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Green growth and clean coal technologies in India

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1. Introduction

India is currently world's fourth largest energy consumer with installed electricity generation capacity at 267,637 MW1as on 31st March 2015. The addition of renewable energy capacity has taken place mostly only recently in last decade. Renewable Energy Sources (RES) currently account for ~ 11.8% of the installed capacity (31,692 MW).

Despite of this large installed capacity, India is facing chronic shortage of electricity generation since long time. Bridging the gap in demand and supply is vital for India's economic growth as well as need to provide energy access to its population. Numerous large projects are being undertaken in various segments of power sector; namely Generation, Transmission and Distribution to improve the situation. Figure 1 presents main contributors in the Indian power sector.

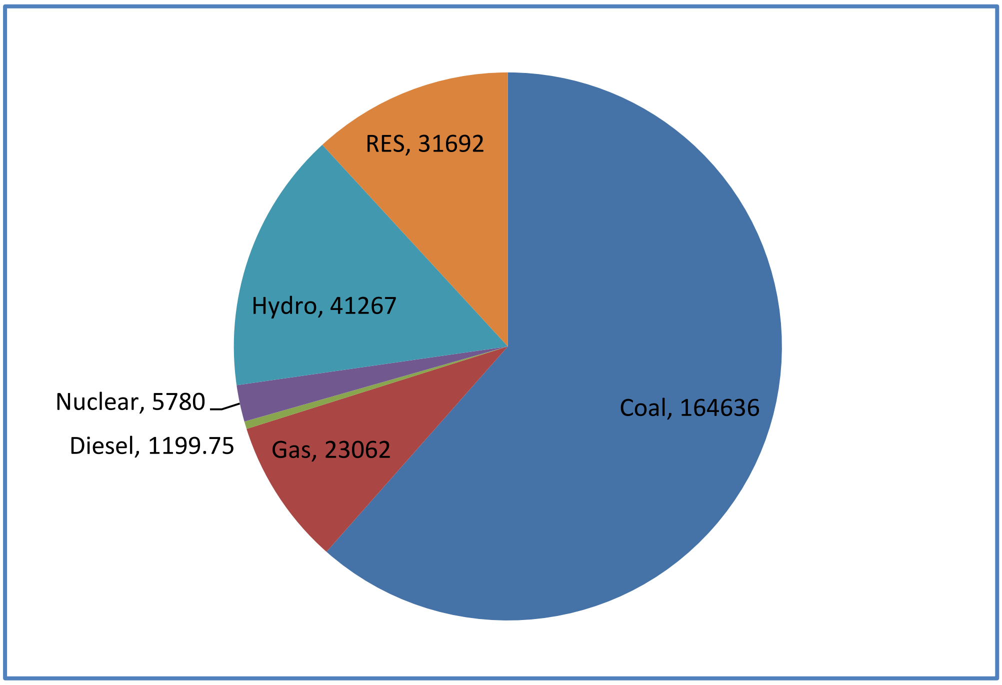

Figure 1 Generation sources in Indian power sector

Source: CEA, 2015

1.1 Status of power sector in India

It is clear that India is and will remain dependent on thermal, and mainly coal, power plants for foreseeable future. The Twelfth Five Year Plan (2012-17) proposed increase in installed power generation capacity of~ 100 GW, based mostly on the coal based power. For coal based power, pulverised coal combustion is the most commonly used technology and the

[1] Executive Summary – Power sector, Central Electricity Authority, 2013

future capacity addition is expected to utilize more efficient pulverised coal combustion technologies, super-critical and ultra-super critical technology. The twelfth plan period targeted 50 % of capacity addition through super-critical units, and the thirteenth plan 100 % of capacity addition in coal based power using super-critical technology[2].

India's electricity sector also faces many challenges from high cost of coal production to inefficient transmission infrastructure, from shortage of natural gas to less availability of nuclear resources etc. The process of planning to implementation of the new power plants is also very slow and faces many hurdles, as mentioned below[3].

1.1.1 Fuel shortages

Coal demand by power sector and coal imports, both are expected to increase in near future. The domestic coal production would therefore require to keep pace with the power sector, or otherwise there will be higher coal imports and its adverse impact on the economy. Government of India has announced in March, 2015 that reducing/stopping coal imports altogether is its top priority and it has planned increasing Coal India Limited to 1 billion tonnes per year. This would need CAGR of 11.3% compared to CAGR of 4.3 % for last two decades. To achieve this ambitious target, several challenges are needed to be addressed such as better clarity on coal resource availability, improved mining technology, major improvements in coal transportation infrastructure etc.

1.1.2 Financial health of state distribution utilities

Most of the State distribution utilities in India have been in very poor financial health. The losses of distribution utilities in India are expected to be in the range of Rs 1.16 trillion (US$ 21.4 billion) by 2014-15. The main reasons for this are high distribution and commercial losses and high amount of cross subsidies.

1.1.3 Environmental approvals and land clearances

Land acquisition is one of the key hurdles for new power plants. Further, obtaining environmental approvals are also difficult due to the need to deal with various organizations such as Ministry of Environment and Forests, Ministry of Aviation, Department of Forests, and other government institutions. The overall process is very lengthy and time consuming which inevitably delays the sanctioning and implementation of new power plants.

In spite of the above mentioned challenges, India can hardly afford to slow down the growth of the power sector as India's energy demand is expected to grow at very high rate during the next decade. It may be seen in Figure 2 that India's overall energy demand will reach 1559 Mtoe in 2035, according to New Policies Scenario (NPS) of WEO 2014. The much conservative 450 Scenario projects that energy demand reaching 1369 Mtoe in 2040, which is ~23% less than under the NPS. Looking at both these projections, it is clear that though the growth would come from all fuels the hydrocarbons, especially coal, would be the key in

[2] GoI 2010, TERI 2013
[3] The Indian Power Sector: Investments, Growth and Prospects, Report by Indian Brand Equity Foundation, 2013 Coal is available but of poor quality. Natural gas capacity is limited

meeting India's projected energy demand. The largest demand growth would come from coal, almost doubling from 352 Mtoe in 2012 to 682 Mtoe in 2035 at a CAGR of 2.8%.

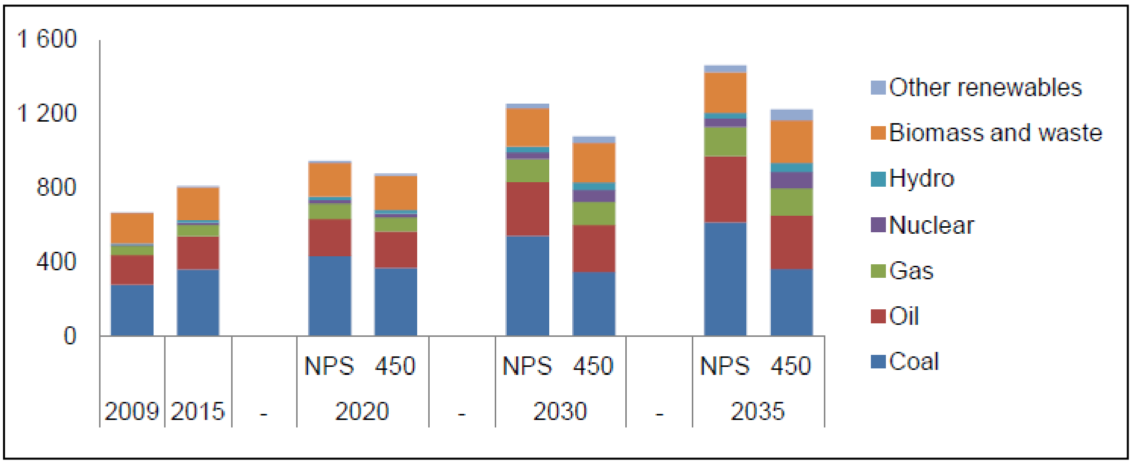

Figure 2 India's Energy demand projections 2012 – 2035

Source: World Energy Outlook, IEA, 2014

1.2 Status of coal resource in India[4]

Coal is the most abundant fuel resource in India, considering the limited reserves of petroleum and natural gas, and safety issues of nuclear power. India is the world's third largest coal producing country and the fourth largest coal importer. State owned Coal India Limited (CIL) is the largest company in the world in terms of coal production and contributes ~ 80% of coal production in India. Generally, Indian coals have low calorific value and high levels of inorganic impurities. Also, coal ash is difficult to remove beyond a certain level due to non-homogenously mix nature. The typical characteristics of Indian coal being used for power generation are given in Table 1.

