Parivesh

A News Letter from ENVIS Centre - Central Pollution Control Board

Editorial

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Editorial

Among the fossil fuels, coal has acquired the dubious distinction of being the dirtiest one. Such an attribute is on account of environmental damage and pollution problems caused during mining, processing, end use and wastes of coal. Land subsidence in underground mines, ugly scars of land in abandoned open cast mines, emissions of fly ash during combustion of coal and huge quantities of ash generated from boilers of coal based power plants and industrial houses are among the hosts of problems associated with handling and use of coal. Emission of carbon dioxide, an important component of "green house gases" (GHGs) and global warming, is yet another emerging concern linked with burning of coal.

However, inspite of all the odds, coal constitutes a major source for catering to our growing energy needs. With the proper technologies and initiatives for better management, it is possible to reduce the hazards otherwise caused. Through scientific mining practices followed by land reclamation, beneficiation for ash reduction at source, improvement in combustion methods, use of efficient electrostatic precipitators/bag filters for trapping of fly ash emission and effective management of ash including its utilisation for bricks, cement and such other purposes, many of the problems can be prevented and controlled.

With these objectives in view, the Central Pollution Control Board (CPCB) has laid down the environmental guidelines for coal mining activities, prescribed the use of beneficiated coal with lower ash content in power plants and laid down the norms for emissions and effluents from coal combustion systems.

In this Issue of Parivesh, as collated by my colleagues Dr. S. Paliwal, Shri Lalit Kapur and Dr. B. Sengupta, an overview of the present status and possibilities for clean coal initiatives are highlighted.

Dilip Biswas
Chairman,

CPCB

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Clean Coal Initiatives

COAL RESERVES

India with 2.7 percent of the world reserves, ranks sixth in the world in coal resources, occurring in Gondwana and tertiary formations. The Gondwana coals are largely confined to river valleys such as the Damodar (West Bengal and Bihar), Mahanadi (Orissa), and Godavari (Maharashtra and Andhra Pradesh). Coal fields of Assam of Jaintia and Barail series belong to the Tertiary age. The lignite deposits of Jammu and Kashmir, Kerala, Tamil Nadu and Gujarat are also of the Tertiary age. The geographical distribution of coal reserves is shown in Fig. 1.

1.a Distribution of Coal Reserves

Most of the coal reserves in India are concentrated in the peninsular part within 78 to 88 degrees East longitude and 22 to 24 degrees North latitude. As per Geological Survey of India, the estimated coal reserves, down to a depth of 1,200 metre, stood at 208751.5 million tonnes as on 1.1.99. Of these estimated reserves, down to a depth of 1,200 metres, which is considered economically viable are 90 percent of the total reserves. About 83 percent of total resources are non-coking coals and 14 percent belongs to coking coals (Table 1).

Table 1 : Gradewise Reserves of Non-Coking Coal (billion tonnes)

S. No.	**Name of major Coal fields**	**Superior Grade (A+B+C) (5800 Kcal/Kg)**	**Intermediate Grade (D) (5000 Kcal/Kg)**	**Inferior Grade (E+F+G) (4000 Kcal/Kg)**
1.	Raniganj & Mugma	9.76	3.10	4.50
2.	Rajmahal	0.46	1.71	8.24
3.	Jharia	0.19	0.44	5.47
4.	East Bokaro	0.02	0.02	0.02
5.	West Bokaro	0.01	0.04	0.12
6.	Ramgarh	-	0.02	0.02
7.	South Karanpura	1.06	1.08	2.43
8.	North Karanpura	0.68	1.23	8.31

9.	Singrauli	1.21	1.52	6.48
10.	Pathakhera	0.07	0.10	0.19
11.	Pench-Kanhan	0.64	0.32	0.45
12.	Umrer	-	-	0.09
13.	Kamptee-Silewara	0.43	0.33	0.61
14.	Wardha Valley	0.35	1.55	2.31
15.	CIC	1.71	0.29	0.29
16.	Korba	0.72	0.44	6.86
17.	Talcher	0.95	0.65	21.91
18.	Ib-Valley	0.56	2.45	17.75
19.	North Eastern	0.83	-	-
20.	Godavari Valley	2.07	2.36	4.63
21.	Other Minor Coalfields	2.05	1.95	16.00
TOTAL (billion tonnes)		**23.80**	**19.60**	**106.76**
Percent(%)		**(16)**	**(13)**	**(710)**

Besides being a major source of energy generation, coal is also utilised as feedstock for a variety of products as shown in the schematic diagram on coal utilisation (Fig. 2).

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COAL PRODUCTION & DEMAND

Coal production in India sharply increased from 30 million tonnes in 1940 to over 290 million tonnes in 1998-99. Now, India ranks 3rd amongst the coal producing countries in the World. Future demand of coal for major industrial uses is given in Table 2.

Table 2 : Coal Demand Forecast (Million tonnes)

Sector	Estimated Coal Demand			
	1996-97*	**2001-2002**	**2006-2007**	**2009-2010**
Power	199	285	400	500
Steel	25.53	49	60	68
Consent	11.34	21	30	37
Others	50.57	61	75	85
Total	286.46	416	565	690

* Actual Coal supplied.

About 70 percent of total production is used by the power generation sector while steel and cement are also among the major consumers (Table 3).

Table 3 : Consumption of coal in power sector

Year	Coal consumption (million tonnes)	Electricity installed capacity (MW)
1995-96	184.52	58675
1996-97	199.00	60,000
1997-98	212.92	63038
1998-99	208	67000

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COAL MINING PRACTICES

India's total land area is 3.29 million sq. km and within this only 0.45% area (about 16,000 sq. km) is coal bearing. Out of this coal bearing area, active coal mining area is about 2500 sq. km. Maximum land degradation in coal mining is caused by open-cast mining and it is currently confined to 20% of the coal bearing land. Additional areas that could be used for open-cast mining would be around 5 to 10% of the coal bearing land. Thus, the area where land degradation has taken place and is likely to take place is around 0.2% of the land mass.

