Coal Beneficiation In India

Status and Way Forward

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New Delhi

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1 Executive Summary

- Government policy that power plants of capacity of 100 Megawatt (MW) or above, located between 500-749 km from the pit head, must be supplied with raw or blended or beneficiated coal with ash content not exceeding 34 percent on quarterly average basis from June 2016, assigns responsibility of meeting the target ash content on the coal supplier. This is a significant change that will facilitate supply and use of beneficiated coal. However, the policy is anchored primarily on environmental considerations; it will have to be balanced with economic considerations to have greater impact.

- Coal beneficiation being a physical process, an ideal separation between burnable (coal) and 'un-burnable' material (rejects) does not take place, as ash is inherent in Indian coal. The small yet significant amount of burnable material found within the rejects and vice versa results in an overall loss of heat value which is too valuable to ignore in the context of power generation.

    - With Indian coal, the mineral matter, of which ash is a major part, is inherently ash embedded in the combustible part of the coal and therefore cannot be easily removed. Attaining an ash content of 34 percent or lower at reasonable yields may even be impossible for coal from certain mines in India.

    - Coal beneficiation is a process where coal is subjected to a medium of defined specific gravity. Heavier coal sinks (rejects) and lighter coal floats (clean coal). This specific gravity is defined by the 'washability' characteristics of the coal seam. It is different for different seams in the same area and for different geographical areas.

    - While Indian coal is generally believed to be difficult to wash, various indices like 'Washability Index' and 'Near Gravity Material Index' (NGMI) are used to determine the difficulty level.

    - When raw coal of, say, 40 percent ash is washed to produce 32 percent ash clean coal, the yield is 75 percent in the Korba coalfield and 65 percent in Ib Valley and Talcher coalfields.

- In addition, the rejects that contain combustible matter cannot be safely disposed off due to problems of self-ignition. At the national level, the ideal situation would be for coal to be washed to the extent possible and rejects having gross calorific value (GCV) of 1800 – 2000 kilocalories per kilogramme (kcal/kg) used in power plants, utilising atmospheric fluidised bed combustion (FBC) technology.

- This will involve additional incremental costs such as (a) additional mining of coal to make up for loss in the process of washing (b) overall reduction in thermal efficiency in power generation (c) investment of capital in washeries and the in FBC plants. The benefits include, but are not limited to (a) reduced transportation cost (b) lower demand on rail capacity (c) reduced operating cost at power stations (d) lower emission of local pollutants.

- As economic and environmental benefits of coal beneficiation at the national level do not often translate into financial savings at the plant level, a case for justifying public support may be made. Utilisation of the National Clean Energy Fund (NCEF) for investment in coal quality improvement in general, and coal washing in particular, will offer unambiguous support for shifting coal policy from being quantity based to quality based.

- At a macro-economic level, coal beneficiation is likely to be a case for economic efficiency more than energy saving, and also more efficient as a measure to reduce local air pollution than as an instrument of climate policy. Coal beneficiation can also add value and improve marketability of Indian coal especially as coal quality declines with decreasing thickness of coal seams.

2 Introduction

The Indian economy is likely to be among the fastest growing large economies in the world for the next few years and its growth momentum is expected to be sustained for at least the next two decades. To meet the consequent growth in demand for energy, the Government of India (GOI) plans to increase coal production from 607 million tonnes (MT) in 2014-15[1] to 1.5 billion tonnes (BT) by 2019-20. This is required to (a) boost domestic economic activity (b) increase the share of manufacturing in the gross domestic product (GDP) to improve prospects for employment generation and (c) widen access to electricity for all.[2]

India has the world's third largest proved coal reserves, estimated at over of 131 BT,[3] and is also the world's third largest coal producer in volume terms. Coal production and use in India has the highest backward and forward linkages with mining, power generation, railways, steel, fertiliser, cement, transport and other industries. About 67 percent of power generation in India is currently based on coal and its share is likely to remain above 60 percent in the next two decades.[4] Use of domestic coal is strategic as it minimises capital outflow and increases energy security.

Mandatory beneficiation of coal (particularly coal washing), which is the process of putting coal through a technical separation mechanism to reduce ash content, improve sizing, consistency and overall quality, is mentioned among the measures that India is undertaking as part of its clean coal policy in its Intended Nationally Determined Contribution (INDC) document,[5,6] to combat global warming. Case studies that examined specific coal and steel plants in the past have shown that coal beneficiation results in higher thermal and economic efficiency leading to lower environmental impact under specific conditions.

2.1. Rationale for Coal Beneficiation

The intrinsic quality of Indian coal along with the dominant practice of opencast mining has meant that Run-of-the-Mine (ROM) Indian non-coking coal contains a high share of ash and other minerals. ROM coal typically has high ash content of 30-50 percent and low calorific value (2500-5000 kcal/kg). In general, high ash content creates problems for coal users that include, but are not limited to, erosion, difficulty in pulverisation, poor emissivity and flame temperature, low radiative transfer, generation of excessive amounts of fly-ash containing large amounts of un-burnt carbon. In addition, the transport of ROM coal across long distances is wasteful as it carries large quantities of ash-forming minerals that results in shortages of rail and port capacity. The transport of high ash coal across long distances also contributes to emission of carbon-dioxide (CO_2) and other green-house gases (GHG) from the mode of transport (rail and road).

Past case studies that have looked at specific power plants in India have shown that the use of beneficiated non-coking coal (a) facilitates use of higher quality fuel with consistent heat value (b) reduces fuel quantity requirements (handled and transported) for the same heating value (c) enhances utilisation of installed capacity (d) reduces capital funding requirements (e) reduces fuel transportation capacity and cost of transportation and (f) decreases fly ash volume in both pre-combustion and post combustion stages. Even FBC that are designed to burn low grade high ash coal are understood to operate more efficiently with higher grade low ash coal.

Government policies overwhelmingly favour beneficiation of coal. The most recent measure is Gazette Notification G.S.R 02 (E) dated 02 January 2014 of the Ministry of Environment, Forest and Climate Change (MOEF&CC) which states that 'power plants of capacity of 100 MW or above located between 500-749 kilometres (km) from the pit head shall be supplied with raw or blended or beneficiated coal with ash content not exceeding 34 percent on quarterly average basis from 05 June 2016'.[7] In addition, all new coal plants have been mandated to use supercritical technology, and 144 existing plants have been assigned mandatory efficiency targets which will require use of higher quality coal.[8] Despite the benefits and supportive policy interventions that have been in place for over two decades, coal washing has not been adopted on a large scale by coal producers and users (particularly power generators). This report offers an overview of coal beneficiation with emphasis on barriers to adoption of coal beneficiation by the suppliers and the users of coal, particularly users of thermal coal.

3 Benefits of Coal Washing

3.1. Indian Coal Quality

Indian coal, which is of Gondwana origin is heterogeneous in nature.[9] These coal deposits are thought to have been transported by water across long distances carrying impurities after which coalification is said to have taken place. Such types of coal are said to be of 'drift origin' and have mineral matter finely disseminated with coal matter causing significant deterioration in quality in the formation stage itself. The mineral matter of which ash is a major part is inherent ash (as opposed to free ash) embedded in the combustible part of the coal and therefore cannot be easily removed.[10] More than 75 percent of Indian coal has ash content of more than 30 percent or higher, with some where the ash content is as high as 50 percent.

Table 1: Possible Ash Content Reduction in Select Mines Based on Simulation Studies

Name of Mine	34±1% ash		30±1% ash		28±1% ash		25±1% ash	
	Clean coal yield (%)	Ash content Rejects (%)	Clean coal yield (%)	Ash content Rejects (%)	Clean coal yield (%)	Ash content Rejects (%)	Clean coal yield (%)	Ash content Rejects (%)
Bachra	81.30	59.00	n.a	n.a	n.a	n.a	n.a	n.a
Belpahar	57.10	56.50	n.a	n.a	n.a	n.a	n.a	n.a
Bharatpur	81.50	68.30	n.a	n.a	n.a	n.a	n.a	n.a
Bina	100.0	n.a	91.10	71.00	85.40	70.20	78.00	66.50
Dipka	94.80	73.10	78.80	57.00	71.00	53.30	n.a	n.a
Hesalong	75.30	70.00	n.a	n.a	n.a	n.a	n.a	n.a
Jagannath	76.20	59.00	n.a	n.a	n.a	n.a	n.a	n.a
Lakjura	60.20	56.00	n.a	n.a	n.a	n.a	n.a	n.a
Manuguru	90.80	75.70	80.40	69.90	75.90	70.30	n.a	n.a
Muraidih	58.80	61.10	n.a	n.a	n.a	n.a	n.a	n.a
Rajmahal	79.50	54.50	n.a	n.a	n.a	n.a	n.a	n.a
Sasti	91.00	67.20	72.60	57.30	69.20	57.20	n.a	n.a

Source: ADB, 1998, India: Implementation of Clean Technology through Coal Beneficiation, Technical Assistance Consultant's Report

This is high compared to coal traded on the international market where ash share rarely exceeds 15 percent. The conclusion of simulation studies undertaken by Asian Development

Bank (ADB) in consultation with Central Mine Planning and Design Institute Ltd (CMPDI) on samples of coal from 12 mines in India in 1998 was that it was impossible to reach ash content lower than 30 percent and that 30±2 percent should be the target for washing Indian coal (see table 1).[11]

Even on a purely theoretical basis, the lowest ash level that can be achieved was found to be around 16 percent (Manuguru).[12] In other cases lowest ash level possible in theory was estimated to be around 22 percent at yields which came down to 16-20 percent. Overall, the conclusion of the study was that under practical conditions in a given washery, ash levels below 30 percent at a reasonable yield could be reached only in a very few cases.