Table 1 Typical characteristics of Indian coal

Property	Value
Ash Content	25 – 55 %
Moisture content	4 – 7 % (18 % during monsoon)
Sulpher content	0.2 – 1%
Gross Calorific value	3100 – 5100 kcal/ kg
Volatile matter content	20 – 30 %

The ash in Indian coals is mostly high in silica and hence, abrasive. This requires careful adoption of appropriate technology when designing power plant such as[5]

- Adequate capacity of coal and ash handling equipment;

[4] APJEM Arth Prabhand: A Journal of Economics and Management Vol.2 Issue 8 August 2013, ISSN 2278-0629

[5] Report on Existing Gaps and Potential for CCS and CCT Areas in the Thermal Power Industry in India, TREC –STEP, 2012

- Adequate capacity and ruggedness of milling equipment to ensure availability?
- Provision of particulate separators commensurate with the high flue gas dust loading;
- Measures to minimize erosion
- Provision of appropriate heat transfer surface distributions (radiant: convective) in the boiler.

Considering the importance of coal to the Indian power sector, which is also the highest contributing fuel for greenhouse gas emissions in India, it is obvious that minimizing emissions and environmental effects of the coal industry needs to be prioritized in order to minimize the impact of overall power sector on the environment. It may be seen that no single measure would be sufficient for this, so India needs to explore the entire mix of clean coal technologies and mechanisms such as emissions trading.

1.2.1 Clean coal technologies

The concept of clean coal technologies (CCT) is an umbrella term, including variety of technologies to reduce various emissions from coal industry such as fly ash, particles and gasses such as carbon dioxide (CO_2), carbon oxide (CO) and nitrous oxides (NO_X). Clean coal technologies help in reducing air emissions and other pollutants from coal based power generation plants. Initially the focus of clean coal technologies was on sulphur dioxide and particulate matter, as they are the worst pollutants causing various problems. The focus of clean coal technologies has now been shifted to carbon dioxide (due to its impact on global warming) as well as other pollutants. It is important to note that there are still major concerns regarding the economic viability and overall feasibility of these technologies and the commercial availability.

2. Clean coal technologies

Lot of research work is going on globally since long time to minimize the environmental impacts of various processes related to coal. CCT (Clean Coal Technology) is an umbrella term, encompassing a wide array of technologies and innovations that can help reduce various emissions – fly ash, particles and gasses such as carbon dioxide (CO_2), carbon oxide (CO) and nitrous oxides (NO_X) etc from the coal industry and minimize above mentioned concerns. There are still concerns regarding the economic viability and overall feasibility of these technologies and the timeframe of delivery.

There are numerous CCTs aimed at minimization of environmental impacts during various processes in coal life cycle. The typical CCT alternatives for three major processes in coal life cycle namely coal preparation, coal burning and carbon capture and storage (CCS) are shown in Figure 3.

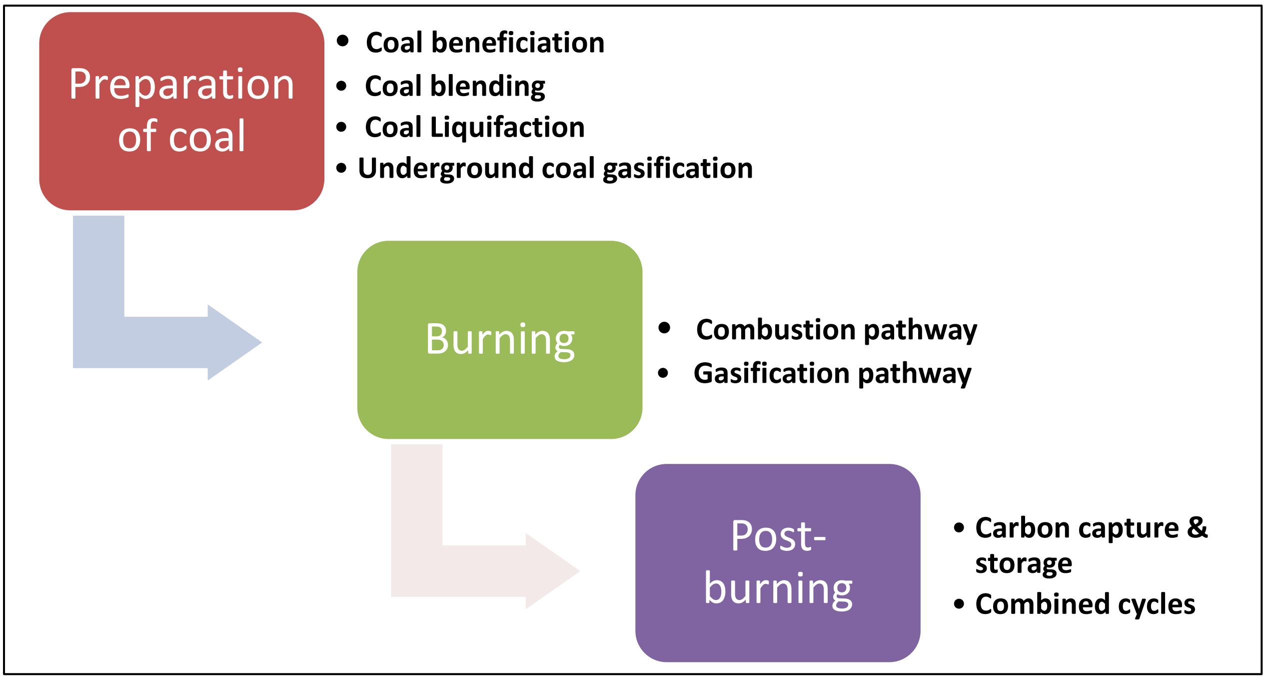

Figure 3 CCTs during various stages of coal life cycle

2.1 Coal Preparation stage

2.1.1 Coal Beneficiation

Coal beneficiation is the first process in the life-cycle coal. This is the technology that improves the quality of the coal by removing the impurities using various means. Extraneous impurities in the coal are easiest to remove by mechanical means, which separate the coal and impurities on the basis of different specific gravities. Chemical methods of cleaning are required to be employed for other types of impurities. These methods are classified as dry and wet coal beneficiation. Dry methods usually are more efficient due to less usage of water and energy. Coal is first broken down into specified sizes and washing/cleaning methods are then employed for various sizes. Coarse coal is generally handled by dry separation in air jigs or hydraulic jigs, while cyclones and concentrators are used for medium-size coal, and coal fines are separated by flotation or agglomeration. Advanced techniques of coal cleaning such as heavy media cyclone, barrel-cum-cyclone, and vorsyl separator are utilized in case the coal contains heavy metals as impurity. NTPC plants at Satpura and Dadri and Reliance plant at Dahanu are the first plants in India to have shifted to clean coal.[6].

2.1.2 Coal Blending

In many situations, it is advisable to blend indigenous coals with imported coals having higher CV and lower ash content. This reduces overall cost by combining low cost coals with more expensive coal, In addition it also reduces dependence on a single source of supply i.e. mainly imported coal). Another important purpose of blending is also to improve process economics and/or to obtain optimal combustion performance. Reliance Energy's Dahanu

[6] A Case for Enhanced Use of Clean Coal in India:An Essential Step towards Energy Security and Environmental Protection, Zamuda and Sharpe, 2007

power plant is one the first such application in India, where blending of high ash indigenous coal with low ash Indonesian imports is being carried out[7].