Underground production of coal peaked in the late seventies and has fallen slowly since then. Surface mining, on the other hand, has soared from16 to 160 million tonnes per annum. Of the 588 mines in India, 355 are under-ground, but opencast accounts for 75 percent of production and employs only 16 percent of the total mining work force. Productivity is higher in the opencast sector. However, the pace of growth cannot be sustained for long, as stripping ratios will increase and mining operations run into land access and other environmental problems. Underground mining is largely a 'board and pillar' operation. Longwall was introduced in 1978 and by 1993, 20 longwall units were installed.

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COAL QUALITY

The quality of Indian coal is mainly attributed to its origin. Due to drift origin of Indian coal, inorganic impurities are intimately mixed in the coal matrix, resulting in difficult beneficiation characteristics. Over 200 million tonnes of coal reach the consumers with ash content averaging 40 percent. Based on ash content, gross calorific value and useful heat value, Indian coal is classified in six categories as given in Table 4.

Table 4 : Grading and Quality of coal

Grade	(Ash + Moisture %) Approx.	Useful heat value(UHV) (Kcal./Kg)
A	19.5 or less	Above 6200
B	24-19.5	5600-6200
C	28.7-24	4940-5600
D	34-28.7	4200-4940
E	40-34	3360-4200
F	47-40	2400-3360
G	55-47	1300-2400

Sulphur content in Indian coal is generally less than 0.6 percent and the Chlorine content is less than 0.1 percent. Mercury in coal ranges from 0.01 to 1.1 ppm in Indian coals against upto 20 ppm in Russian coals, 0.2 to 2.0 ppm in Belgium coals, 0.03 to 1.3 ppm in Canadian coals and 0.01 to 2.0 ppm in American coals. (Source : Mishra et.al.(1997) "Clean coal technolgy – Indian context"; Indo-European Seminar on Clean coal technology, New Delhi)

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CLEAN COAL COMBUSTION TECHNOLOGIES

Steam turbines can run on a variety of fuels but coal continues to remain a popular choice. However, the traditional coal-fired plants suffer from two major drawback: overall efficiency levels are low and pollution levels are high.

Growing environmental concerns and the need to improve conversion efficiency levels have led to the development of clean coal technologies. The most popular of these technologies are Fluidised Bed Combustion (FBC), Pressurised Fluidised Bed Combustion Combined Cycle (PFBC) and Integrated Gasification Combined Cycle (IGCC).

Improvement in overall performance of steam turbines for thermal power plants can be brought about largely through two kinds of advancement. Firstly,through improvement in mechanical efficiency by reducing aerodynamic and leakage losses as the steam expands through the turbine. Secondly, through improvement in thermodynamic efficiency by increasing the temperature and pressure at which heat is added to the power cycle.

Supercritical Technology

The steam temperature can be raised to levels as high as 580 to 600° C and pressure over 300 bar. Under these conditions, water enters a phase called "supercritical" with properties in between those of liquid and gas. This supercritical water can dissolve a variety of organic compounds and gases, and when hydrogen per-oxide and liquid oxygen are added, combustion is triggered. Turbines based on this principle are called Supercritical Turbines. These turbines offer outputs of over 500 MW. Some manufacturers are planning to commission steam turbines of 800-1,000 MW output in the next few years.

The supercritical turbines can burn low grade fossil fuels and can completely stop Oxides of Nitrogen (NOx) emissions and keep emissions of sulphur dioxide to a minimum. For example, lignite or brown coal has a high water content. So, it is normally not used for power generation. Yet, when lignite is added to water that has been heated to 600° C at a pressure of 300 bar, it will completely burn up in one minute while emitting no NOx and only 1 percent of its original sulphur content as SOx. This also eliminates the need for desulphurisation and denitrification equipment and soot collectors. Although large amounts of energy are required to create supercritical water, operating costs could be significantly different from existing power generating facilities because there would be no need to control gas emissions. The demand for cooling water is also reduced, almost proportionally to an increase in the efficiency.

Currently, supercritical power plants reach thermal efficiencies of just over 40 percent, although a few of the more plants have attained high efficiency upto 45 percent. A number of steam generator and turbine manufacturers around the world now claim that steam temperatures upto 700° C ("ultra" supercritical conditions) are possible which might raise plant efficiencies to over 50 percent, but by using expensive nickel-based alloys. Because supercritical water is corrosive, expensive nickel alloys must be used for the reaction equipment and power generators.

The main competition to supercritical system is from new gas turbine combined cycle plants which are now expedited to achieve an overall efficiency of 60 percent, making a huge difference in generating and life-cycle costs. However, the new gas turbines will release exhaust into waste heat recovery steam generator at temperatures above 600° C, thus necessitating the use of the high chromium steel and nickel alloys as used in the supercritical coal-fired plants.

The economic benefits of taking steam temperature above 635° C, the costs of nickel-based alloys are yet to be resolved. 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. In addition, increased pressure leads to a loss of thermal flexibility and this can also increase costs.

Fluidised Bed Combustion

During the seventies and also in eighties,, it appeared that conventional pulverised coal-fired power plants had reached a plateau in terms of thermal efficiency. The efficiency levels achieved were of the order of 40 percent in the US and the UK.The corresponding figures for India, however, were lower at 36 to 37 percent.