High ash content is among the reasons why Indian coal scores poorly on energy content. Most of the coal produced in India is in the range of 3,500 – 5,000 kcal/kg which is lower than the calorific value of coal found in major countries such as the US, Russia and China. India's rank as the world's third largest coal producer reported in volume terms drops to fifth place after China, US, Indonesia and Australia when reported in energy terms.[13]

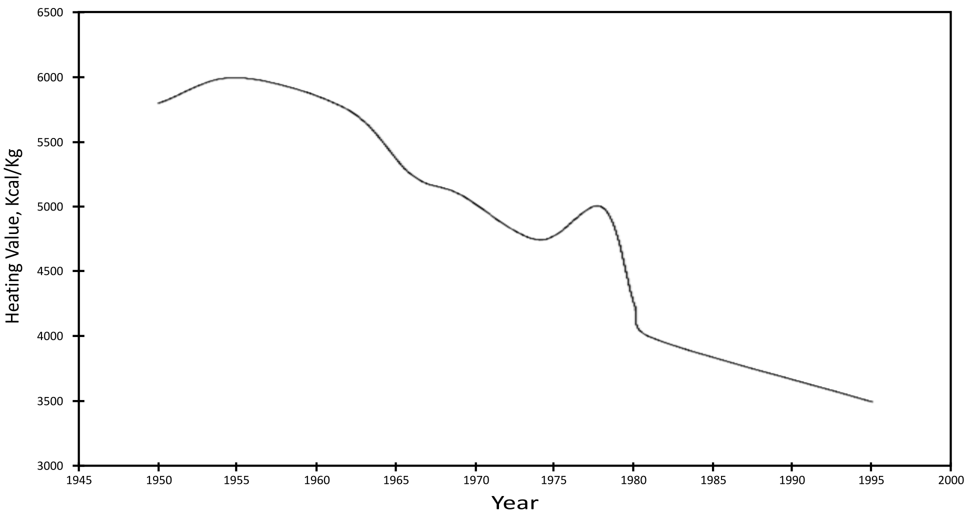
Table 2: Coal Characteristics by Type

Type of Coal	Heating value	Content (% weight)			
	(kcal/kg)	Moisture	Carbon	Ash	Sulphur
Anthracite	7170-7528	2.1-12	72-87	6.9-11	0.5-0.7
US Pittsburgh	7361-7409	1.1-5.13	73-74	7.2-13	2.1-2.3
Chinese	4612-6046	3.3-23	48-61	28-33	0.4-3.7
Indian	3107-5019	4-15	30-50	30-50	0.2-0.7
US Powder River Basin	4636-4684	28-30	48-49	5.3-6.3	0.37-0.45
Lignite	3346-4134	32-33	35-45	6.6-16	0.54-1.6

Source: MIT, The Future of Coal, 2007

The average GCV of coal supplied to power plants in India declined from about 5,900 kcal/kg in the 1950s to just over 3,500 kcal/kg currently.[14] The focus on 'easy-to-mine' coal from

Chart 1: GCV of Non-coking Coal 1950-2000



Source: Presentation by Gurudas Mustafi, CEO & Director, MBE Coal & Mineral Tech. India Pvt. Ltd at IEF Coal Summit, 2016.

shallower depths given the growth in demand for thermal coal in the last two decades is said to have contributed to the decline in coal quality and the trend of decreasing energy content per tonne of coal production in India is expected to continue.[15]

The push for rapid expansion of coal production to achieve the target of 1.5 BT by 2020 may exacerbate the trend and this could reduce focus on beneficiation even through simple activities such as rock and shale removal during the course of mining. If this happens it could increase the free ash content and contribute to further deterioration in calorific value of Indian coal.

Box 1: Basics of Ash Content in Coal[16]

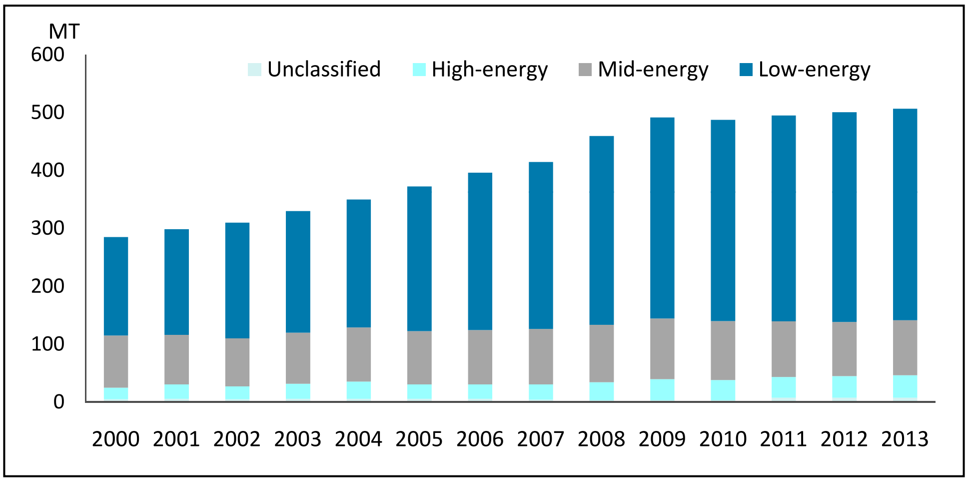
Coal is composed of a complex combination of organic and inorganic compounds. The organic compounds in coal include elements of carbon, hydrogen, oxygen, nitrogen, sulphur and trace amounts of other elements. The organic compounds in coal produce heat when coal is burnt but they may also be converted into synthetic fuels and other organic chemicals. When coal is burnt, most of the inorganic mineral matter and trace elements generally form ash and some minerals break down into gaseous compounds. The mineral content of coal determines the kind of ash that will be produced and the melting point of the ash dictates the design of the furnaces and boilers. If the melting point of ash content is relatively low (coals rich in iron bearing minerals) then the molten ash is collected at the bottom of the boiler or furnace as 'bottom ash' requires one design. If the melting point is relatively high (coals rich in aluminium bearing minerals) then all ash will not melt easily and will be released as 'fly ash' through the furnace or boiler and is collected through electrostatic precipitators at the bottom of the flue stack, requiring a different design. If power generating plants or furnaces that are designed to burn one type of coal then they must continue to be supplied with that kind of coal alone, or undergo extensive and costly redesign to adapt to a different type of coal. Furnaces designed to use coal that produce high amounts of heat will suffer severe losses in efficiency if they use coal that burns with substantially less heat. Thermal coal used in Indian power stations has low sulphur and low alkali content, but the alumina and silica content in the ash is more than 90 percent, making it high resistivity ash.[17] This raises issues in collecting fly ash using electrostatic precipitators.

According to the International Energy Agency (IEA), since the 2000s, production of high and mid-energy coal (more than 4,200 kcal/kg) has stagnated in India, while the production of low energy coal (less than 4,200 kcal/kg) has more than doubled (see chart 2).[18] This means that 1.5 tonnes of Indian coal has to be mined to get the same energy content of 1 tonne of Australian coal. Projections by the IEA assume some improvement in the quality of coal mined in India by 2040 on account of a marginal increase in the share of coal from under-ground mines, but coal quality is assumed to remain a problem for India in the next two decades. The view among Industry experts within India is more optimistic on both quality as well as quantity of domestic coal production.[19]

With Indian coal there are two broad concerns over quality. First is the concern over consistency in physical quality such as size, and the second is the concern over chemical quality. Both concerns may be addressed by coal beneficiation methods, but they are also interrelated. Efficiency of beneficiation to improve chemical composition depends on liberation of inert matter, which in turn depends on physical quality as it varies with size ranges of coal.[20] Beneficiation may be carried out at the mining stage to eliminate stone and shale bands and also by selective mining. Beneficiation can be continued at the post mining stage through separation of stones, crushing, screening, etc, followed by coal washing.

There are two quite separate aspects to the impact of upgrading coal quality. One is the possible short-term benefits that result from using upgraded coals in existing power plant boilers including reduction in emissions that contribute to local pollution. The other is the longer-term benefit arising from the use of advanced clean coal technologies which may demand the use of upgraded coal by design in order to realise its potential for increased thermal efficiency. There are other process implications of coal upgrading, but they are mainly second order effects. For example, reducing the ash content of coal may make it easier to grind, so that the energy used in the mills is reduced. The amount of pyrite present is also likely to be reduced in washed coal.