2.1.3 Coal Liquefaction[8]

Coal liquefaction is an industrial process in which coal as raw material is converted into liquid hydrocarbon mixture through chemical reaction. There are two methods, one by direct conversion and second by indirect conversion via gasification route. In the direct process, catalyst is used to dissolve hydrogen present in coal. Therefore the process is called as hydrogenation. In the indirect method, coal is first gasified and the produced hydroger is then converted to oil in a catalytic converter. This process produces hydrocarbons as by-products such as methanol, ethanol, and diesel oil and methane. In India, Oil India Ltd. has undertaken test work, pilot plant runs and feasibility studies using direct liquefaction technology from Headwaters, USA.

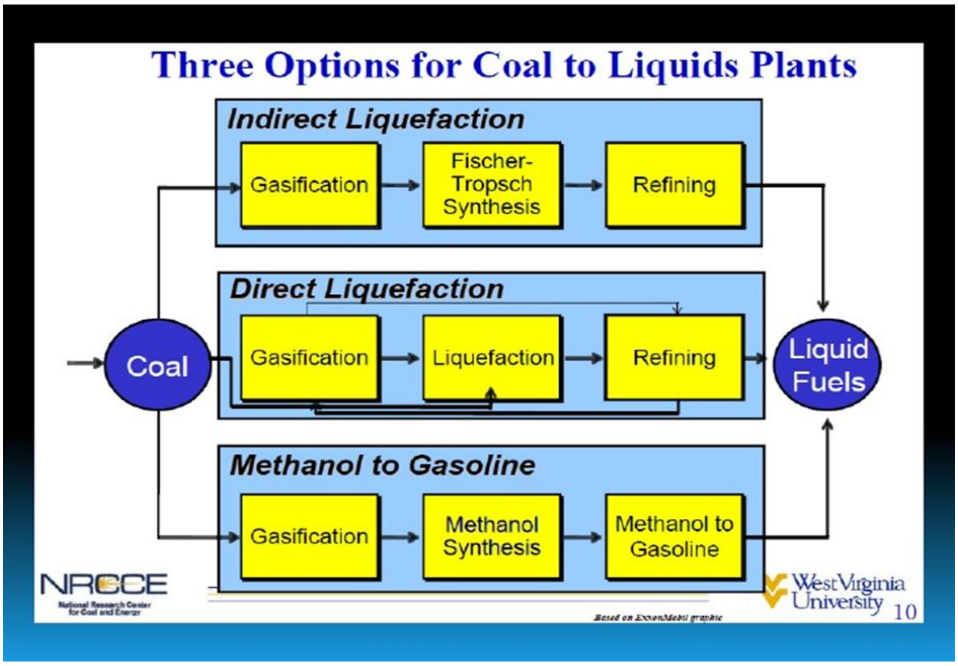

Figure 4 Coal Liquefaction alternatives

Source: NRCCE

2.1.4 Underground coal gasification

Underground coal gasification (UCG) is basically in-situ gasification of coal/lignite deposits to produce gas, a cleaner fuel. UCG process is not commercially proven, very capital intensive and requires sophisticated technology. But it offers tremendous economic benefits as it removes the all coal handling processes such as coal beneficiation and coal transportation. It also removes the problem of ash disposal. Due to these benefits, technology is being pursued in several countries, including India. In India, total UCG potential is estimated at 15,000 billion cu. m. of gas. The sites identified as suitable based on geological and hydrological surveys are Gujarat coal and lignite deposits, South Karanpura

7 Prospects of coal and CCTs in India, IEA Clean Coal Centre, 2007

8 Implementing Clean Coal Technology Through Gasification And Liquefaction – The Indian Perspective, H.B. Sahu, 2013

coal fields, and lignite fields in Rajasthan appear suitable for this from geological and hydrological survey data considerations.

2.1.5 Coal bed methane

There are total prognosticated CBM resources of 2600 billion cubic metres in the country. Out of these a total of 280 billion cubic metres of initial-in-place reserves have been already identified by various operators in the country (as on March 31, 2014). The details of reserves are presented in Table 2.

This field is relatively new for the country and the bidding process for exploration and production of Coal Bed Methane (CBM) was started only in 2001. Until now 4 rounds of bidding have taken place and, a total of 30 CBM blocks have been awarded to state owned, private and joint venture companies. Currently, 29 CBM blocks are operational out of total allotment of 33 blocks**Error! Bookmark not defined.**.

Table 2 Initial-in-place CBM resources of India

Sr. No.	Block Name	In-place CBM resource (in BCM)	Operator	State
1	SP (East)-CBM-2001/ I	47.86	RIL	Madhya Pradesh
2	SP (WEST)-CBM-2001/ I	55.5	RIL	Madhya Pradesh
3	Raniganj (South)	54.37	GEECL	West Bengal
4	RG (East)-CBM-2001/ I	60.88	ESSAR	West Bengal
5	Raniganj (North)	7.36	ONGC	West Bengal
6	NK-CBM-2001/ I	9.63	ONGC	Jharkhand
7	BK-CBM-2001/ 1	30.02	ONGC	Jharkhand
8	Jharia	14.72	ONGC	Jharkhand

Source: Hydrocarbon Exploration and Production Activities, Directorate of Hydrocarbons, 2013-14

2.2 Coal burning stage

Burning is the major stage in the coal life cycle with maximum environmental impacts. There are main pathways being developed worldwide. Pathways are essentially technology routes for preparation and utilization of coal for electricity generation. A pathway may be considered as linear progression of technology development along the route over the period of time. For CCT, two primary pathways are coal combustion, which is a pre-dominant route and coal gasification, a relatively new route. There are also other enabling technologies which can be used alongwith both of these technologies.

2.2.1 Combustion pathway

Pulverized coal combustion

Combustion is predominant and well established route for burning coal. PC combustion is being used in over 90% of coal-fired plants worldwide and also in India. There are three main types namely sub-critical, super-critical and ultra-supercritical with increasing thermo-dynamic efficiency. A supercritical steam cycle typically has pressure > 226 bars and temperature > 537°C .Ultra-super critical cycle typically operates at 357 bars/625°C. There are further performance improvements still expected in PC combustion technology with expected efficiency upto 55 % by 2020

Figure 5 Sipat thermal power station, NTPC

Source: www.bilaspur.gov.in

In India, BHEL signed an industrial partnership agreement in 2007 with Alstom, to enable BHEL to produce 1,000-MW supercritical plants. NTPC plant at Sipat, and Ultra Mega Power Plants at Mundra and Sasan are supercritical plants operational in India. BHEL, IGCAR and NTPC are also planning to develop India's first ultra-supercritical plant by 2017.

Fluidized bed combustion

Fluidized bed combustion (FBC) is a well-established method of burning low-grade coals, biomass, and other waste fuels. It produces less NO_x and SO_x than a conventional PC combustion and is also more efficient. There are two types of FBC boilers currently available namely: Circulating Fluidized Bed Combustion (CFBC) and Pressurized Fluidized Bed Combustion (PFBC). BHEL, Thermax Babcock and Wilcox, Thyseenkrup already supply CFBC systems in India. India's first CFBC boiler of 175 t/h capacity was installed and commissioned at Sinarmas Pulp and Paper (India) Ltd., Pune by BHEL. It has proved to be a promising technology for low grade fuels and research is going on towards increasing the plant sizes which will definitely improve its commercial viability.

2.2.2 Gasification Pathway

Gasification is relatively new route compared to combustion and is particularly suitable for hybridization with other fuels. In the gasification process, coal, steam, and either air or pure oxygen (O_2) react at high pressure and temperature to produce a synthesis gas (syngas), Syngas consists mostly of carbon monoxide (CO), hydrogen (H_2), and some impurities. The combustion of this gas is cleaner and more efficient than the combustion of coal. There are three main types of gasifiers suitable for coal gasification namely fixed bed, fluidized bed, and entrained bed systems.

- Fixed Bed Gasifier: This type is the most basic and gasification reactor has separate zones for each stage in the process namely drying, devolatilizing, gasification, and combustion. Coal is typically fed from the top and is required to in the size of 10–50mm . The fuel bed is then blown using either air or oxygen. This type of gasifier doesn't need a separate heat exchanger and has lower oxygen consumption. Because of this, this type has the lowest energy requirement of all gasification processes.