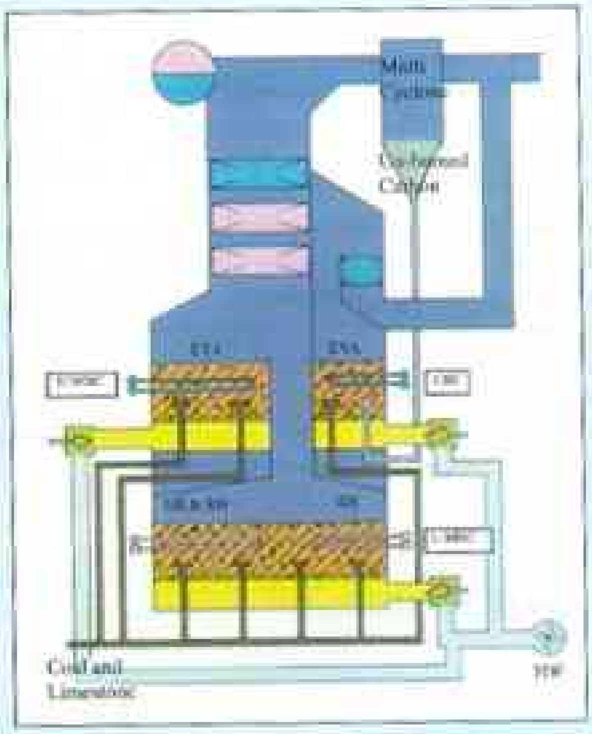
An alternative technology, Fluidised Bed Combustion (FBC), was developed to raise the efficiency levels. In this technology, high pressure air is blown through finely ground coal. The particles become entrained in the air and form a floating or fluidised bed. This bed behaves like a fluid in which the constituent particles move to and fro and collide with one another.

Fluidised bed can burn a variety of fuels-coal as well other non-conventional fuels like biomass, petro-coke, coal cleaning waste and wood. This bed contains only around 5 percent coal or fuel. The rest of the bed is primarily an inert material such as ash or sand.

THEORY OF FLUIDIZED BED COMBUSTION

When air is supplied at the bottom of furnace in the range of a certain speed through Bed Material (BM), for which we select limestone of 1 to 3mm dia., BM gets floating and bubbling in the air. This phenomenon is called "Fluidized Bed".

When crushed coal of 10mm dia. or smaller at this unit is fed while the fluidized bed is heated up to the coal ignition temperature of around 450 degC, it begins to burn by itself. The fluidized bed temperature of Main Bed Cell [MBC] is controlled between 760 and 860 degC in a normal operation and coal is slowly burnt in the fluidized bed. Un-burned carbon is collected by Multi Cyclone [MC] at the MBC-outlet to be burnt again in Carbon Burn-up Cell [CBC] for the improvement of combustion efficiency.



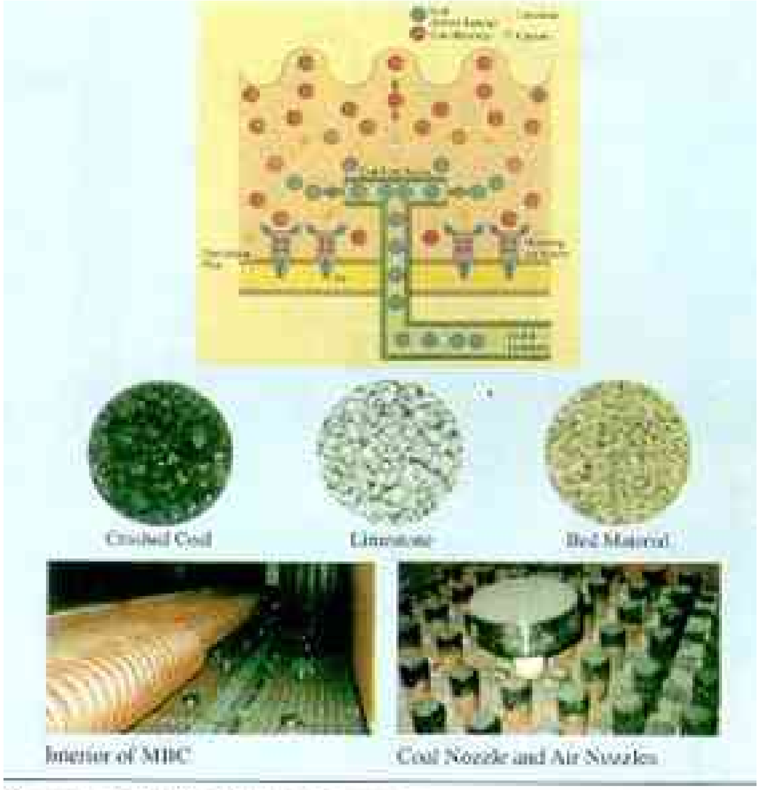
Since boiler tubes are arranged in the fluidized bed, heat transfer to water and/or steam can efficiently be made. Low SO_x emission can be achieved by in-furnace de-sulpherization owing to the bed material of limestone and furthermore, lower combustion temperature enables and ensures low NO_x emission.

MAIN SPECIFICATIONS OF A-FBC BOILER

	Specifications
Rating	[illegible] (MCR)
SH steam pressure	[illegible]
SH steam temperature	[illegible]
RH steam temperature	[illegible]
Ca/S molar ratio	[illegible]
Combustion temp.	MBC: 760 to 860°C CBC: [illegible]

	Specifications	
Superficial velocity	U-MBC	[illegible]
	L-MBC	[illegible]
	CBC	[illegible]
Number of cells	U-MBC	[illegible]
	L-MBC	[illegible]
	CBC	[illegible]
Number of coal feed nozzles	U-MBC	[illegible]
	L-MBC	[illegible]
	CBC	[illegible]
Number of un-burned carbon feed nozzles	CBC	[illegible]

The temperature in FBC is around 800-900° C compared with 1,300-1,500° C in Pulverised Coal Combution (PCC). Low temperature helps minimise the production of NO_x. With the addition of a sorbent into the 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. The capital costs could be 8-15 percent lower.



Concept of Fluidised Bed Combustion

FBCs are essentially of two types bubbling and circu-lating. While bubbling beds have low fluidisation veloci-ties to prevent solids from being elutraited, circulating beds employ high velocities to actually promote elutriation. Both these tech-nologies operate on atmos-pheric 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.

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.

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.