Chart 2: Evolution of Steam Coal Production by Coal Grade in India



Source: World Energy Outlook Special Report: India Energy Outlook

Inconsistency in quality of coal supplied is a recurring problem with ROM coal use in India. In the early 1990s it was reported that over 24 hours of a single day, variation in ash content was at times as high as 8-10 percent, which adversely affected the performance of the power plant.[21] It is possible that in the case of power plants which are drawing their supplies from individual mines there would be greater consistency in the quality of coal. This is so in case of some of the pit-head thermal plants which are linked to specific mines. However, the number of such plants was small even in the 1990s, with only 12 of the 68 power plants obtaining coal from a single mine.[22] At times, it was reported that four to five mines were linked to a single power plant, depending upon the demand with greater variation in coal quality. Transportation and the seasonal variations contributed to the deterioration in quality that was often beyond the tolerance of the power plant.

Table 3. Ash Range of Coal Received by Various Power Plants

Ash content	<25%	25-30%	30-35%	35-40%	40-45%	>45%
Number of power stations	2 (5%)	5 (11%)	11 (25%)	12 (28%)	8 (19%)	5 (12%)

Source: R. K. Sachdev, Cleaning of Thermal Coal: Emerging Indian Scenario, in XIV International Coal Preparation Congress, Johannesburg, 2002

Two decades ago coal delivered to power plants was estimated to contain ash that was 10-20 percent above specification in ash content. A sample of 43 thermal power stations studied over a period of three years in the early 2000s showed that 59 percent of them received coal with more than 35 percent ash, while 84 percent received coal with at least 30 percent ash.[23] The ash content in coal as delivered to power plants in India currently averages about 40 percent.[24] As noted earlier, the share of inferior coal used for power generation is expected to stabilise at current levels or increase progressively.[25] With few exceptions, the majority of coal-fired power plants are likely to receive coal from more than one source. As most of the plants do not yet have blending and homogenisation facilities, the multiplicity of supply sources is likely to add to the problem of inconsistency in coal quality.

3.2. Environmental Benefits of Coal Beneficiation

Main emissions from coal and lignite based thermal power plants in India are CO_2, oxides of nitrogen (NO_X), oxides of sulphur (SO_X) and air-borne inorganic particles such as fly ash, carbonaceous material (soot), suspended particulate matter (SPM) and other trace gas species.[26] Thermal power plants were among the Large Point Sources (LPS) accounting for 50 percent of CO_2 and SO_X and about 20 percent of NO_X in 2013.[27] Coal beneficiation has the potential to reduce the level of these emissions.

3.2.1. Reduction in Carbon-di-oxide Emissions

CO_2 emissions from power plants depend on the carbon content in coal and the quantity of air required for combustion. When combustion of coal is incomplete, a small portion of the un-burnt carbon goes with the fly ash and the remaining un-burnt carbon goes in the bottom ash. The exact portion of un-burnt carbon can only be determined by experimental measurements.[28] Accurate estimates of the amount of CO_2 emissions from power plants depend on whether the carbon lost in fly ash and bottom ash is taken in to account. If the carbon lost in bottom ash and fly ash is not taken into account (for example, if a top down gross coal usage approach is used as basis) then CO_2 emissions can be higher by about 10-12 percent depending on the amount of un-burnt carbon lost in ash. Estimation of CO_2 emissions from power plants in India stood at just below 1 giga tonne (GT) in 2013. CO_2 emissions per unit of electricity generation from Indian power plants range from 0.783-1.496 kilogram per kilowatt hour (kg/kWh).[29] The average CO_2 emission for Indian power plants estimated by Central Electricity Authority (CEA) for 2014-15 was 0.82 kg/kWh.[30]

Box 2: Issues in Estimating CO_2 emissions from Coal Based Power Generation

A study based on coal samples from 4,243 state owned coal mines and 100 of the largest coal mining areas of China concluded that default emission factors used to calculate emission inventories of China are 40 percent higher than actual emission factors.[31] The mean net carbon content of Chinese coal was estimated to be 26.59 tonnes of carbon per terajoule ($tC\ TJ^{-1}$) which is within 2 percent ($25.8\ tC\ TJ^{-1}$) of the Intergovernmental Panel on Climate Change (IPCC) default value. However, the net heating value of Chinese coal was found to be 20.95 petajoule per million tonnes ($PJ\ Mt^{-1}$) which is much lower than the IPCC default of 28.2 $PJ\ Mt^{-1}$. Similarly the oxidation rate of 92 percent for Chinese coal was lower than the IPCC default of 98 percent. Since the emission factor is a function of carbon content, heating value and oxidation rate China's CO_2 emissions were said to have been overestimated by at least 12 percent. A similar study on Indian coal could also alter estimates of the extent of CO_2 emission from Indian power plants.

Improvements in power plant efficiency through the use of clean (washed) coal can have significant benefits it terms of reduction in CO_2 emissions, arising from the general improvement in thermal efficiency of the power plant. Test results have demonstrated CO_2 emissions in the range of 1.11 kg/kWh of power generated are reduced by 6.5 percent to 1.045 kg/kWh when using 30 percent ash coal versus 42 percent ash.[32]

According to empirical studies, an increase in efficiency from 28 percent to 33 percent on account of using low ash coal would result in a reduction in CO_2 emissions of up to 15 percent, or some 190 gram per kilowatt hour (g/kWh) generated. If the average efficiency is raised from 33 percent to 38 percent, a further reduction of some 175 g/kWh is achievable. With the widespread application of state-of-the-art technologies such as supercritical pulverised coal combustion (PCC) or integrated gasification combined cycle (IGCC) which also benefit from the use of upgraded coals, average efficiencies might be brought up close to 43 percent.[33] The CO_2 emission at the stack of a 1000 MW thermal power plant calculated for different coal grades at different ash levels is shown in table 4. The key observation from the data is that the reduction in CO_2 is not significant for lower ash coals at the plant level.

Table 4: CO_2 emissions for different coal grades of Indian coal

Ash %	CO_2 emission MT/year	Reduction in CO_2 emission in %
41.00	5.730	-
36.00	5.614	2.03
34.00	5.599	2.28
32.00	5.586	2.51
30.00	5.574	2.72

Source: ADB, India: Implementation of Clean Technology through Coal Beneficiation, Technical Assistance Consultant's Report, 1998; Assumptions: Heat rate of raw coal: 2500 kcal/kWh; Heat rate for washed coal: 2462.5 kcal/kWh; combustion efficiency: 100%; operation: 6000 hours per year at designed capacity

3.2.2. Reduction in Other Pollutants

Emission of pollutants like SO_X, NO_X, and SPM from coal fired power plants is a source of pollution for surrounding areas unless appropriate measures are taken to control them. In general, NO_X and SO_X are formed from the combustion of coal where air is used or where nitrogen and sulphur are present in the fuel. SO_x, mainly SO_2, are produced from the combustion of the sulphur contained in many types of coal. SO_X emissions from coal combustion mainly depends on the sulphur content in the coal, unlike the emissions of CO_2 and NO_X which depend on the operating conditions (air intake) and the design of the plant. Sulphur content in Indian coal (barring lignite which has higher sulphur content) is much lower compared to coal from other countries. The small amount of sulphur found in power plant coal ash is of no practical significance in reducing SO_X emissions and so all the sulphur in the coal is considered to have been converted to SO_X. The range of SO_2 emissions for Indian power plants was estimated between 5.210g/kWh-9.899g/kWh.[34]

A substantial part of NO_X is known to come from the air used in the combustion of coal. To achieve complete combustion with high ash raw coal, a higher percentage of air is used which may result in the formation of higher percentage of NO_X. The emission of NO_X can be controlled with the introduction of low NO_X burners. With the use of beneficiated coal which can be combusted efficiently with less air, the formation of NO_X could be reduced. The range for NO_X emissions from thermal power plants is between 1.612g/kWh-3.490g/kWh.[35]

Effectively thermal power plants in India are estimated to produce more than 2 grams each of SO_X and NO_X with every unit (kWh) of power generated. On an average a 210 MW power plant is estimated to emit more than 10 tonnes of SO_X and equivalent amount of NO_X by burning Indian coal each day.[36] The Dahanu power plant was the first to introduce SO_X / NO_X removal technologies and other plants are expected to follow.

Studies of coal use in the US showed that washing reduces sulphur content by 10-20 percent.[37] For Mexican coal, ash reductions of 30-50 percent were reported to have resulted in 20-30 percent reduction in sulphur content. A minimum 10 percent reduction in SO_2 is considered a conservative assumption of the emissions-savings potential from coal washing. For a 600 MW plant, operating at an 80 percent plant load factor 10 percent reduction in SO_2 amounts to 1,682 tonnes.[38] The reduction on SO_X and NO_X components upon coal beneficiation can allow for smaller emissions control devices rather than larger ones to control pollution, which is a saving on investment. The air pollution level in respect of SPM will also be reduced due to lower dust emission during unloading and stocking of supplied coal, as beneficiated coal has more or less constant moisture content.