- Fluidized Bed Gasifier: This type employs counter-current principle and has vigorous movement of fine coal particles inside the reactor, where temperatures go up-to 850–1,050°C. The turbulent and vigorous mixing accelerates the chemical reaction. Also, there are no separate zones contrary to fixed bed gasifier. Typically it utilizes a vertical cylindrical refractory lined vessel along with recycle cyclone. This type is specifically suitable for high ash and high reactive coals.

- Entrained Bed Process: This type utilizes very finely ground coal of around 0.1 mm and process at very high temperatures in the range of 1,400 to 1,600°C. Due to higher temperatures, the coal gasifies almost instantly. The product gas typically has ~ 80 % of the energy of the feed coal. The ash in the coal is removed as the liquid slag in this gasifier.

IGCC (Integrated Gasification Combined Cycle)

The integrated gasification combined cycle (IGCC) plant consists of a gasifier incorporated into a combined cycle system comprising of both a gas turbineand a steam turbine, . Thus, IGCC is a hybrid system including coal fired steam power generation and gas turbine based power generation. Typically, the gas turbine produces 65% of the power and the steam turbine produces the remaining 35% power. In comparison to combustion-based technologies, IGCC offers numerous advantages such as:

- Increased efficiency from the combined cycle
- Improved environmental performance
- Lower cost of cleanup technologies
- Greater ease of carbon capture
- Lower incremental cost of capture at present

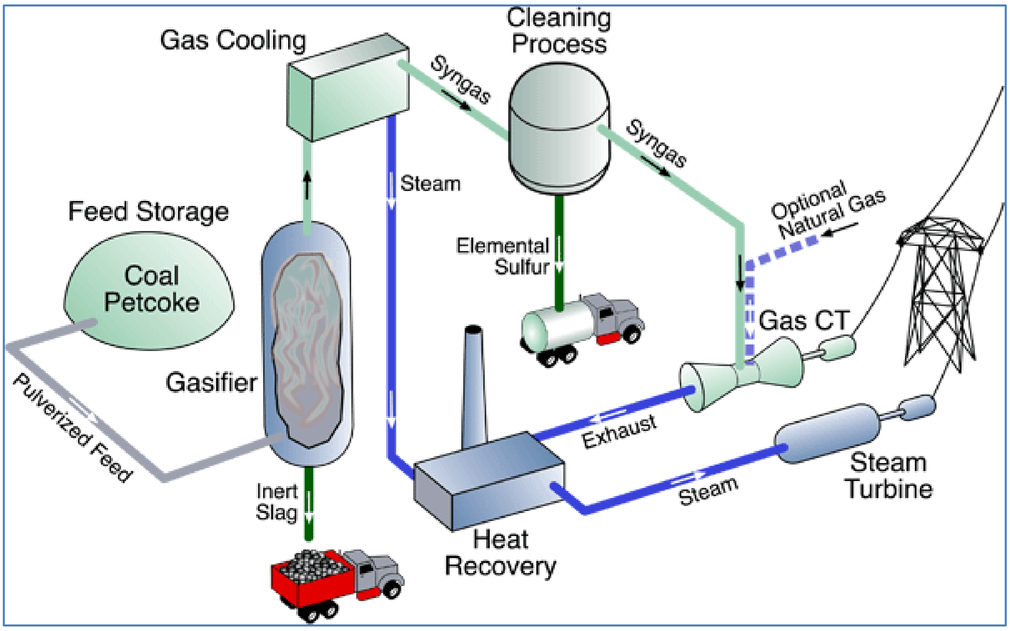

Figure 6 Simplified flow diagram of IGCC process

Source: www.forexjournal.com

But this also is very new technology with only four plants operating commercially in USA and Europe. The technology is also very complex and highly costly. BHEL had set up a larger-scale (6.2-MWe) IGCC pilot plant for which two scale-up plants are now scheduled[9].

2.3 Post burning stage

2.3.1 Carbon capture & Storage (CCS)

CCS is being developed for use in either combustion or gasification pathways. For the combustion pathway, post-combustion capture seems most appropriate. The CO_2 would be removed by scrubbing with solvents such as an amine solution. For the gasification pathway, the CO_2 would be more effectively removed using pre-combustion capture. In effect, syngas can be de-carbonized through a water-gas shift conversion, leaving H2 as the fuel for downstream applications and captured CO_2 for either storage or other purposes. Therefore, a major technical challenge for coal-fired generators is the CO_2 capture side of CCS so that future plants can be built to be CO2 capture-ready for when CCS becomes available. Currently, India has annual CO_2 emissions of around 1343 Mt with approximately half being emitted from large point sources suitable for CO_2 capture.

[9] Clean Coal Power Generation Technology Review: Worldwide Experience And Implications For India, The World Bank Report, 2011

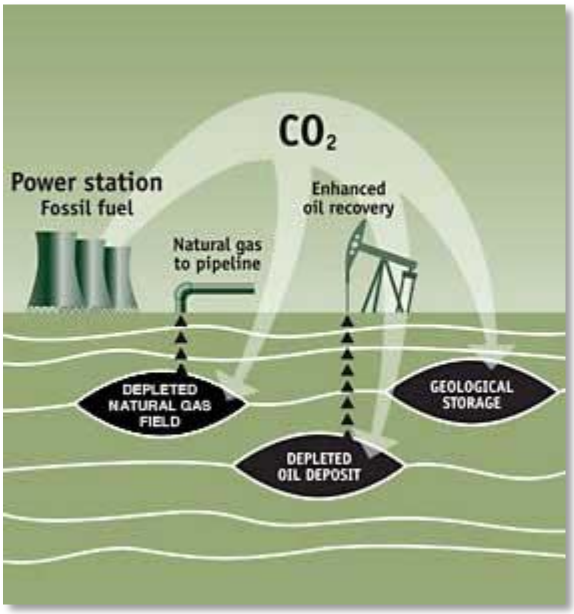

Figure 7 CO_2 storage alternatives

Source: http:/ / www.quazoo.com/ q/ Carbon_capture_and_storage

2.3.2 Combined cycles

Co-generation in the power sector has been identified as another way of reducing emissions and achieving better energy output. In cogeneration systems, combined cycles are typically used to produce electricity as well as thermal energy of required quality. Along with above mentioned IGCC system other advanced combined cycles, that can be utilized for co-generation are as listed below:

Integrated Gasification Humid Air Turbine (IGHAT)

It is an advanced version of the IGCC technology, which utilizes a humid air turbine and intercoolers on a multi-stage compressor, to produce low grade heat. The IGHAT cycle is supposed to eliminate the steam turbine completely and utilize heat to warm water in various heat recovery sections.

Pressurized Pulverized Coal-fired Combined Cycle (PPCC)

It utilizes pulverized coal firing in gas turbines. The gas is cleaned at very high temperatures of 1400–1600°C and a high pressure of ~18 bar. It is suitable for combined heat and power generation using various low grade fuels. In combined heat and power generation with a waste heat recovery system, the efficiency is expected to reach 46–47 %, along with reduction of emissions of CO_2, NO_x, and SO_2 by 10, 20, and 30 % respectively.

3. Potential and status of clean technologies in India

3.1 Status of technology development and demonstration

Technology wise developments in India are given in this section

3.1.1 Coal beneficiation

Currently, the capacity for the beneficiation of thermal coals is estimated at ~ 70 million tonnes per annum in India, with an additional 20 million tonnes per annum proposed. But this capacity also is being utilized only partially. During 2005-06, India produced 380 million tonnes of thermal coals, out of which only 17 million tonnes were beneficiated. This indicates that only about 22 million tonnes of coal i.e. 5% of the total annual coal production were fed for beneficiation (assuming an average yield of 80% for beneficiation process).