Circulating Fluidised Bed Combustion (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 feedstocks in CFBC due to the low operating temperature of 850-900° C. CFBC boiler is not bound by the tight restrictions on ash content either. It can effectively burn fuels with ash content upto 70 percent (Fig. 7).

CFBC can successfully burn agricultural wastes, urban waste, wood, bio-mass, etc which are the low melting temperature as fuels. 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 the staged-combustion about 90 percent of fuel-bound nitrogen is converted to elemental nitrogen (N_2) as main product.

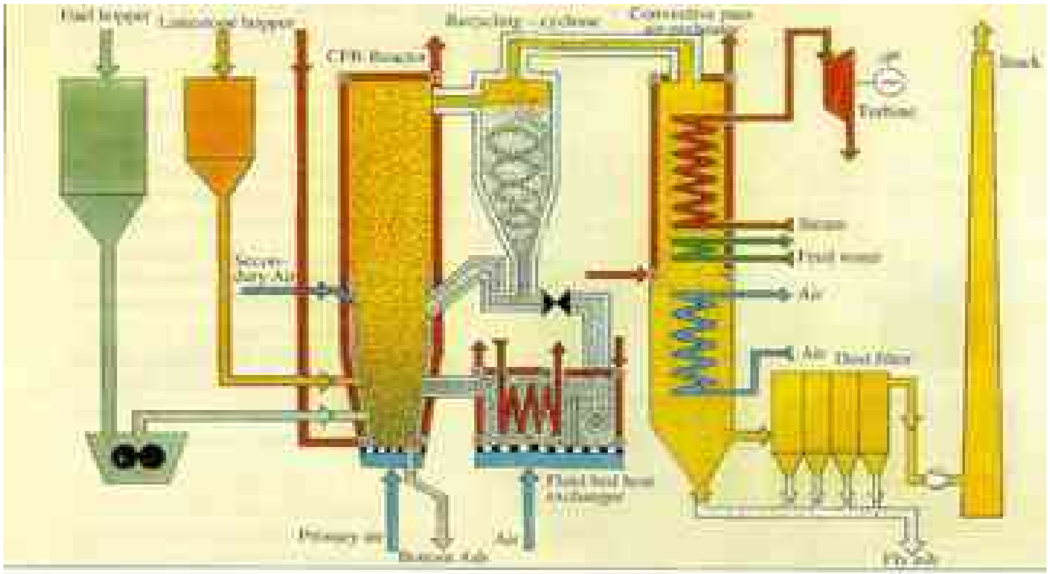


Fig. 7 Flow Diagram of Circulating Fluidised Bed Power Station

Status of development of technology in India and World

In India, Bharat Heavy Electricals Limited (BHEL) has developed bubbling fluid bed boilers upto capacity rating of 150 tonne per hour for high ash coals and washery rejects. For units of capacity higher than 30 MW, circulating fluidised bed combustion (CFBC) technology is more economical for high ash coals and / or high sulfur coals. For higher capacity CFBC boilers, BHEL has entered into a technical collaboration agreement with M/s Lurgi Babcock Energy Technik, Germany to make boilers upto 200 MW. BHEL is currently executing an order for two units of Lignite fired CFBC boilers of 125 MWe each (390 tph steam flow) in Gujarat and has commissioned one coal fired unit of 30 MWe (175 tph) capacity in Maharashtra in 1996.

The first CFBC power plant of 110 MW at Nuclu. Colorado, USA is operating since 1990. Several such CFBC power plants are operating in Germany, UK, Canada and Japan using various kinds of coal and bio-mass fuels. The largest CFBC power plant is the 250 MWe unit in Gardane, France, commissioned in 1996. Presently, 350 MWe units are being constructed in Canada and Japan. CFBC is a mature technology with more than 300 CFBC boilers in operation world wide ranging from 5 MWe to 250 MWe. With line stone addition, 90 percent of the sulfur emission can be retained. With staged combustion and with relatively low combustion temperature of 850 / 900° C, NO_2 formation is about 300 to 400 mg/Nm^3 only against 500 to 1000 mg/Nm^3 in conventional PF fired boilers.

Pressurised Fluidised Bed Combustion Combined Cycle (PFBC)

A new type of fluidised bed design, the pressurised bed, was developed in the late eighties 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 exhaust gas from the gas turbine is utilised in the downstream steam turbine. This technology is called pressurised fluidised bed combustion combined cycle (PFBC) (Fig. 8).