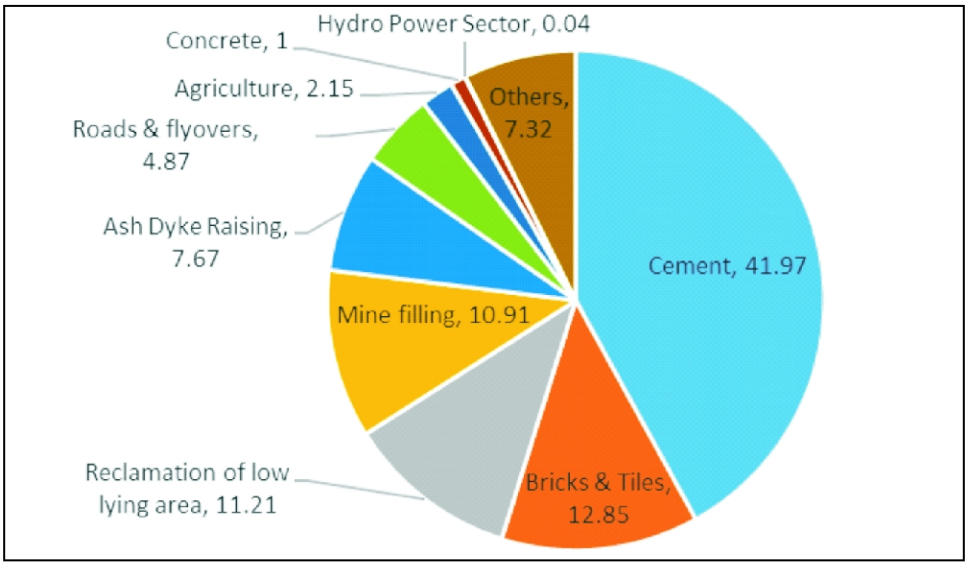
With the use of low ash coal, the concentration of SPM in the flue gas can be reduced, resulting in reduced load of particulate in the Electrostatic Precipitator (ESP) / bag filter. At any particular efficiency level of operation for the ESP / bag filter, reduction in the particulate load of the inlet gas can reduce the emission of SPM, thus improving the quality of air. The SPM level in the stack gas of different power plants in India surveyed in the late 1990s varied between 100-966 mg/NM^3 (milligrams per cubic meter at normal pressure) against the standard of 150 mg/NM^3 maximum. Some plants consuming coal at ash level 42 percent were found to be maintaining SPM level in flue gas within the permissible limit of 150 mg/NM^3,[39] while others consuming coal at the same ash level had much higher SPM, presumably on account of malfunctioning of the ESPs used to trap fly ash. According to empirical studies, ESPs can achieve over 99 percent cleaning efficiency. However, this depends on the chemical composition of the ash content in coal. Ash from Indian coal with high silica content of the order of 55-65 percent and alumina content of the order of 25-35 percent have high resistivity that reduces ESP performance.[40]

Industry experts point out that ESPs are often used only during the day when pollution is visible in urban areas so as to contain costs.[41] This exposes a critical challenge in introducing technologies for reducing pollution in power generation in India. Power generators are under pressure to contain generation costs to keep power tariff levels stable while at the same time they are also expected to invest in technologies to reduce pollution. In other words they are expected to produce a public good such as clean air at the expense of a private investment that they cannot recover through tariff. It is unlikely investment in pollution reduction technologies will be done voluntarily unless there is an incentive to do so, such as public funding support.

3.2.3. Reduction in Ash Handling

By reducing the ash content in coal in the pre-combustion stage through washing, not only is the deleterious effect caused by ash reduced but also the cost of handling ash. Coal washing reduces fly ash generation in the post combustion stage and also extends the life of ash disposal landfills. Using washed coal at a plant would extend a given ash disposal site life by 12- 20 percent.

Chart 3: Sector-wise Share (%) of Fly Ash Use (1st half of 2015-16)



Source: ENVIS (Environmental Information System) Centre on Flyash

Of the total ash (30-40 percent on an average in thermal grade coal) in coal, about 20 percent is deposited in the form of bottom ash and the remaining 80 percent in fly ash. For a typical 210 MW plant using coal with 30 percent ash on average, over 250 tonnes of ash are generated per year. As a result, the dust concentration in flue gas, in the absence of any control measure, is estimated at 37.5 g/NM^3).[42]

Table 5: Fly Ash Production and Use

Description	2011- 12	2012-13	2013-14	2014-15	1st Half of 2015-16
Nos. of Thermal Power Stationsfrom which data was received	124	138	143	145	132
Installed capacity (MW)	1,05,925.30	1,20312.30	1,33,381.30	1,38,915.80	1,30,428.80
Coal Consumed (million tons)	437.41	482.97	523.52	549.72	251.69
Average Ash Content (%)	33.24	33.87	33.02	33.50	33.23
Flyash Generation (million tons)	145.42	163.56	172.87	184.14	83.64
Flyash Utilisation (million tons)	85.05	100.37	99.62	102.54	46.87
Percentage Utilisation	58.48	61.37	57.63	55.69	56.04

Source: ENVIS (Environmental Information System) Centre on Fly ash

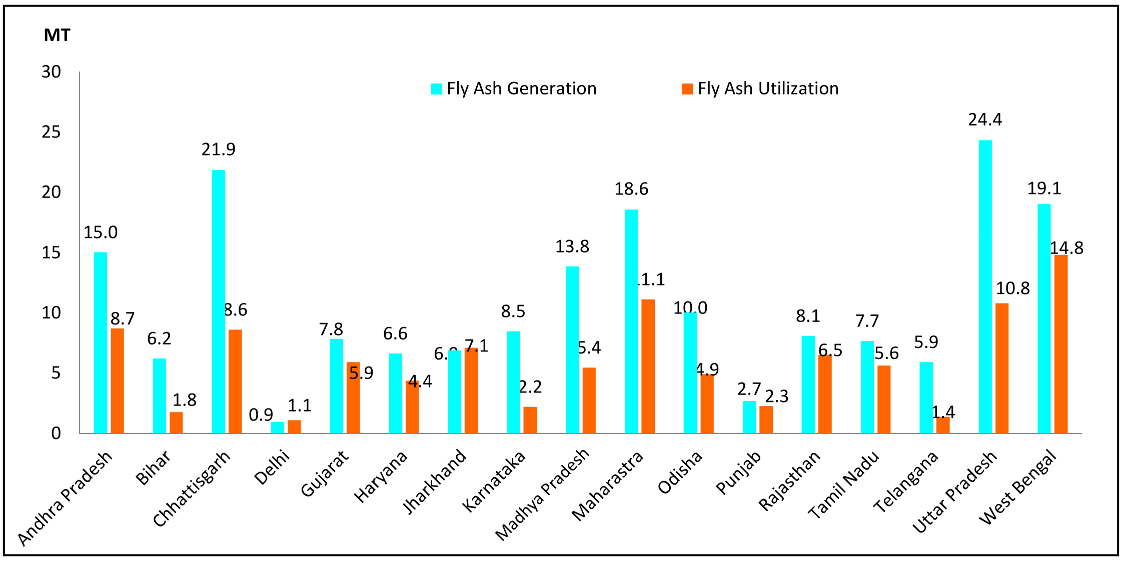
India currently produces about 184 MT of fly ash from coal out of which roughly half is reportedly utilised.[43] A large number of technologies have been developed for gainful utilisation and safe management of fly ash under the Fly Ash Mission of the Ministry of Science & Technology, GOI since 1994. As a result, fly ash earlier considered to be 'hazardous industrial waste', has now acquired the status of a useful and saleable commodity.

The utilisation of fly ash has increased from 6.64 MT (less than 3 percent of fly ash produced) in 1996-97 to about 103 MT in 2014-15 (about 55 percent of fly ash production). To reduce the requirement of land for disposal of fly ash in ash ponds and to address the problem of pollution caused by fly ash, the MOEF&CC has issued various notifications on fly ash utilisation. The first notification was issued in September 1999 which was subsequently amended in 2003 and 2009. The 2009 notification prescribes targets of fly ash utilisation in a phased manner for all coal and lignite based power plants so as to achieve 100 percent utilisation of fly ash.

Box 3: Types of Fly Ash

Fly ash produced from different types of Indian coal differs in chemical composition. Fly ash from anthracite and bituminous coal is rich in silica, alumina and iron oxides and is classified as class F as per ASTM C 618, whereas lignitic (sub-bituminous) coal produces fly ash having high calcium oxide content and is classified as Class C. Class C fly ash is generally more pozzolanic and possesses some hydraulic/ cementitious properties also as compared to Class F fly ash, which is inert but will react with hydrated lime in the presence of water to form cementitious compounds.[44]

Chart 4: Fly Ash Generation and Utilisation by Coal/Lignite Power Plants



Source: Central Electricity Authority

Fly ash generation increased 2.5 times from about 68 MT in 1996-97 to over 184 MT in 2014-15. In the same period, fly ash utilisation increased more than 15 times from over 6 MT to over 103 MT. Seven states namely Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Maharastra, Odisha, Uttar Pradesh (UP) and West Bengal are reported to have generated more than 10 MT of fly ash with UP accounting for the maximum of over 24 MT in 2014-15. Delhi and Jharkhand have reportedly achieved fly ash utilisation levels of more than 100 percent and the states of Gujarat, Punjab, Rajasthan, and West Bengal more than 75 percent in 2014-15.