In India, policy guidelines were introduced in 1997, which restricted the use of unwashed coal in thermal power plants situated more than 1,000 km away from the mine site as well as those located in critical, sensitive, and urban areas. Research has been initiated and field trials were made for ROMJIG and RAMDARS systems for cleaning and deshaling of coal at the Bina and Yellandu mines, respectively. The use of 100 % washed coal in thermal power generation is targeted by 2017[10].

3.1.2 Coal Liquifaction

In India, Indian Institute of Technology, Kharagpur[11] initiated the primary research on coal liquefaction, with the objective of developing indigenous catalysts. The syngas was first produced using fixed bed gasification process at 800–900°C. Tests were carried out on number of chemicals such as zeolite supported iron catalyst. The oil output of 4 litres per day was soon reached. Coal liquefaction research was also pursued in R&D laboratories of IOCL which has put up a pilot plant for conversion of low sulphur Assam coal to oil at Duliajan, in Assam. This was due to the fact that Assam coal with its low ash content has better suitability to liquefaction. Coal India is planning to set up a commercial-scale coal liquefaction plant of coal processing capacity of 3.5 Mt per annum.

The Ministry of Coal has supported R&D on improved coal mining and processing technologies since 1976. These activities have focused more on the adaption of proven technologies from around the world to Indian conditions (e.g., high-ash coals and high-ambient temperatures).

3.1.3 Supercritical and ultra-supercritical technology development in India

BHEL had collaborated with Alstom in 2007, which enabled BHEL to produce 1,000-MW size power plants based on supercritical technology. BHEL had also signed a MOU with Siemens for cooperation in the field of advanced power plant technology. India's first supercritical thermal power station was erected in Sipat, Chhattisgarh by NTPC. The total approved capacity of Sipat is 2980 MW, which includes 3x 660-MW supercritical units in Stage I and 2x 500-MW supercritical units in Stage II. The stage I of the plant is currently under installation. The two commissioned UMPPs at Mundra and Sasan are another examples of supercritical power plants in India.

[10] A case for enhanced use of clean coal in India, Zamuda and Sharpe, Workshop on Coal Beneficiation and utilization of rejects, 2007

[11] Potential of Clean Coal Technology in India: An SME Perspective, European Business and Technology Report, 2013

3.1.4 IGCC technology development in India

BHEL pioneered IGCC research in India by setting up a IGCC pilot plant (6.2-MWe) at its R&D Center in Tiruchirapalli (Trichy) in 1985. It included pressurized fluidized bed gasifier and a 4.0-MW Mitsubishi gas turbine using cold-gas clean up. BHEL's also has considerable annual expenses towards IGCC research and development at about 8 crores/year.

The scaling up of the BHEL pilot plant is also planned at Vijaywada Thermal Power Station 125-MW IGCC project along with Andhra Pradesh Generating Company (APGENCO). Separately, NTPC has also proposed building a 100-MW IGCC demonstration plant, with focus on adapting IGCC technology to Indian conditions.

Figure 8 BHEL IGCC development facility at Tiruchirapalli (6.2 MW)
Source: BHEL

3.1.5 CCS technology developments in India

Carbon capture and storage involves separating the CO_2 from flue gas, transporting it to a storage location and injecting it into suitable underground geological formations such as depleted oil and gas fields, un-mineable coal seams and saline water-bearing reservoir rocks. All forms of CCS require careful preparation and monitoring to avoid environmental damage. The CCS is also extremely costly and the technology is also not fully commercialized. The CCS is an emerging technology within Europe but at very early stage in India. Currently, India has annual CO_2 emissions of around 1343 Mt, with about 50% being emitted from large point sources suitable for CO_2 capture. A recent Government of India initiative to develop a total of sixteen Ultra-Mega Power Projects (UMPPs) will add approximately 36,000 MW of installed capacity, with a corresponding increase in CO_2 emissions of approximately 275 Mt per year. Considering India's status as a large emitter of CO_2 it may be worthwhile for India to also explore CO_2 capture and storage as a mitigation option.

3.1.6 Mundra ultra mega power project

New power plant installations in India have started adopting numerous clean coal technologies in India. One recent example is Mundra Ultra Mega Power Project, located in Gujarat state. The plant is India's first and one of the two UMPPs commissioned till date and is part of the government's 2005 'Power for All by 2012' initiative. This project is developed by Tata Power Ltd which is India's largest private sector company in power sector. Mundra power plant contains 800 MW sized supercritical boiler. The plant has an output of 4000 MW (five boilers x 800 MW each).The boilers were supplied byUK based manufacturer Doosan Babcock, the make which is also being used for the supply of many other of India's new supercritical plants. Most notably the seven units at Kudgi, Lara and Raipur. The Mundra project was completed in March 2013. The plant's location near the major Mundra coal port allows it to use an imported high quality coal from Indonesia. Although more expensive than domestic coal, its lower levels of sulphur and ash mean reduced emissions and less space that needs to be allocated for ash disposal facilities. The plant's emissions of greenhouse gases is estimated at 0.75 kg of CO_2 per kWh, compared with the national average of 1.259 kg per kWh for coal based power plants. Mundra power plant also utlizes electro static precipitators to control particulate matter emissions, low NOx burners which reduce NOx emissions by some 35 %, dust control and dust suppression systems and a coal ash storage pond. Mundra Power plant can be considered as the most modern and energy efficient coal-based power plant in India.

Figure 9 Mundra Ultra Mega Power Plant

Source: TATA power

3.2 Key policy initiatives

Some of the important policy initiatives from Government of India are as listed below

- A clean energy tax on imported and domestic coal (set at INR 50 per tonne) was introduced in 2010. Funds raised from this tax go into a National Clean Energy Fund and are invested in the research, development and deployment of clean and renewable energy projects, in particular solar power projects.

- In 2012, the Indian government announced plans to expand its domestic action plan to cut greenhouse gas emissions (the National Action Plan on Climate Change – NAPCC – launched in 2008) by adding a new mission plan on clean coal and clean carbon technology to minimise the large volumes of CO_2 emissions from coal-fired power plants. Initiatives in the mission plan include developing next generation coal-fired power plants using advanced supercritical boilers and integrated gasification combined cycle technologies.

- In order to significantly reduce India's energy shortages in the future, the Ministry of Power launched in 2005-06 an initiative to facilitate the development of UMPPs, each having a capacity of approximately 4000 MW. All UMPPs are required to be developed using supercritical technology with higher thermal efficiencies and less CO_2 emissions. Moreover, all planned UMPPs are required to prepare and submit an environmental impact assessment to the Ministry of Environment and Forests in order to receive environmental clearance.

- India's Twelfth Five Year Plan (2012-2017) highlights the need to invest in R&D of ultra-supercritical (USC) units. It notes that 50 % of the Twelfth Plan target and the coal-based capacity addition in the Thirteenth Five Year Plan would be through super-critical units. The plan highlights coal bed methane as another promoting technology. It notes the difficulties with implementing coal gasification because of the high ash content of Indian coal; hence the efficiency gains would be minimal. Furthermore, it points to the importance of UCG technology as it will enable utilisation of deep coal deposits in the medium term. For that reason, it encourages pilot projects to be undertaken in this field.

- Renovation and modernization (RM) and Life Extension (LE) activities have been given a brief background, like plans, etc, high priority from Indian government due to various advantages such as lower cost and shorter implementation periods compared to new plants. 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. Under 12th plan, RM and LE activities were identified for 72 power plants totaling to 16532 MW.

There are also lot of International Collaborations for technology research, development and demonstration of clean coal technologies (Table 3)[12].