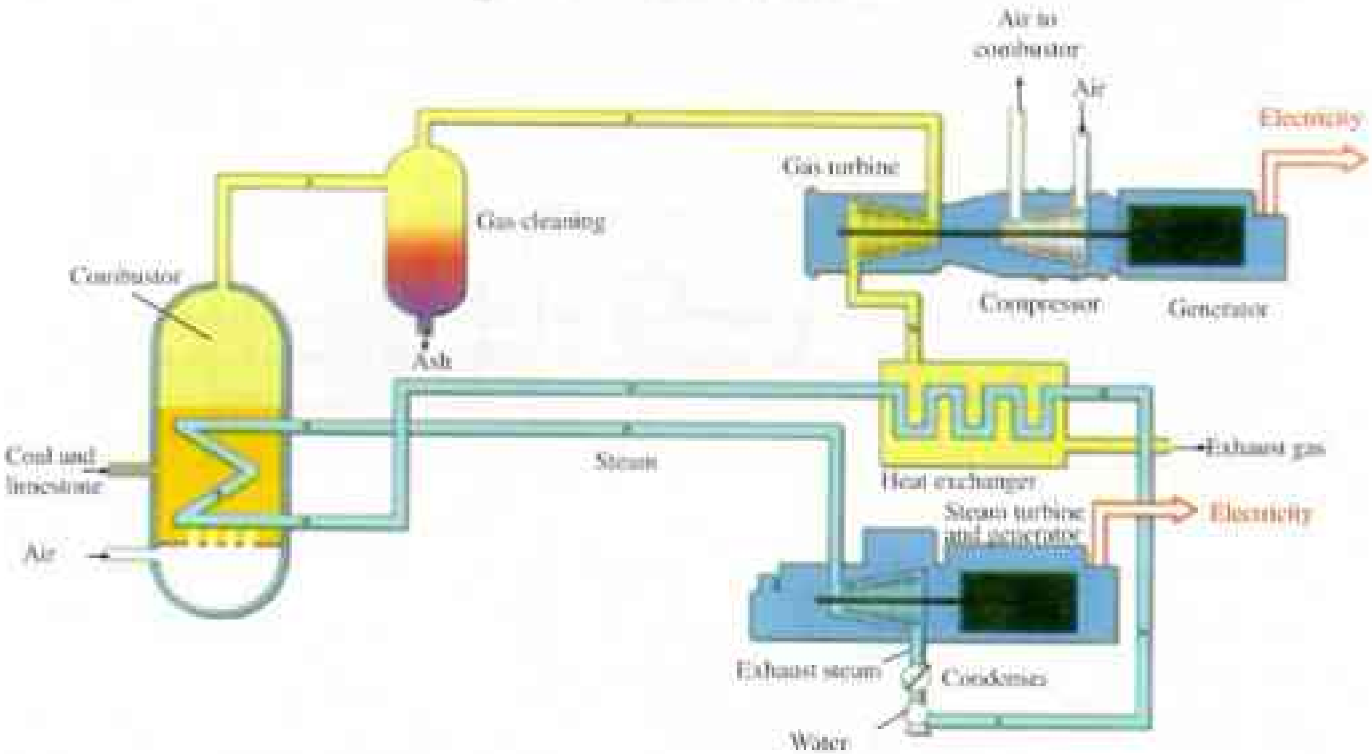


Fig. 8 Pressurised Fluidised Bed Combined Cycle
Source : Coal power for progress (4th edition) World Coal Institute

The bed is operated at a pressure of between 5 bar and 20 bar and 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 upto 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.

PFBC plants are smaller in size than the atmospheric FBC and PCC plants and therefore have the advantage of siting 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 hog 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.

Status of PFBC Technology Development

The first demonstration plant of capacity of 130 MWe (+224 MW, co-generation) has been operating in Stockholm, Sweden since 1991 meeting all the stringent environmental conditions. Another demonstration plant of 80 MWe capacity is operating in Escatron, Spain using 36% ash black lignite. The third demonstration plant of 70 MWe at TIDD station, OHIO, USA was shut down in 1994 after a eight year demonstration period in which a large amount of useful data and experience were obtained. A 70 MWe demo plant has been operated at Wakamatsu from 1993 to 1996.

Presently, a 350 MWe PFBC power plant is planned in Japan and another is on order in USA (to be operated at SPORN). UK has gathered a large amount of data on a 80 MWe PFBC plant in Grimethrope during its operation from 1980-1992 and is now offering commercial PFBC plants and developing second generation PFBC. ABB-Sweden is the leading international manufacturer which has supplied the first three demonstration plants in the world and is now offering 300 MWe units plants. In India, BHEL-Hyderabad has been operating a 400 mm PFBC for the last eight years and has collected useful research data. IIT Madras has a 300 mm diameter research facility built with NSF (USA) grant. A proposal by BHEL for a 60 MWe PFBC plant is under consideration with the Government of India.

Integrated Gassification Combined Cycle (IGCC)

The integrated gassification combined cycle is a process in which the fuel is gasified in an oxygen or air-blown gasifier operating at high pressure. 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.

Often, IGCC is referred to as "Cool Water" technology, a name drawn from the ranch in California's Mojave Desert that once occupied the site where it was developed. Coal all shorts burns so well with the Cool Water technology - upto 99 percent of sulphur contamination is eliminated.

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
- Steam turbine generator

The feedstock which is fed into the gasifier is more or less completely gasified to synthesis gas (syngas) 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 (Fig. 9)

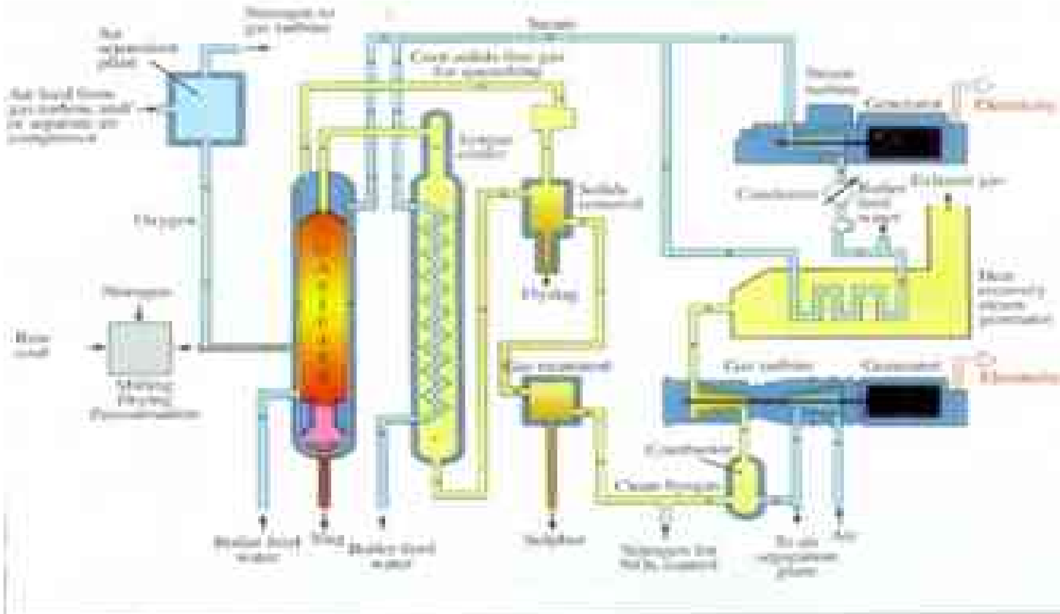


Fig. 9 Integrated Gasification Combined Cycle
Source : Coal power for progress (4th edition) World Coal Institute

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 syngas with nitrogen from air separation unit and by saturation with water. The direct removal of sulphur compounds from the syngas results in the effective recovery of elemental sulphur, yielding a saleable raw chemical product. Gasification and gas cleaning are an extremely effective filter for contaminants harmful to both gas turbines as well as environment. The IGCC technology is not only environment friendly, but also efficient in power generation (upto 50 percent).