Fly ash is used by the cement industry as a pozzolanic material in the manufacturing of Portland Pozzolana cement. As this saves both precious limestone and coal, it is considered a high value added use. Fly ash use in the cement industry increased from about 2 MT in 1998-99 to over 43 MT in 2014-15 and constituted nearly 43 percent of total fly ash utilisation. Fly ash as a substitute for soil/sand is used for reclamation of low lying areas, thereby saving top soil. About 4 MT of fly ash was used for reclamation of low lying area in 1998-99 which increased to over 11 MT in 2014-15.

Many road and embankment projects have been completed across the country using fly ash, but according to the Central Road Research Institute (CRRI), many practicing engineers are not well versed with fly ash usage which limits its use.[45] Though fly ash use in roads and embankments accounted for over 12 percent of total fly ash utilisation in 2014-15, its use is reported to be falling since then. Other uses of fly ash include back filling/stowing of mines, building materials like bricks, blocks and tiles and also, as it has many micronutrients, as fertiliser in the agricultural sector,.

3.3. Economic Benefits of Coal Beneficiation

3.3.1. Plant Operations

Power plants that use coal of higher quality have a performance advantage over those using lower quality coals. In general, higher the ash content of coal, lower is the heating value per unit weight of coal. When the percentage of ash content is reduced, the heating value of coal is increased and so less raw coal has to be burnt to produce a given quality of electricity.[46] When low ash coal is used, plant operators can reduce scheduled and unscheduled maintenance required to remove ash collection. Lower ash coal can also reduce corrosion of plant ductwork that reduces plant life.

Low ash coal can reduce damage to all coal handling equipment such as such as conveyors, pulverizers, crushers and storage. The use of higher ash coals increases the load on the plant that in turn increases the quantity of plant site energy needed to operate the plant and thereby reduces the energy available for power generation. This increases plant operating cost and decreases its profit potential.

Beneficiation improves overall plant operations that directly affect the profitability of a coal plant over the long term and also reduces the likelihood of facing environmental penalties and disputes. It improves the life of emission control devices. Most of the ash present in coal travels through the combustion process and is captured by emission control devices such as electrostatic precipitators. Washed coal use reduces the amount of ash produced and collected by these devices and extends their useful lives. The ash percentage in coal used in blast furnaces used for steel making should ideally be 18 percent. Higher ash content adversely affects the productivity of the blast furnace. A single percentage point increase in ash content is estimated to result in 3-6 percent decrease in the productivity of the blast furnace.[47]

Table 6: Savings due in Reduced Ash Content, Split into Different Parts for Four Power Plants

	A (old) %	B (newer) %	C (old) %	D (old) %
Fuel (free on board)	2	6	2	4
Transportation	49	27	19	68
Operation	0	0	11	0
Maintenance	39	27	14	23
Derate*	0	22	34	0
Availability	10	18	20	5
Total	**100**	**100**	**100**	**100**

** to lower the rated capability of electrical or mechanical apparatus*

Source: Chelliah, Raja J et al (ed), Eco-taxes on Polluting Inputs and Outputs, Academic Foundation, New Delhi, 2007

Boilers in thermal power plants are designed to accommodate a range of variation in the specifications of coal that can have an impact on performance and efficiency. Deviation from the range can impair not only the thermal performance of the boiler but also associated duct work. If there is fluctuation in grain size distribution, top size, ash and moisture content, and heat value of coal fed to the power plant, it is not possible to ensure adequate homogenisation of coal grades in the absence of proper and adequate blending facilities at the plant.[48] One of the consequences of this is that grinding mills and boilers are not used at the optimal level and old boilers designed for low ash coal do not receive the desired quality of coal which leads to poor performance of the power plant.

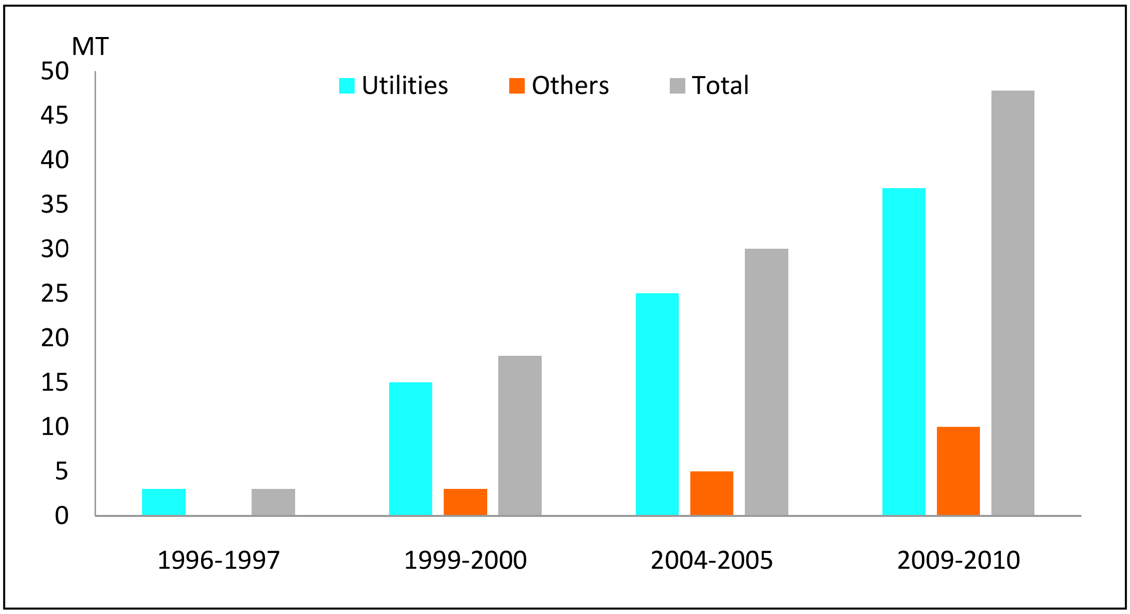
A break-even cost analysis for savings from reduced ash content split into different parts for four power plants using data from four representative Indian units in three power stations and typical coal data concluded that (a) a premium of about Rs 9/tonne could be paid for each percentage point reduction In the ash content of the typical high-ash bituminous coal fired in older power plants; (b) cleaning high-ash coals for use in newer plants that were designed for high-ash coals was less attractive; and (c) a premium of about Rs 6/tonne could be paid by newer plants for each percentage point reduction in ash content.[49] The estimated savings were said to arise mainly from reduced maintenance cost within the power plants, increased plant availability, and reduced coal transportation costs (see chart 5). Though these values need to be tested for current conditions, they offer indicative estimates of savings from coal washing.

Empirical studies have also established that when the ash content in coal exceeds 75 percent, its Useful heat Value (UHV) is reduced to zero and that when the ash content is increased from 6 per cent to 75 per cent, the gross and net overall efficiencies are reduced by a third of their original values.[50]

3.3.2. Transport of High Ash Coal

India is unique among nations that use coal for power generation in that it hauls coal over much greater distances from mine to power station. This is partly due to the fact that until the 1970s, generation, transmission and distribution of power were under the state governments as per provisions in the Indian Constitution. State governments owned generating plants and also transmitted and distributed power. This meant that coal had to be hauled to the respective state generating plants from the coal rich states in the East. This began to change in the late 1970s when a Constitutional amendment allowed the Central government to own generating plants and transmit power across the country. As per projections made in the early 1990s, it was expected that as much as 30 percent of total coal required for power utilities would be transported over 1,000 km in 1999-2000 against 21 percent in 1991-92.[51] The average lead distance for coal was 654 km against general lead of 741 km for all commodities moved by rail in 1989-90.

Chart 5: Likely Savings in Railway Load in Transporting Beneficiated Coal



Source: R. K. Sachdev, Cleaning of Thermal Coal-Emerging Indian Scenario, In XIV International Coal Preparation Congress, Johannesburg, 2002

Many attempts were made to address the problem of hauling ash across long distances in the last two decades. The average ash content of around 38 percent in power grade coal E, F and G in 1991-92 was expected to gradually increase by about 1 percent a year and touch 42 percent in 1999-2000. The additional load of incombustible materials like shale/stones in power coals was predicted to result in severe environmental problems in the form of higher air as well as ground pollution, due to increased SPM and solid waste. Apart from its detrimental effect on the environment, the extra load which the railway system would have to carry meant extra cost to the economy as well as added air pollution through the transport system. These arguments favoured the introduction of the policy of reducing the ash to 34 percent for power plants situated over 1,000 km from the coal mines. The policy was expected to result in substantial relief in terms of reduced railway tonnages as well as an improvement in the environment around the power station location. About 6-7 percent of waste was expected to be disposed off at the mine site where its disposal was seen to be environmentally benign.