[12] Prospects of coal and CCTs in India, IEA Clean Coal Centre, 2007

Table 3 International Collaborations related to clean coal

Collaboration	Indian Agency	Areas of cooperation
India – IEA Collaboration	Ministry of Power ,BHEL, NTPC	Clean coal R&D, CO_2 capture and storage
US-India Energy Dialogue	NTPC	UCG, CTLFBC, IGCC, CCS, CBM, CCT in general
Asia-Pacific Partnership for Clean Development and Climate (APP-CDC)	International non-treaty agreement designed to accelerate the development and deployment of clean energy technologies	Coal mining, clean coal technologies
USAID-India Greenhouse Gas Pollution Prevention (GEP) Project	Ministry of Power, NTPC, CenPEEP	Power plant Efficiency, Ash utilization
FutureGen	Participation in US-led FutureGen project	Production of Electricity and hydrogen from Coal
Carbon Sequestration Leadership Forum	Ministry of Power, NTPC, NGRI	CO_2 storage in basalt rocks
The Big Sky Carbon Sequestration Partnership	NGRI	CO_2 storage in basalt rock

3.3 Key stakeholders[13]

Indian R&D efforts are rather limited in the CCT field, with BHEL being the only organization with prominent R&D budget. However there are several collaborative efforts that are under way for a number of technologies. I t is essential to streamline and prioritize technology choices for short, medium and long term point of view, which will help in appropriate and environment friendly development of the coal power sector in India.

Table 4 Indian Stakeholders for CCT

Category	Stakeholder
Central government ministries	Ministry of Coal, GoI Ministry of Power, GoI
State and Private Utilities	NTPC, National Thermal Power Corporation TATA Power, Developer of Mundra UMPP Reliance Power, Developer of Sasan UMPP
Power plant equipment suppliers	BHEL, Bharat Heavy Electricals Ltd Thermax Babcock & Wilcox Ltd

[13] Reference: Assessment Report on Cleaner Coal Technology, Clean Energy Research and Deployment Initiative, 2010

Category	Stakeholder
	Thyssenkrupp Industries India Pvt Ltd Alstom Projects India Ltd
CCT R&D organizations	BHEL, Bharat Heavy Electricals Ltd CPRI, Central Power Research Institute CFRI, Central Fuel Research Institute CARD, Centre for Applied Research and Development, Neyveli Lignite Corporation CenPEEP, Centre for Power Efficiency and Environmental Protection IGCAR, Indira Gandhi Centre for Atomic Research CMRI, Central Mining Research Institute
Coal companies	Coal India Ltd. Neyveli Lignite Corporation

4. Techno-economics of clean technologies

4.1 Coal Beneficiation

There are numerous advantages for coal beneficiation as listed below[14]:

1. Increase in power generation – The use of washed and cleaned coal improves efficiency of power generation and can increase generation from existing plants by a minimum of 10% in India.

2. Economic power generation- The mandatory use of cleaner fuel in new power plants and also in refitted older plants would result in lower capital and operating costs per unit generated power, due to lesser fuel handling and more efficient power generation. The use of washed coal would result in considerable savings. For example investment required for 50,000MW increase (as planned during the Eleventh Plan) would be reduced by amount of ~ $6000 million (Rs246,000 million).

3. Better utilized railway transportation capacity –With washed coals, the railways will get an additional 7.5% of net capacity as compared to shipping raw coals to deliver the same energy content to the power plant.

4. Cleaner power generation – The use of cleaned and washed coal could alone bring down the emissions from the existing power plants by about 10%. The combined use of washed coal and CCTs in capacity addition of 50,000MW would be able to reduce carbon emissions by 7.5 million tons per year.

[14] A case for enhanced use of clean coal in India, Zamuda and Sharpe, Workshop on Coal Beneficiation and utilization of rejects, 2007

In the mid 1990's, the price for providing washed coal was approximately $2.5 (Rs 100 at exchange rate of Rs 40/$) per raw ton. The price was calculated to be $ 3.75 inclusive of raw coal and clean coal transportation. In last few years, because of intense competition the same price has been reduced by at least 30%.

4.2 Pulverized Coal Technology[15]

Pulverized coal technology is the oldest and most widely used coal-firing option worldwide and in India. There are different types of plants with different efficiency mainly depending on the steam conditions (pressure and temperature) in the power cycle

Supercritical and Ultra-supercritical systems are new and more efficient technologies with total of ~520 installations worldwide and installation capacity of ~ 300 GW (22% of the total coal capacity) . The country wise distribution of these installations as of 2007 is as follows:

- 155 units, 107 GW capacity(Size from 300 to 1,100MW each) in the United States
- 53 units, 4.268 GW (USC) capacity (Size from 200 to 1,000 MW each) in the Western Europe.
- 108 units, 68 GW capacity (Size from 500 to 1,000 MW) in Japan
- 20 units, 13 GW capacity (Size of 500 and 800 MW) in Republic of Korea
- 250 units (Sizes 300 MW, 500 MW, 800 MW, 1200 MW) in Russia
- 46 units, 30 GW capacity in China

Typically supercritical and ultra-supercritical plants utilize high grade coal, but there are also few plants burning low grade coals. It is to be noted that these low grade coal generally had high moisture and low ash, contrary to typical Indian coal having high ash and low-medium moisture. Only plants in Russia operate on high ash coal with ash ranging from 36 to 72 % (averaging 44 %).

International prices for supercritical and ultra- supercritical plants are found to be comparable. In the last three years, prices of power plant equipment in general (independent of the type of power plant) have increased by up to 25-30 % and they are mostly in the range of $1,300-1,700/kW range. These prices are valid only for the OECD countries though.

Typical prices for power plants in developing country like China are as follows:

- 300 MW subcritical: $630/kW;
- 600 MW supercritical: $540/kW; and
- 1,000 MW USC: $540/kW.

[15] Clean coal power generation technology review: worldwide experience and implications for India, The World Bank background paper, 2008

Prices of power plants in India are observed to be in between OECD and Chinese prices. For example, 500-660 MW plants (without FGD and SCR) are quoted at approximately $1,000/kW. The prices reflect the impacts of both steam conditions and economies of scale (impact of size). Also scope of the services provided in these prices is not completely clear

4.3 Circulating Fluidized Bed Combustion

The circulating fluidized bed (CFB) technology is suitable for power generation using low grade fuels such high-ash fuels, and lignite, brown coals. The typical size for CFB plant is about 100 MW. CFB has been already demonstrated by numerous installations throughout the world (e.g., Australia, China, Czech Republic, Finland, France, Germany, India, Japan, Poland, Republic of Korea, Sweden, Thailand and the United States). Worldwide there are about 600 units operational today totalling to approximately 40 GW of installed capacity. Most of CFB units in operation today have been manufactured by Alstom and Foster Wheeler. However, there are other smaller suppliers, including manufacturers in China, India, Poland and the Republic of Korea.

The main drivers for the utilization of CFB are the technology's ability to use low quality fuels or fuels that are difficult to burn in other types of boilers, the need to reduce SO_2 emissions. The technology also requires relatively simple manufacturing making it suitable for developing countries like India.

4.3.1 Costs of CFB plants

Typically CFB costs are comparable with pulverized coal plants with FGD units, i.e. $ 1,200-1,500/kW.

The capital costs of CFB plants are dependent on fuel properties, percentage of locally manufactured items and site conditions.

4.4 Integrated gasification combined cycle

IGCC (Integrated Gasification Combined Cycle) is very new technology with only four plants operating commercially in USA and Europe. The technology is also very complex and highly costly. It is important to note that there are no large IGCC systems in operation utilizing fluidized bed gasification technology, which is suitable for low-grade Indian coals. There are only few commercial suppliers of IGCC technology available worldwide.

The suppliers using entrained bed gasifier are

- General Electric
- Shell
- ConocoPhillips
- Mitsubishi

Siemens has extensive experience in providing gas turbines for large IGCC plants and recently developed its own gasification technology. Additionally Lurgi (moving bed gasifier) and GTI's U-Gas (fluidized bed gasifier) also have experience in large plants producing syngas and chemicals.

4.4.1 Costs of IGCC

IGCC technology is much more costly than regular coal based power plants. Typically, capital cost requirement for IGCC based power plants are approximately 10 to 30 % higher than similar sized pulverized coal plants. The global cost estimates for IGCC technology wer published by US DOE in mid-2007. The reported cost estimates for pulverized coal plants and IGCC plant of 750 MW size and using bituminous coal as fuel are as follows:

- Subcritical plant: $1,548/kW
- Supercritical plant: $1,574/kW
- IGCC plant: $1,841/kW

4.5 Carbon capture and Storage[16]

Carbon Capture and Storage (CCS) technology is the new and emerging technology for mitigation of CO_2 emissions. It is also known as CO2 sequestration as it consists of capturing CO_2 emissions from single large emission sources (such as power plants) and then storing it permanently and securely. It also involves transportation of CO_2 from power plant location and storage site.