However, IGCC is 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 will 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.

The use of gasification for 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. 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 8.

Table 8 : Merits of Advanced coal combustion systems

Parameters	Conventional pulverised fired	Super critical pulverised fired	PFBC /CFBC	IGCC	Hybrid Cycle (Gassification 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 MW_e)	All commercial sizes available	Upto 350 mw sizes available	250-300 MW_e, currently limited by the size of large gas turbine units available	Demonstration plant proposed at around 90 MW_e
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
Environmental Performance CO_2 (g/KWH)	830	- -	810 585	460 150	-

SO_2 (mg/KWH NO_x (mg/KWH)	600 600	-	585	300	- -
Availability	Proven to be excellent	Proven to be good	Limited experience	Demonstration so far not satisfactory	Not yet demonstrated

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COAL BED METHANE (CBM) RECOVERY

It is well known that coal is framed due to bio conversion of fossilised organic matter, In the process of coal formation, anaerobic conditions led to generation and trapping of methane in this 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 (microporosity). Microporosity 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.

The existence of gas in coal has been known for many decades. It is only in the last decade and a half that this gas has emerged as a viable energy source with coal as both source and reservoir rocks. In USA, the CBM exploration was first initiated and an energy resource has also been recognized. By 1995, USA has produced about 2.5 Bcfd (billion cubic feet per day) of CBM from 9000 wells, which is about 5 percent of the total gas consumption of USA. In CBM exploration, China is emerging as a major player and Australia is on the threshold of commercial production.

The generation of methane gas results from high temperature and pressure due to continuous burial. During the transformation process, coal becomes rich in carbon and large amount of fluid matter is released like methane, carbon dioxide and water. Such generation of fluid is significant in bituminous and higher rank coal with maximum yield of 150-200 cm^3 per gram of coal. Indian's coals have gas content values ranging from 1 to $23 m^3$/tonne.

In India, the Reliance Gas has carried out comprehensive geologic assessment of coal/lignite basins based on which about 20,000 km^2 of area has been identified as prospective for CBM with estimated in place resource of about 2000 billion cubic metres. The recoverable reserve of about 800 billion cubic metres and gas production potential of about 105 million metre cum per day over a period of 20 years has been estimated. CBM potential is thus about 1.5 times the present natural gas production in India, which is capable of generating about 19000 MW of electricity. The potential of gas production in India is given in Table 9.

Table 9 : CBM production potential in India

CBM Prospects	**Ref. No.**	**CBM production Potential**	**Energy Equivalent**	
Basin/Area		**(million cubic metres/day)**	**Power Gen. (MW)**	**LNG (MMtpa)**
Cambay Basin				
North Gujarat	15	30	5500	7.50

Barmer Basin				
South Rajasthan	16	19	3500	4.75
Damodar Basin				
Raniganj	3	12	2200	3.00
Jharia	4	3.5	650	1.00
East Bokaro	5	2.5	450	0.60
North Karanpura	6	6.0	1100	1.50
Rajmahal Basin				
Rajmahal	1	4.5	800	1.20
Birbhum	2	6.0	1100	1.50
Others				
Singrauli	7	1.0	180	0.25
Sohagpur	8	4.0	720	1.00
Satpura	9	1.5	270	0.40
Ib-River	10	5.0	900	1.25
Talchir	11	2.5	450	0.60
Wardha Valley	12	1.5	270	0.40
Godavari Valley	13	4.0	720	1.00
Gauvery Basin	14	2.5	450	0.60
All India	1-16	105.5	19260	26.55

(Source : Coalbed Methane : A Survey by Reliance Gas (P) Limited)

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Clean Coal Initiatives

POST COMBUSTION TECHNOLOGY

NOx Abatement from Thermal Power Plants

In the case of coal-fired thermal power plants in India, the focus at present is on control of particulate emissions. However, it is expected that increasingly stringent norms on invisible and harmful NOx emissions will require catalytic control technologies. In view of this, the indigenous technology for 'Selective Catalytic Reduction' adaptable to both low and high levels of NOx emissions developed by ACC's R&D Division at Thane, is a significant step. A patent application has been filed in India on the technology.

The National Thermal Power Corporation (NTPC) participated in the technology demonstration and joined the TIFAC expert committee for the project by providing their facilities and support at the Badarpur Thermal Power Station, near Delhi (Fig. 10).

Fig.10, Demonstration of NOx Reduction System Development by ACC
at Badarpur Power Station

The pilot plant systems have been conceived, designed, installed and commissioned by the team of R&D engineers within ACC and involved significant innovations. Some difficulties encountered in curing the extruded catalyst section have been successfully overcome. The team observed the performance of the catalyst using 100 litres of catalyst with sample flue gas tapped from a chimney at the Badapur Thermal Power Station. The analysis has been carried out using two separate analysers, one at the inlet to the catalyst and the other at the outlet (which was also monitored for oxygen and ammonia slippage). The technology has given excellent results of >95% NOx reduction.

In the earlier phase of the project, the technology demonstration was carried out at the Caprolactum Plant of FACT (The Fertilizers & Chemicals Travancore Ltd.), Kochi (bench scale level of Catalyst volume 4 litres).

