largest coal consumer is the power sector. In the past, all coal-fired plants installed were with conventional pulverised coal combustion and subcritical steam conditions. Although efficiency of some stations remains poor, efforts have been made to improve the performance of others via renovation and life extension exercises. Improving efficiency of existing plants and repowering with newer technology will help conserve coal supplies and reduce emissions on a local and global basis.

A. Conservation of fuel

Introduction of tariff based competition after 2000 made the introduction of supercritical steam parameters in the country. From January, 2012 onwards ,Government of India preferred to clear projects with super critical technology with higher efficiency. Hence now super critical sets with 660 MW and 800 MW ratings with 568/596 degree Celsius and 596/596 degree Celsius are being added to meet the huge power addition program of the country to meet the growing needs.

From 13th Five Year Plan, clearance is proposed only for super critical and ultra super critical power plants in India. These plant will have much higher efficiency to meet the requirements of low tariffs as well as for reduced emissions.

Government of India's Advanced ultra super critical programme with 300 bar 710/720 degree Celsius with IGCAR, Midhani, NTPC and BHEL will make the nation to have the latest technology on par with advanced countries with highest efficiency.

B. Clean coal technologies

There is a growing focus on the adoption of more advanced technologies and the deployment of clean coal technologies. Several forms of fluidised bed combustion technology are well established within the country and their numbers are growing. These comprise a large number of bubbling FBC units plus a growing number of CFBCs. Coal-fuelled IGCC technology has been developed by BHEL and a large-scale demonstration has been proposed.

The choices of India's clean coal technology in an environmentally acceptable manner suggest that no single technology would meet all the challenges and adoption of a portfolio of CCTs would be appropriate.

C. Carbon Capture

To enable carbon capture, development of oxy fuel combustion demonstration projects are in progress in full swing for Indian coals at BHEL Trichy R&D complex. Biomass co-firing has been already demonstrated in pilot scale successfully with Indian coals. Many development projects are being undertaken by Indian researchers and technology developers, some in collaboration with overseas organisations.

To enable carbon capture, the country is working on three fronts- Capture and Storage (CCS), Carbon Utilization (CCU) (algae route) and also Carbon Fixation (CCF) to harmless chemicals. Many pilot scale projects are initiated taking slip streams from the power plants. Once successful, these can be easily retrofitted into the existing thermal power plants.

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13.0 LIST OF FIGURES:

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15.0 ABBREVIATIONS:

S.No.		ABBREVIATIONS
1	Abandoned Mine Methane	AMM
2	Advanced Ultra-Supercritical	AUSC
3	Air Reactor	AR
4	Air Separation Unit	ASU
5	Artificial Neural Network	ANN
6	Asia-Pacific Partnership for Clean Development and Climate	APP-CDC
7	British Geological Society	BGS
8	Build-Own-Operate	BOO
9	Bureau of Energy Efficiency	BEE
10	Bharat Coking Coal Ltd	BCCL
11	Bharat Heavy Electrical Limited	BHEL
12	Bypass Over Fire Air System	BOFA
13	Circulating Fluidised Bed Combustion	CFBC
14	Cabinet Committee On Economic Affairs	CCEA
15	Carbon Sequestration Leadership Forum	CSLF
16	Central Bureau of Investigations	CBI
17	Central Electricity Authority	CEA
18	Central Fuel Research Institute	CFRI
19	Central Mining Research Institute	CMRI
20	Central Power Research Institute	CPRI
21	Centre for Applied Research and Development	CARD
22	Centre for Power Efficiency and Environmental Protection	CENPEEP
23	Chemical Looping Combustion	CLC
24	Circulating Fluidised Bed Combustion	CFBC
25	Clean Development Mechanism	CDM
26	Coal Bed Methane	CBM
27	Coal Mine Methane	CMM
28	Coal-To-Liquids	CTL
29	Combined Cycle Gas Turbine	CCGT
30	Computational Fluid Dynamics	CFD
31	Conservation Action Trust	CAT
32	Direct Coal Liquefaction	DCL
33	Electrostatic Precipitator	ESP
34	Fischer-Tropsch Liquefaction Process	FT
35	Flue Gas Desulphurisation	FGD
36	Fuel Reactor	FR
37	Gas Tungsten Arc Welding	GTAW
38	Greenhouse Gas	GHG
39	Greenhouse Gas Pollution Prevention Project	GEP
40	Gross Calorific Value	GCV

S.No.		ABBREVIATIONS
41	High Temperature Fischer-Tropsch Liquefaction Process	HTFT
42	Higher Heating Value	HHV
43	Indian Space Research Organisation	ISRO
44	Indirect Coal Liquefaction	ICL
45	Integrated Gasification Combined Cycle	IGCC
46	International Partnership for the Hydrogen Economy	IPHE
47	Jindal Steel & Power Ltd	JSPL
48	Mining Exploration License	MEL
49	Ministry of Coal	MOC
50	National Action Plan for Climate Change	NAPCC
51	National Clean Development Mechanism Authority	NCDMA
52	National Energy Technology Laboratory	NETL
53	Neyveli Lignite Corporation	NLC
54	Centre for Applied Research and Development	CARD
55	Operation And Maintenance	O&M
56	Particulate Matter	PM
57	Photovoltaic	PV
58	Post Combustion CO_2 Capture Technologies	PCC
59	Pressurised Fluidised Bed Combustion Combined Cycle	PFBC
60	Process And Equipment Development Unit	PEDU
61	Product Recovery Train	PRT
62	Project Design Memorandum	PDM
63	Pulverised Coal Combustion	PCC
64	Pulverized Coal	PC
65	Reliance Industries Limited	RIL
66	Renovation And Modernisation	R&M
67	Selective Catalytic Reduction	SCR
68	Separated Over Fire Air System	SOFA
69	Solid Fuel Evaluation Test Facility	SFBTF
70	State Electricity Regulatory Commissions	SERC
71	Station Heat Rate	SHR
72	Strategic Energy Technology Systems Ltd	SETSL
73	Tata Energy And Resources Institute	TERI
74	Tata Energy And Resources Institute, North America	TERI'NA
75	Tiruchirappalli Regional Engineering College Science and Technology Entrepreneurs Park	TREC-STEP
76	Ultra Mega Power Project	UMPP
77	Ultra Supercritical	USC
78	Underground Coal Gasification	UCG
79	Unit Heat Rate	UHR
80	Virgin Coal Bed Methane	VCBM

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