There are various technologies for capturing CO_2 such as chemical absorption, membrane separation, physical adsorption, or cryogenic separation methods. Chemical absorption process is the most developed process but large volumes of absorbents, large equipments and higher costs have limited the applicability of the current technology. Physical processes are based on cryogenic cooling or solid adsorbents.

4.5.1 Capture and storage costs

CO_2 capture is an energy intensive process as it reduces the net power generation from the power plant by ~ 15%. The CO_2 capture and sequestration is also very cost intensive and the typical cost is estimated as $40–80 per tonne CO_2 stored. Considering the energy penalties and capital expenditure, the CCS technology has very high impact on the power generation economics with cost of power generation almost doubled compared to the power plant without CCS.

For CO_2 transportation, pipeline and CO_2 injection costs are estimated as $ 2–8 and $5–20 per tonne respectively. In a conventional coal-based plant the cost and energy penalty for CCS is comparatively higher as the CO_2 is captured from flue gas, comprising of many impurities needing separation. The IGCC technology is found to be more suitable for implementing CCS. In IGCC, the produced syngas is passed through a water shift reactor and converted into CO_2 and H_2. The CO_2 is then separated and can be fixed at the pre-combustion stage itself. This results in reduction the overall cost of CO_2 capture and slight reduction in the

[16] Implementing Clean coal technology in India: Barriers and Prospects, India Infrastructure Report, 2010

energy penalty in power generation. The applicability of CCS technology has remained limited till now due to high overall costs and lack of demonstration and pilot installations.

5. Ways forward

Table 5 and Table 6 present the key priorities and constraints for India and their implications on the clean coal technologies decision making for the future[17].

Table 5 Key priorities for India

Priority	Description	Implication on clean-coal-technologies
Need for rapid growth of economy	• Electricity supply demand gap needs to be reduced to ensure economic growth • Electricity access situation needs to be improved drastically • Poor financial condition of power sector companies	• Commercially matured technologies would be required • Solutions with shorter gestation periods and low capital requirements would be preferable • Affordable and reliable electricity supply is required
Need to improve energy security situation	• Coal is the most dominant part of Indian energy sector • India have considerable coal reserves so coal has strategic importance • Power generation with a mix of fuels and technologies	• Technologies suitable and adaptable to Indian conditions will be required • Technologies with fuel flexibility (especially low grade fuels) preferable • New and evolving technologies need to be explored and monitored
Need to protect local environment	• Coal power plants have high impact on local environment (air, water, land resources). This needs to be minimized	• Technologies with higher efficiency and cleaner power generation will be preferable • Evolving technologies which offer better emission reduction opportunities will need to be monitored
Reduction in emissions to meet the national target 2020	• Coal based power generation accounts for large proportion of emissions. Reduction in these emissions would have significant	• High efficiency and low-cost technologies would be most relevant • Technologies with future target of Zero emissions would be important from long term perspective

17 Cleaner Power in India: Towards Clean Coal Technology Roadmap, Anant Chikattur and Ambuj Sagar, 2007

Table 6 Key constraints for India

Constraint	Description	Implication on clean-coal-technologies
Indigenous coal reserves	• Large proportion of reserves are yet to be proven, which leads to huge uncertainty in terms of availability • Indigenous coal has high ash content and has low calorific value • India is net importer of coal	• Technologies suitable for Indigenous coal would be relevant • Other technologies also have important role considering the uncertainty in Indian coal reserves and high demand of coal
Financial Resources	• Poor financial condition of power companies especially state utilities • Limited funding available for R&D and pilot demonstrations • Low cost power generation important	• Low capital cost technologies preferable • Focussed efforts on only key relevant technologies is essential
Technological capacity	• Only limited R&D efforts have been initiated • Manufacturing and operational experience is also limited	• Focus and investment in R&D needs to be increased • Limited capacities will have higher impact on short-term technology choices • Coherent technology development roadmap is required with better co-ordination between industry-academia-government

5.1 Identification of technologies relevant to India

Considering the priorities and constraints for India, the following technologies have been identified as suitable/ important from Indian perspective

a) Coal beneficiation

b) Pulverized Coal combustion

c) Fluidized Bed Combustion

d) Integrated gasification combined cycle

e) Carbon capture and storage

a) Coal beneficiation

There is a wide spread belief that coal beneficiation would increase the net cost of power generation. It has been now proven with various case studies that coal beneficiation has significant positive impact on the power generation both in terms of economics and reduction in environmental impacts[18]. Some of the documented benefits are as follows[19]:

- Reduction in coal transportation costs
- Increase in overall plant efficiencies
- Reduction in maintenance costs
- Reduction in auxiliary power consumption
- Improved performance of Electro-static precipitator system
- Reduction in emissions per unit power generation
- Reduction in ash deposit formation

b) Pulverized coal combustion: Sub-critical, Super-critical, Ultra-supercritical

Majority of the power generation capacity in India is based on pulverized coal combustion technology. Sub-critical technology is being used since olden days and will continue to be in use even if the new generation capacity is expected to be supercritical and ultrasupercritical technologies. However, the performance and efficiency of these plants would be needed to be improved by various renovation, modernization and/or life extension measures. Subcritical plants have an important role especially in short-term[20].

Supercritical technology is advanced and commercialized alternative for subcritical technology which offers numerous advantages such as

- Much better efficiency in power generation due to higher performance parameters
- Reduction in auxiliary power consumption
- Suitability to various fuels
- Commercialized technology with operational experience available in India
- Number of technology options available internationally

The Ultra-supercritical and Advanced Ultra-supercritical technologies offer further improvements in the performance of the power plant, but the technologies are not yet commercially matured and there is no O&M experience available in India. These technologies are certainly important from medium term perspective.

[18] A Case for Enhanced Use of Clean Coal in India: An Essential Step towards Energy Security and Environmental Protection, Zamuda and Sharpe, Presented at Workshop on Coal Beneficiation and Utilization of Rejects, Ranchi, India, 2007

[19] Potential of Clean Coal Technology in India: An SME perspective, European Business and Technology Centre, 2013

[20] Clean Coal Power Generation Technology Review: Worldwide Experience And Implications For India, Background paper for India: Strategies for Low Carbon Growth, World bank Report, 2008

c) Fluidised-bed Combustion

Fluidised-bed combustion allows power plants greater flexibility in burning a wide range of coals and other low grade fuels. There are numerous installations already in India providing good technical know-how and operating experience for the technology. The key advantages of the technology are[21]

- Flexibility in fuels
- Suitability to biomass co-firing (Carbon-neutral option)
- Low SO2 and NOx emissions
- Low overall cost
- Reliable and matured technology

The main disadvantages of the technology compared to pulverized coal technology is higher solid waste generation and availability of limited size commercial power plant sizes (typically only upto 300 MW). The Circulating Fluidized Bed Combustion (CFBC) technology is more adaptable to high ash Indian coals and is suitable for power generation from the coal washery rejects. The Pressurized Fluidized Bed Combustion (PFBC) technology offers higher efficiency but is not as commercially matured as CFBC.

d) Integrated gasification combined cycle (IGCC)

IGCC is essentially a combined cycle of steam based and the natural-gas-based electricity generation, using coal and natural gas as fuels respectively. The gasification route offers various advantages over combustion route as mentioned below[22]:

- Higher overall efficiency due to combined cycle
- Cleaner power generation due to very low emissions
- Suitability for carbon capture (pre-combustion)
- Possibility of poly-generation i.e. producing various chemical products along with power generation.

However, the technology is not yet commercialized and there are only a few demonstration plants available worldwide. The technology also has some drawbacks which need to be catered during commercialization of the technology[22].