Average lead distance of coal shipments in India have fallen from the level of the 1990s but continue to remain high at 486 km in 2015-16 and 545 km in 2014-15. Given the long haulage distances, the lower ash coal will result in reductions in freight costs for transporting the same energy content. India continues to use the same track for freight and passenger traffic unlike most developed countries that use dedicated tracks. The difference in speed of the two (passenger and freight) erodes the capacity of the Indian rail network. Network congestion is further aggravated because the share of coal traffic is concentrated on about a dozen routes.[52] The golden quadrilateral (GQ) connecting Chennai, Mumbai, Kolkata and Delhi carries over 70 percent of non-coking coal for power generation, but the GQ accounts for only 16 percent of the network.[53] In 2003-04, more than a third of the thermal coal transported was in the Kolkata-Delhi segment of the GQ. Coal beneficiation may be among the most viable solutions towards reducing the pressure on the railways.

Table 7: Distance-wise requirement of thermal coal

Distance (km)	Million Tonnes			
	1996-1997	2001-2002	2006-2007	2011-2012
Pit-head	70	89	99	155
<500	54	51	55	70
>500 <1000	35	30	43	60
>1000	55	95	148	300
Total	214	265	345	501

Source: R K Sachdev, Beneficiation of Power Grade Coals: Its Relevance to Future Coal Use in India, Urja Vol 32, No 1, July 1992

To quantify the benefits of transporting low ash coal as opposed high ash coal a typical case of a 1,000 MW power plant requiring around 3.77 MT of raw coal per year with 41 percent ash is considered. Using coal with an ash content of 36 percent, the amount of coal needed decreases to 3.33 MT/year. Assuming a transport distance of 700 km, the freight savings amount to Rs. 218 million/year or Rs 65.5/tonne/year. Assuming a reduction in ash to 32 percent and a transport distance of 2,000 km, freight savings increase to Rs 881 million/year or Rs. 287/ tonne/year.[54]

The rationale underpinning the saving is straightforward. Following beneficiation 25 percent of the coal weight is removed. As the reduction in thermal energy content on account of washing is less than the reduction in weight of coal there is net reduction in transportation demand of about 20 percent per unit thermal energy. In general, clean coal generates more heat than raw coal per tonne but there is a trade-off between the mix of coal qualities and transportation costs. A reduction in the price of washed coal should lead to higher share of cleaned coal in raw coal. At the same time, raw coal can be bought at a lower cost per unit of thermal energy. The coal heat remains a fixed share of energy used in generation of electricity but cost reduction of coal transmits to the unit cost of electricity generated. The cost of transportation per tonne of coal is the same for raw coal and washed coal. However the unit transportation cost differs among sectors due to variation in the distance to mines and the scale of purchase.

ROM coal obtained from mechanised opencast mines is usually sized up to -1,500 mm, but may be as large as -2,000 mm. Coal handling plants in India crush ROM coal to a nominal size of-250 mm, as stipulated by Indian Railways, though on occasion, the maximum size may be up to 500 mm.[55] Beneficiated coal has a maximum top size of 75-100 mm. There are less crushing activities for beneficiated coal in comparison to raw coal which has a top size of more than 200 mm. After preparation, ROM power coals are loaded either through low to high or to very high capacity (200-2,000- 4,000 tonnes/hour) pithead coal handling plants or directly from the coal stockpiles using some form of dozer—reclaimer combination.[56] The rail wagons are usually weighed after completion of loading and it is seldom possible to make adjustments if the wagons are found to be overloaded or under-loaded.[57] The Indian Railways charge a penalty for both overloading and under-loading. As the raw coal purchase price contains a higher share of transportation costs per unit heat value than the clean coal price, it incorporates a higher implicit subsidy per unit of energy delivered.[58]

Table 8: Quality of Coal and its impact on payload in rail transport

Size (mm)	Ash (%)	Moisture (%)	Density (kg/m^3)	Load (Tonnes)
ROM Coal				
-250	25	1.5	1503	4904
-250	30	2.0	1552	5064
-250	35*	2.0	1610	5254
-250	40*	2.5	1660	5417
-250	45*	2.2	1720	5613
Clean Coal				
-100	33	8	1524	4973
-100	32	10	1508	4921
-100	32	10	1512	4934
-50	33	7	1530	4993
-50	33	5	1541	4855

Source: S. Bhattacharya and Ashim Kumar Maitra, Impact of Coal Beneficiation on Rail Transport in India, Coal Preparation Vol. 27, Issue 1-3, 2007

A generalised yield of 80 percent for washed coal is estimated to result in savings in cross country transport of 55 MT or equivalent of 42 trains per day.[59] On this basis if all the coal transported by rail in 2011-12 were washed, the saving in transport cost is estimated to be sufficient to finance the construction of 467 km of track every year.

As the washing processes leads to a marginal increase in the moisture content of the coal and a reduction in the specific gravity of coal, it can also reduce the payload per train as shown in table 8. Pay-load after beneficiation can be as much as 35 percent higher than the carrying capacity stipulated by the Indian Railways. On account of the reduced specific gravity of washed coal, a wagon could carry as much as 85 tonnes of beneficiated coal, which is within the limit of 87 tonnes stipulated by the Indian Railways. Transportation of washed coal would extend the life of coal wagons because of reduced abrasiveness. If the life of wagons is extended by 5 percent the saving on one coal carrying rake would be Rs. 1.825 million.[60]

According to the Central Fuel Research Institute (CFRI), Dhanbad, if all non-coking coal transported over 1,000 km in 2002-03 were washed to reduce ash share from 40 percent to 34 per cent, it would reduce 11 MT of coal to be transported, 8 MT of fly ash emissions and also reduce CO_2 emissions by 23 MT.

Table 9: Summary of Benefits of Coal Beneficiation

Item	Effects
Reduction in transport costs	Depends on distance and ash reduction (e.g. 1,000 km distance and ash reduction from 41% to 34% results in saving of 15%)
Reduction in CO_2 emissions due to reduced fuel consumption in transport	Depends on distance and ash reduction (e.g. 1000 km distance and ash reduction from 41% to 34% results in 15% reduction in CO_2 emissions)
Decrease in auxiliary power	10% decrease for every 10% reduction in feed coal ash
Improvement in thermal efficiency	3% improvement for every 5 % reduction in feed coal ash
Improvement in plant load factor	1.5% improvement for every 10% reduction in feed coal ash
Reduction in operating and maintenance cost	20% cost reduction for every 10% reduction in feed coal ash
Reduction in capital investment for ash new power plants	5% reduction in capital investment when using coal with 34% instead of 41%
Reduced land requirement for ash land disposal	Using coal with 34% ash instead of coal with 41% ash reduces requirement by about 30%
Reduced water requirement for ash water disposal	Using coal with 34% ash instead of coal with 41% ash reduces consumption by about 30%
Reduction in CO_2 emission	Reduction in the range of 2-3% when using washed coal
Improvement in ESP efficiency	Using washed coal improves ESP efficiency from 98% to 99%

Source: ADB India Report on Implementation of Clean Technology through Coal Beneficiation

4 Coal Beneficiation Technologies

Typical steps in coal preparation include (a) crushing; (b) screening into different size fractions; (c) physical, chemical or mechanical processes (commonly known as 'washing') to remove undesired impurities; (d) dewatering; (e) thermal drying; and (f) blending. Washing of coal represents the most important step of coal preparation. First ROM coal is subjected to qualitative and quantitative analysis to arrive at the most suitable method for cleaning to obtain the desired quality. In general, coal washing technologies are based on the difference in density between coal and other heavier rock. The most common way to wash coal is by dense media separation (generally magnetite based) in which crushed raw coal is introduced into cyclones or a bath, where the heavier rock falls to the bottom while the lighter coal floats and then is removed for drying.[61]

Indian coals consist of high near gravity material with unsatisfactory crushing characteristics that are not amenable to dry beneficiation by conventional rotary breakers and dry shale extractors (spring - leaves types). Wet washing of coals is therefore unavoidable.[62] Amongst various washing processes available, jigs are considered adequate for a standard two product beneficiation. Jigs also offer cost effective technology with a clean coal yield of 75–85 percent at about 34 percent ash content.[63]

Indian coal washeries reportedly use somewhat outdated European technology, but these have been adapted and optimised for 'difficult-to-wash' Indian coals.[64] Main coal washing technologies currently in use in India for coking coal are:

- Heavy media (HM) cyclones
- Deshaling jigs, HM bath, Batac jig and froth floatation
- Deshaling jigs, HM cyclone and flotation
- HM washer, cyclone and flotation
- Jig (coarse coal), jig (small coal) and froth flotation
- Jig and heavy media

Technologies for washing non-coking coal include:

- Rotary breaker and barrel washer
- HM washer, baum jig and floatation

- Run-of-mine (ROM) jigs, batac jigs
- HM washer, HM cyclone
- HM cyclone, hydro cyclone and spiral

4.1. Dominant Washing Technologies[65]

4.1.1. Heavy Media Bath

Coal of size -50 mm to +6 mm is fed to the heavy media bath (HMB). Both clean coal and rejects from the bath are fed to the dedicated de-pulping and rising (D/R) screens from which they are fed to the clean coal and reject bunkers via respective bunkers. Underflow from the D/R screens is collected in a dilute media sump and fed to a magnetic separator for recovery of magnetite, which is reused in the bath. However there is a loss of magnetite of around 0.5 to 0.7 kg/tonne of raw coal. The media density in the bath is maintained by an automatic density control system that regulates the amount of magnetite and water to provide the correct media density.