SELECTIVE CATALYTIC REDUCTION (SCR) TECHNOLOGY

SCR technology was initially developed in Japan during the late seventies as a post combustion NOx control technique. The technique is preferred as the Best Available Control Technology (BACT) 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 $3\ N_2 + 6\ H_2O$

A mixed metal oxide system, primarily containing titania-vanadia along with promoters is used as the SCR catalyst. At ACC, the indigenously available titanium dioxide has been suitably modified to yield the high surface area titania which is the catalyst support. This can be cites as high technology application of the indigenous titania extracted from the rich deposits of Indian Institute. The formulation extruded into honeycomb monoliths offers minimum pressure drop to the large volumes of flue gas in the operating systems. Special binders, plasticizers and extrusion aids have been identified and used in the extrusion technology.

Under Home Grown Technology (HGT) of Technology, Information, Forecasting and Assessment Council (TIFAC), the technology for manufacture of honey-comb catalyst has been scaled up to semi-commercial levels of operation using a high vacuum, high-pressure extruder procured from Germany. The complex dies used for the honeycomb extrusion are designed and fabricated locally. Cell configurations developed vary from 12 cells per square inch for use in high dust atmospheres to 60 cells per square inch for use in dust-free stack gases. The catalyst development is a result of the interactive efforts of scientists from the disciplines of catalysis, ceramics and chemical engineering.

RESULTS OF THE PILOT PLANT TRIALS

In pilot plant trials, the performance of the catalyst has been monitored over several weeks and no deactivation is observed. At optimized conditions of operation, the performance obtained is given in the table in the next column:

Biotechnology has been identified the world over as the discipline that can make the most significant contributions towards the future development of sustainable solutions. Essentially, biotechnology involves the conversion of biological wealth, through biological tools into bio-products. It is crucial to recognise both the need for and the significance of indigenous technologies in view of the fact that such climatic conditions as temperatures, humidity, dust, etc. have a profound effect on biological processes.

Despite the imminent need for indigenous technologies, it has been seen that a large number of indigenously developed techniques are abandoned at the laboratory stage, for want of the funds that are required to transform the technique into technology.

Operating conditions

Linear velocity (Nm/s) 2.4

Space velocity (h^{-1}) 5,000

Temperature (° C) 350

NH_3/NOx ratio 1.0

Catalyst performance

Total NOx in outlet (ppm) <15

NH_3 slippage (ppm) <10

DENSE PHASE COAL ASH SLURRY DISPOSAL SYSTEM

The disposal of bottom ash and fly ash from thermal power station in the form of high concentration slurries has been demonstrated to have significant advantages over disposal with traditional lean phase slurry or dry placement methods. These advantages include fully contained, dust free handling, high tonnage per disposal hectare, dense deposit and a low life cycle cost per tonne of material handled.

AUSTA energy, an Institute under Queensland Electricity Commission, Australia first demonstrated High Concentration Slurry Disposal (HCSD) Technology at Stanwell Power Station in the year 1992. With the increase of flyash concentrations in the transport water, the amount of free water i.e. the water released from the body ofthe flyash decreases rapidly as shown in Fig. 11.

Fig. 11 Slurry and Free Water Volumes per Dry Tonne of Fly Ash

For solid concentrations in the range of 60 to 75 percent by mass the amount of free water is less than 10 percent of the transport water. The slurry behaves like non-Newtonian fluid with the flow in the deposit area being self limited. The settling of the flyash occurs as a uniform mass which result in a high density deposit over a limited area, thus making large deposits possible in a small units. The operational advantages of HCSD technology are:

- No free water at discharge
- No Ash Dam Required
- Use of Existing Ash Dams and Retro-fit Situations
- Self Distribution of Slurry
- In-Situ Deposit Density
- In-Situ Permeability
- Deposit Drying

- No Generation of Fugitive Dust

The specific energy consumption compared to lean phase and dry disposal systems for a 2x350 MW Station, transporting 445,000 tonnes per annum of ash over a distance of 1400 m, is shown in Fig. 12.

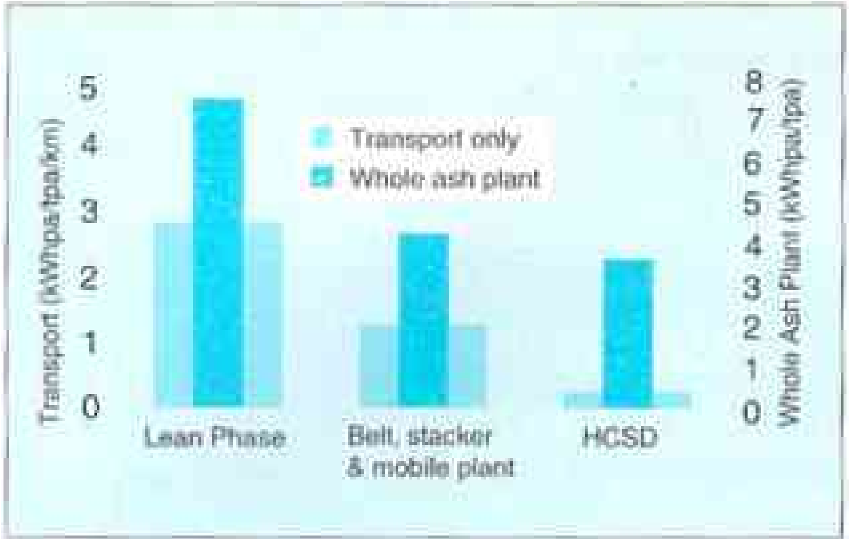

Fig. 12 Specific Power Consumption

The cost comparison between HCSD and other options are given in the following table.

	Lean Phase System	Conveyor / Mobile Plant Placement System	HCSD
Cost per tonne disposed of Ash	$8.05	$4.51	$2.80

Note : Costs are for whole of life ownership and are expressed in 1995 Australian dollars. These include mechanical plant, electrical plant and control systems, capitalised over a 25 year operating life, on a net present value basis.