- High technological complexity
- Higher capital costs
- Technology not yet matured/commercialized and there are only few vendors
- Very less work done globally on fluidized bed gasifier based IGCC technology, which is suitable to high ash Indian coals

[21] Existing Gaps and Potential for CCS and CCT areas in the Thermal Power Industry in India, TREC-STEP report

[22] Cleaner Power in India: Towards Clean Coal Technology Roadmap, Anant Chikattur and Ambuj Sagar, 2007

India retains some IGCC research experience, owing to work conducted by BHEL. There have been some proposals for IGCC plants in the country, although progress has been very slow thus far. Jindal Steel and Power Ltd and State-run Rashtriya Chemicals and Fertilizer and Gas Authority of India Ltd are developing first two major coal gasification projects producing grid connected power.

e) Carbon capture and storage

As mentioned earlier in the paper, CCS involves separating the CO_2 from flue gas, transporting it to a storage location and injecting it into suitable underground geological formations, which includes depleted oil and gas fields, un-mineable coal seams and saline water-bearing reservoir rocks. Carbon capture and storage is currently not seen as an immediate priority for the Indian government, although it has shown interest in being involved in research & development (R&D) activities on CCS in order to access global knowledge sharing and technology transfer processes.

Recommendations

It may be seen that clean coal technologies are still evolving and there multiple choices for technologies in various stages of coal life cycle. Considering this, keeping long term options open by not making rigid technology choices will be logical for a developing country like India. In short and medium term, the sector can be pushed forward by implementing policies and regulations to meet following objectives[23].

a) Improvement in the efficiency of the power plants (generating stock, T&D network, and end-use sectors)

b) Implementation of supercritical and ultra-supercritical technology based generation plants

c) Feasibility and suitability assessment for emerging technologies

d) Enforcement and tightening of environmental pollution controls utilizing better pollution control technologies and increased public awareness

5.2 Clean coal technology roadmap for India

The roadmap is presented (Table 5) for the identified technologies considering the short term (~5-10 years), medium term (~15-20 years) and long term (~30-35 years) perspectives[24,25,26,27,28,29,30]. Focus activities are identified for each time frame considering the current status of the technology, both international and Indigenous.

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[23] Cleaner Power in India: Towards Clean Coal Technology Roadmap, Anant Chikattur and Ambuj Sagar, 2007

[24] CLEAN COAL POWER GENERATION TECHNOLOGY REVIEW: WORLDWIDE EXPERIENCE AND IMPLICATIONS FOR INDIA, Background paper for India: Strategies for Low Carbon Growth, World bank Report, 2008

[25] Potential of Clean Coal Technology in India: An SME perspective, European Business and Technology Centre, 2013

[26] Cleaner Power in India: Towards Clean Coal Technology Roadmap, Anant Chikattur and Ambuj Sagar, 2007

[27] CANADA's CLEAN COAL TECHNOLOGY ROADMAP, CANMET ENERGY TECHNOLOGY CENTRE

[28] Implementing Clean coal technology in India: Barriers and Prospects, India Infrastructure Report, 2010

[29] Existing Gaps and Potential for CCS and CCT Areas in the Thermal Power Industry in India, TREC-STEP report

[30] Prospects of coal and clean coal technologies in India, Steven Mills, IEA – Clean Coal Centre report, 2007

5.3 Summary

At global level, the future of clean coal technologies is bright and they will definitely play a key role in global efforts of reduction in environmental impact of power generation. The clean coal technologies offer both: more efficient power generation and cleaner power generation i.e. reduction in GHG emissions per unit of power produced. The recent developments in clean coal technologies have been very encouraging and have increased possibility of reaching "near-zero–emission power generation".

At India level, though Research & development efforts for clean coal technology started quite some time back i.e. more two decades ago. The efforts were sporadic, lacked focus and had no time bound roadmap for the sector. Due to this, developments in India have been much slower than the global efforts. The implementation of a comprehensive roadmap for technology pathways those are relevant to India is now essential for streamlining research efforts and prioritizing technologies considering the limited financial resources. The successful implementation of technology roadmap needs development of coherent policies and strong interlinkages between industry, academia and government bodies. It is also important to note that there is no clear technology winner, as of now, for clean power generation and separate approaches need to be adopted for short, medium term goals and long term targets. But at the same global technology developments need to be monitored closely with international linkages and technology collaborations.

Table 7 Clean coal technology roadmap for India

Sr. No.	Technology	Current status	Short term action points	Medium term action points	Long term action points	Remarks
1	**Coal beneficiation**	• Benefits already demonstrated and proven in India • Very small quantities currently beneficiated	• Implementation of preliminary technologies for washing and cleaning of coal • Technology and know-how transfer	• Development and demonstration of indigenous technologies suitable to Indian coal • Targeting use of considerable proportion of beneficiated coal	• Prioritizing use of beneficiated coal for power generation	• Adequate policy support and incentive will be required for implementation • Detailed assessment of complete life cycle of coal is needed
2	**Pulverized coal combustion**					
	Sub-critical technology	Established technology in India, but inefficient operation compared to world standards	• Refurbishment of efficient component/ sub-systems in existing plants • Increased focus on renovation, modernization & Life Extension activities	• Complete phasing out of old plants	-	• Very important from short term perspective
	Super-critical technology	Worldwide commercialized, few commercial installations in India as well	• Focus on implementation of UMPPs • Technology transfer from foreign expertise • Pilot installations and demonstration of indigenous technologies	• Performance improvements • Suitability to indian coal and co-firing with other low grade fuels • Cost-reduction in technology	-	• Most preferable option for new capacity generation • Implementations need to be facilitated with favourable policies

Sr. No.	Technology	Current status	Short term action points	Medium term action points	Long term action points	Remarks
	Ultra-supercritical technology	Technology in development stage, No installations in India	• Closely monitoring global developments • Pilot installation and demonstration of technology	• Indigenous technology development & demonstration	• Performance improvements • Suitability to Indian coal and co-firing with other low grade fuels	• Technology is still under development globally. So rigid technology choice need not be done in short term
3	**Fluidized Bed Combustion**	• This technology is important assuming SO_2 emission regulations would come in future				
	CFBC	Commercialized technology for smaller scale projects. Available in India	• Adaptation of technology for use of washery rejects • Demonstration of large size plants	• Development of indigenous technology • Performance improvements (supercritical conditions) • Cost-reduction in technology	• Deployment of large size SC-CFBC plants	• Flexibility and suitability towards various indigenous fuels is also important • Suitable to high ash content fuels
	PFBC	Commercially available worldwide. No development in India	• Monitoring of global developments • Feasibility assessment for India	• Pilot plant research and development	-	• Leads to very low NO_x and SO_2 emissions • Suitable to high ash content fuels
4	**IGCC**					
	Entrained Bed Gasifier	Demonstration / commercial plants	• Monitoring of global developments with	• Demonstration of large size poly-generation	• Development of near zero	• suitable to use with imported high-grade

Sr. No.	Technology	Current status	Short term action points	Medium term action points	Long term action points	Remarks
		in U.S., Europe, Japan, China. Most advanced amongst three alternatives	assessment for India • Assessment for poly-generation plant using imported coal	plant •	emission plants along with CCS	coals
	Fluidized Bed Gasifier	Demonstration stage worldwide. Mostly used for chemical production and poly-generation. Preliminary work on-going in India	• Pilot scale installations in India • Assessment for Poly-generation plants using indigenous coal	• Indigenous technology development for large size poly-generation plants • Cost-reduction in technology	• Development of other combined cycles	• suitable to use with low grade Indian coals and other fuels
	Moving/ Fixed Bed	Emerging technology. Only few pilot installations in world	• Monitoring and collaboration with global expertise	• Pilot plant development	• Large scale demonstration in India • Development of other combined cycles	
5	**Carbon capture and storage**	Technology in demonstration stage worldwide	• Detailed assessment of storage mechanisms and feasibility • Detailed assessment of geological storage capacity • Monitoring and collaboration with global expertise	• Pilot plant development in India	• Large scale demonstration in India	• Not very suitable for high ash coals

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