Classifier Section: Coal of size -6mm (known as fines) is diverted to the fines feed tank. The fines feed tank is fed with water and magnetite separator underflow to prepare the slurry, which is pumped to the screw classifier in the HMB plant. The screw classifier is used to classify fine coal in order to remove -500 mm micro fractions and hence de-slime the fine coal fraction. Raked coal from the screw classifier is further dewatered in the centrifuge to remove surface moisture from the classified product. This dewatered fine coal product from the classifier finally joins the coarse clean coal circuit. Classifier overflow (-0.5mm) is dewatered in the thickener and further in the vacuum filter. This fine fraction available in the form of cakes is conveyed to the stocking area.

4.1.2. Heavy Media Cyclone (HMC)

Raw coal received from mines is fed to the receiving pit having less than 100mm size with 42 to 45 percent ash. The -50mm coal is directly separated in a fixed grizzly while +50mm and -100mm coal is fed through the primary and secondary crushers sequentially. After crushing coal to -50mm it is fed to HMC through de-sliming screen mixed with magnetite powder with proper proportion of specific gravity. Specific gravity is decided in the laboratory by a 'float and sink' test as well as by the cut-off point. The coal and media is fed to the cyclone by a high gravity pump. In the HMC coal and media feed tangentially on the top of the cylindrical portion. Coal is separated according to different cuts depending on their relative density. The high relative density materials flow along the wall of the cyclone and discharge at the underflow orifice called the spigot. They are then fed to D/R screens and washed by fresh water. Coal that has an ash share of more than 60 percent is treated as 'reject'. The lower density coal migrates towards the longitudinal axis of the vessels and exits through overflow orifice called the vertex finder and discharges through the D/R Screen and is further washed by fresh water to coal having an ash content of 32-32.5 percent, which is called clean coal. In the circuit the magnetite is collected by primary and secondary magnetite separators for re-use, and to maintain the cut-off density.

4.1.3. JIGS

The pneumatic process of beneficiation is the best suited for coal having very high percentage of near gravity material. This method involves size reduction and screening of coal to segregate it into defined sizes followed by concentration i.e. separation of particles into fractions more homogeneous in nature. Raw coal is fed onto the beneficiation bed that consists of crosswise and vertical slope. The beneficiation bed is kept vibrating with the help of vibration feeding machine. Air is then supplied in the air rooms which are located below the beneficiation bed by a centrifugal ventilator and is blown through the air holes in the beneficiation bed. The air current through the air holes goes upward to agitate the raw coal. Under the joint performance of vibration and air current the raw coal becomes loose and stratification of coal takes place as per its relative value. Lighter coal forms the upper layer and the heavier raw coal forms the bottom. The upper layer of good coal goes to the conveyer trough, the side leasing block of the beneficiation bed. The heavy/higher density raw coal is gathered at the bottom of the beneficiation bed and it moves to the waste side. As much as 75 percent of the air with dust that goes to the centrifugal ventilator is recycled by spinning a dust remover through the dust collecting guide. The remaining 25 percent is cleaned with the rotary reverse baggage type dust remover and is released into the atmosphere, with dust content less than 150 micrograms per cubic meter of air ($\mu g/m^3$).

Moving screen jig (ROM jig) is another method being tried for cleaning coals, where extraneous dirt comprises distinctly stones/grey shale, which when eliminated yields a coal of consistent quality. In this jig, pulsation of the bed and stratification of the particles are caused by mechanical movement of the pan/screen plate in a pool of water. This jig can handle large sizes up to 400 mm. ROM jig is installed at the Bina opencast mine in the Singrauli coalfield.

4.1.4. Barrel Washing

The barrel washer is a combination of cylindrical and conical construction. In the barrel the beneficiation takes place based on the principles of hindered settling. Coal and water are fed into the cylindrical portion of the barrel which rotates at a certain predetermined speed. The spiral inside the barrel creates waves in the water in which the pulsation of coal takes place. The lighter coal moves with the top layer of the wave and is discharged at the conical end as low ash coal or clean coal. The high ash coal that settles in the bottom is carried by the spirals to upper cylindrical portion and discharged at the top end as rejects. The rejects and clean coal move in the opposite directions inside the barrel.[66]

Table 10: Bina Washery Results

Raw coal screen analysis			Products		
Grain size	**Wt %**	**Ash %**	**Product**	**Wt%**	**Ash%**
250-30 mm	68.78	42.13	De-shaled coal	49.76	31.34
30-0 mm	31.22	38.08	Unwashed coal	31.22	38.08
250-0 mm	100.0	40.87	Saleable product	80.98	33.94
			Refuse	19.02	70.37

Modular Barrel-cum-Cyclone washers with coal slurry as the medium are used for recovery of good coal from the washery rejects and old stock piles. This technology has been installed at the Lodna colliery in Jharia coalfield. This technology has the advantage of modular construction and even smaller units can be installed depending upon the nature of raw feeds to be treated. This technology is seen as useful for coal consumers such as cement plants, sponge iron plants and other industries having small to moderate consumption of coal, unlike the power plants which need large quantities of coal to be cleaned.

Table 11: Kargali Washery Results

Raw coal screen analysis	Products				
Grain size	**Wt %**	**Ash %**	**Product**	**Wt%**	**Ash%**
350-50 mm	45.3	40.75	De-shaled coal	34.26	30.7
50-0 mm	54.7	32.56	Unwashed coal	54.7	32.56
350-0 mm	100.0	36.27	Saleable product	88.96	31.84
			Refuse	11.04	71.96

The Piparwar washery under Central Coalfields Ltd. (CCL) having capacity of 6.5 million tonnes per annum (MTPA) is equipped with two Batac Jigs which form the heart of the plant supplying washed coal of around 82-83 percent yield, having ash less than 34 percent to NTPC for the Delhi based plants. Raw coal feed has ash in the range of 39-40 percent.[67]

Table 12: Wani Washery Results: Supplying to MSEB

Raw coal screen analysis	Products				
Grain size	**Wt %**	**Ash %**	**Product**	**Wt%**	**Ash%**
50-13 mm	68.00	37.80	Washed coal	41.00	24.10
13-0 mm	32.00	40.00	Unwashed coal	32.00	40.00
50-0 mm	100.00	38.50	Saleable product	73.00	31.07
			Refuse	27.00	58.00

Development of the ROM jig opened the possibility of using a very simple process for the beneficiation or de-shaling of lump size coal. This is in operation in Bina and Kargali. Plants with Jig and HM Bath for similar application have been set up for private entrepreneurs to wash power grade coal in different locations adjacent to Mahanadi Coalfields Ltd (MCL), South Eastern Coalfields Ltd (SECL) and Western Coalfields Ltd (WCL) mines.

Table 13: Ghugus Washery supplying to MSEB

Raw coal screen analysis	Products				
Grain size	**Wt %**	**Ash %**	**Product**	**Wt%**	**Ash%**
50-6 mm	85.0	37.90	De-shaled coal	49.80	24.60
6-0 mm	15.0	38.13	Unwashed coal	15.00	38.13
50-0 mm	100.0	37.93	Saleable product	64.80	27.73
			Refuse	35.20	56.71

Source (Table 10 to 13): Gurudas Mustafi, Proven Technologies for Beneficiation of Indian non-coking coal, Presentation at the 2nd Coal Summit, 10-11 December 2007, New Delhi

4.2. Cost of Beneficiation

A study carried out by the Central Mine Planning and Design Institute (CMPDI) for three coal beneficiation plants in the 2000s gives the cost estimates of reducing the ash content of coal from 40 per cent to various levels of ash is given in table 14. It can be observed from the table that the marginal beneficiation cost rises at an increasing rate beyond the reduction of ash below 30 per cent.[68]

Table 14: Cost of Beneficiation of Coal*

Rs/Million kcal

Description	Ash Content	Ash Reduction to			
		34%	32%	30%	25%
	38%	**I. Dipika Mine**			
1. ROM (Run of Mine}Cost	74.53				
2. Beneficiated Coal Cost		95.38	102.84	116.73	151. 92
3. Beneficiation Cost. (2-1)		20.85	28.31	42.20	77.39
4. GCV = kcal/kg	4166	4397	4585	4773	5244
	41%	**II. Kalinger Mine**			
1. ROM (Run of Mine}Cost	81.12				
2. Beneficiated Coal Cost		112.69	116.71	127.96	171.97
3. Beneficiation Cost. (2-1)		31.57	33.59	46.84	90.85
4. GCV = kcal/kg	4166	4337	4227	4715	5186
	42%	**III. Piparwar Mine**			
1. ROM (Run of Mine}Cost	63.92				
2. Beneficiated Coal Cost		79.89	80.11	80.74	100.56Ml
3. Beneficiation Cost. (2-1)		15.97	16.91	16.82	36.64
4. GCV = kcal/kg	3700	4410	4598	4786	5256

** Based on study conducted by Central Mine Planning and Design Institute reported in Sankar and Mathur (1998)*

Source: Chelliah, Raja J et al (ed), Ecotaxes on Polluting Inputs and Outputs, Academic Foundation, New Delhi, 2007

Irrespective of the technology used, it is known that coal washing consumes energy and water and adds to the producer's cost. In China, for instance, washing is estimated to account for 18 percent of total national water use on coal, the second-largest source of water consumption after agriculture. It is techno-economically feasible, in most cases, to selectively mine the coal, without the impurities. Selective mining is estimated to have great potential to improve the quality of coal in the Talcher mines of Mahanadi Coalfields Limited (MCL). The cost of a surface miner is around Rs 50 million/MT/year. The total system cost to produce 1 MT of coal per year is estimated at around Rs 120 million and this could reduce ash content by about 13 per cent.[69]

4.3. By-products of Coal Beneficiation

Beneficiation of coal is associated with discarding considerable quantities of 'rejects' from the process of washing. The amount of rejects to be disposed depends on the coal characteristics and the technology used for washing. As coal beneficiation is a physical process, an ideal separation between burnable (coal) and 'un-burnable' material (rejects) does not take place. Therefore, a small amount of burnable material is found within the rejects and vice versa resulting in an overall loss of heat value.