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Clean Coal Initiatives

ISSUES AND ACTION POINTS AT A GLANCE

Some of the salient issues and action points relating coal and environment interface in India as highlighted by Dilip Biswas, Chairman, Central Pollution Control Board (CPCB) in his presentation in the Clean Coal Initiatives Roundtable, World Bank, Washington DC in June, 1996 are reproduced as follows:

COAL MINING SCENARIO

- Share of opencast (surface) mining increasing. In 1995-96, out of 270 mt., 196 mt. (74%) coal came from opencast mines.
- Major part of growth in demand in the past two decades was for thermal coal. India has large reserves of 40-45% ash coal, in shallow & thick coal seams, amenable to opencast mining. Current stripping ratio is around 2 cum per ton of coal.

MAJOR ENVIRONMENTAL ISSUES IN COAL MINING IN INDIA

- LAND DEGRADATION. Coal mines cover a total land area of 140,771 hectares (ha). During next 5 years, 57,000 ha. additional land is needed, of which forest land is 13,000 ha.
- AIR POLLUTION. SPM levels in the older coal mining areas of Jharia and Raniganj has increased 6 fold during the last 50 years due to mining and associated industrial activities.
- Fires caused by indiscriminate mining in the past 100 years, affecting the Jharia coalfield, containing major Coking Coal reserves.
- WATER POLLUTION. Mainly caused by the effluent discharge from old coal preparation plants set up along the banks of Damodar river. The water pumped out of the mines is not a significant source of pollution.

Coal Transportation

- Steep increase in coal transportation. beyond 1000 Km.

Distance 1993-94 2006-07 2009-10

Pit head 61 128 155

<500 Km 39 55 70

500-1000 km 22 47 60

> 1000 Km 43 170 215

(All figures in million tonne).

Issues in Transportation

- Wasteful use of Rail Infrastructure in transporting high ash coal.
- Coal routes are saturated or reaching saturation.
- Innovative measures like, Engine on load system, own your wagon scheme and unit train operation.
- Augmentation of rail transport will depend on commensurate investment.

Need for beneficiation

2001-02

Reduction of tonnage (mt) 11

Saving in transport cost (Usm$) 240

Saving in diesel consumption (KI) 63,750

Reduction in bottom ash (mt) 2

Reduction in fly ash (mt) 8

Reduction in CO_2 (mt) 23

COAL BENEFICIATION STATUS

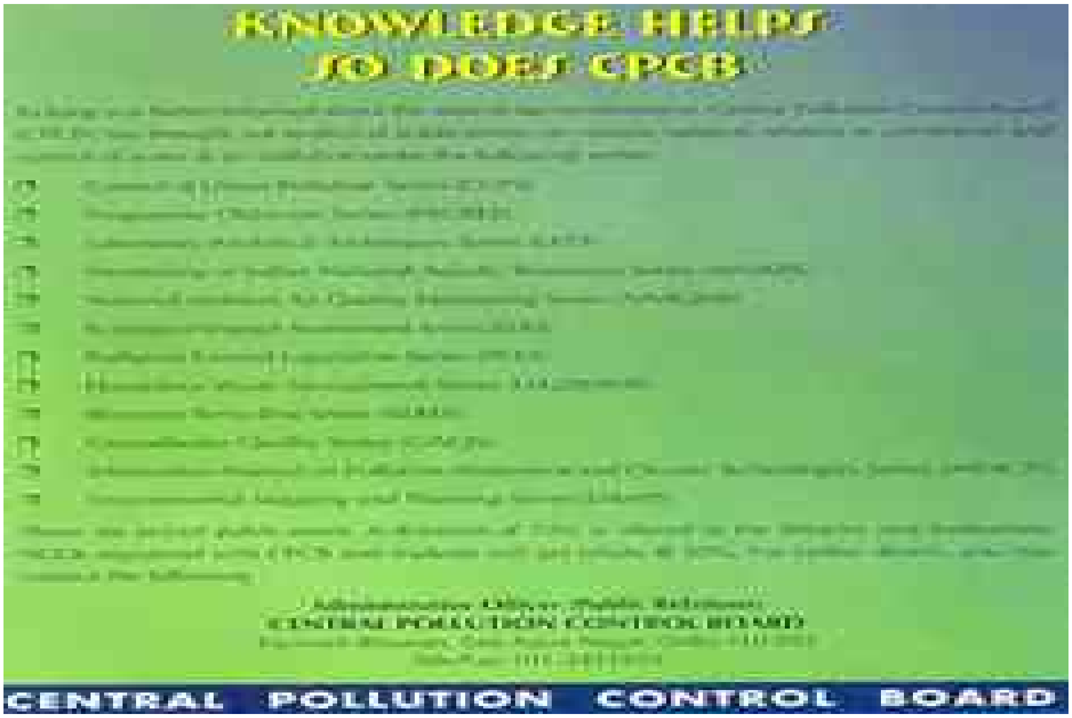
- Only cooking coals are washed now.
- Several proposals are ready for setting up washeries for non cooking coals in Talcher, Korba and North Karanpura coalfields. A pilot plant at Bina opencast pithead in Singrauli coalfield is nearing completion.
- Washability studies indicate reduction of ash level in raw coal from about 41-45% to 30-32% depending on coal quality and distance of transportation.

ENVIRONMENTAL ISSUES IN NON COKING COAL BENEFICIATION

- Disposal of ash at the power plants vis-à-vis disposal of rejects from the pit head washeries.
- Pit head power generation and transmission of electrical energy at high voltage through a national grid.
- Cost and time for augmenting rail and coastal shipping transportation capacity, in case pit head generation option is rejected.

OPTIONS

- Setting up of large pit head power stations.
- Use of beneficiated coal in distant power stations.
- Import of coal for coastal power plants.
- Renovation and modernisation of old plants.
- Adoption of clean combustion technologies.



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