A typical example found in coal washing literature in India is that of washing 1 tonne of raw coal with an ash content of 41 percent separated into 770 kg of clean coal with ash content of 34 percent and 230 kg of rejects with ash content of 65 percent. The 'yield' (ratio of washed coal to raw coal feed) in this case works out to 77 percent. If the gross calorific value (GCV) of raw coal with 41 percent ash is approximately 3,970 kcal/kg after washing, the ash content in the clean coal is reduced to 34 percent and the GCV increases to 4,628 kcal/kg.

Heat value of one tonne of raw coal = 3,970,000 kcal

Heat value of 770 Kg of clean coal = 770*4628 = 3,563,560 kcal

Heat value of 230 Kg of rejects = 230*1767 = 406,440 kcal

Table 15: Yield and Ash of rejects likely to be obtained on washing to 34% ash

Mine	Rejects		
	Yield%	Ash%	GCV (kcal/kg)
Bachra	18.70	59.00	2565
Belpahar	42.90	56.50	2806
Bharatpur	18.50	68.30	1688
Bina			
Dipka	5.30	73.10	1238
Hesalong	24.70	69.00	1627
Jagannath	23.80	59.00	2567
Lakjura	39.80	56.60	2793
Manuguru	9.20	75.70	999
Muraidih	41.20	61.10	2365
Rajmahal	20.50	54.50	2993
Sasti	9.00	67.20	1795

Note: Moisture assumed to be 3%.

Source: ADB, India: Implementation of Clean Technology through Coal Beneficiation, Technical Assistance Consultant's Report, 1998

The loss of heat value in rejects in the process of washing is among key concerns of both washeries and power generators who are mandated to use washed coal. The economics of coal washing in India depends on how the heat value in rejects can be utilised. One of the most common strategies is to use rejects in a pit head power plant using FBC that is capable of burning high ash coal (see chart 10 under Section 9).

There is also the concern over quantity of coal to be mined to make up for loss in the beneficiation process. With the use of beneficiated coal, there is a reduction in power plant heat rate (energy used by a power plant to generate one kilowatthour (kWh) of electricity or the ratio of energy output to energy input). The reduction of heat rate means that for the same quantity of electricity output, the power plant can use lower quantity of coal. This also reduces the overall cost of transportation of coal. However the amount of raw coal to be mined to produce a sufficient quantity of washed coal is higher than the amount of raw coal supplied directly to the power plant. The additional production depends on the ash reduction in washed coal and on the raw coal characteristics.

As observed earlier, for a 1,000 MW thermal power plant, the raw coal requirement is 3.77 MT per year with 41 percent ash. In the case of clean coal with 34 percent ash, only 3.19 MT of coal will be required. To produce 3.19 MT of washed coal with 34 percent ash, 4.14 MT of raw coal will be required assuming a yield of 77 percent. In general for Indian coal, the additional coal to be mined is estimated to be about 10 percent of the typical coal requirement. Beneficiation of non-coking coal for supply to power plants results in generation of washery rejects having GCV in the range of around 1000-3000 kcal/kg with corresponding ash contents of 75.7-54.5 percent respectively.[70]

Rejects with ash content below a certain level is a concern, as this may lead to self-combustion of the rejects. Appropriate construction and shaping of the reject dumps, building only small layers with vibrating machines to prevent oxygen from entering into the dump are among the suggestions put forward. Though this is a relatively inexpensive way of preventing self-combustion, it is not deployed in India to the extent desired as it is seen to be cumbersome.

As observed earlier, rejects having 1800 - 2000 kcal/kg GCV can be utilised for the generation of electricity utilising atmospheric FBC. The technology for FBC of rejects for the generation of electricity has been indigenously developed in India. The capacity of an individual unit for this purpose may be 30-250 MW. However there are constraints on sufficient calorific value- a basic prerequisite is the consistency in fuel quality for using high ash coal in FBC boilers. As the coal washing process normally aims at consistent quality parameters in the washed product, quality variations in the rejects are inevitable, a fact that limits the use of the FBC technology to only a few cases.[71]

5 Literature Survey (Case Studies)

5.1. Asian Development Bank

This study observed that though there was no uniform opinion among power plants it had surveyed on the exact benefits on use of beneficiated coal owing to lack of experience with washed coal, some had indicated a three-percent improvement in plant load factor (PLF) and thermal efficiency for every five-percent reduction in coal ash. Considerable savings in transport costs on use of beneficiated coal was expected to accrue to the distant power plants like Guru Govind Singh thermal power station (TPS) at Ropar, Guru Nanak Dev TPS at Bhatinda, Mettur TPS, Ennore TPS, Nashik TPS, Sabarmati TPS, Raichur TPS and Kota TPS.

Table 16: Variation in Quality of Coal Supplied to Selected Plants

Calorific value	3100-5100 kcal/kg
Ash content	25-55 percent but in general around 41 percent (11 units higher than most boilers are designed for)
Moisture content	4-7 percent
Sulphur content	0.2-0.7 percent
Volatile matter	20-25 percent

Source: ADB, India: Implementation of Clean Technology through Coal Beneficiation, Technical Assistance Consultant's Report, 1998

5.1.1. Key Challenges Identified

Regarding difficulties due to poor raw coal quality, following problems were documented:

a. More coal had to be handled and used in the power plants, and so coal handling and milling system were over-loaded.

b. Because of high ash content, there was more erosion of the grinding elements of coal mills, coal pipes and nozzles. Availability of coal mills was also reduced due to frequent shutdown for cleaning.

c. Due to high ash content, low volatile matter and high moisture (rainy season), oil support was sometimes required for flame stability.

d. High ash content of the coal caused erosion at the coal burners and the flue gas path (super-heater, economiser, air heater tubes).

e. Approximately 50 percent of the total area of the power station was required for ash ponds. There were problems in finding new sites.

f. Ash content in the delivered coal was between 10-15 units higher than the system had been designed for. This reduced plant load factor (PLF) and thermal efficiency. In one case, the power station's thermal efficiency was reduced by approximately 4.5 percent compared to the design efficiency.

g. Land requirement for ash ponds was 0.3 to 0.5 ha/MW, but in two cases it was 1.22 and 1.90 ha/MW of installed capacity.

h. Water requirement for ash disposal varied between 4 m^3/tonne of ash to 12 m^3/tonne of ash. In one case the figure was as high as 60 m^3/tonne. The major portion of this was recycled and reused for ash slurry preparation purpose. The remaining effluents were discharged to nearby rivers and other water bodies

i. Solid waste consisted of bottom ash and fly ash in the ratio 20:80 which was disposed of by mixing with water

j. Other solid waste generated was reported to be non-toxic in all cases. A general composition of ash from four power plants was SiO_2 (60-70 percent) and alumina (23-25 percent)

5.1.2. Key Conclusions

a. Non-coking coal used in power plants should be washed up to 32 ± 2 percent but this should not be a blanket approach for all coal fields, because of varying ROM and washability characteristics.

- The policy that power plants located more than 1,000 km from coal mines should use coal with ash content less than 34 percent applied to every power plant will be very expensive and unlikely to provide 'good environmental value' for money spent.
- Policy should focus on environmental standards to be achieved allowing consumers and suppliers to find the most economic means to achieve those standards.

b. Rejects should have an ash content >60-65 percent to allow safe disposal without the danger of self-combustion.

- If this is not possible, utilising the rejects in a FBC at the washery site for power generation should be considered.

c. Widespread implementation of coal washeries will not occur spontaneously and so the government must (a) encourage private investors to enter the coal washing business (b) internalise environmental costs by enforcing a system of fees and fines reflecting the economic costs of pollution (emissions, land and water use).

- In the context of attracting private operators as partners for Coal India Ltd. (CIL), the build, own and operate (BOO) model will be relatively more difficult on account of the contractual complexity.
- The build, own, operate, trade (BOOT) model will be more attractive to investors as

it offers better balance of risks and rewards than the BOO model. Both these models may be based on a partnership of CIL and private capital.

- To promote the setting up of washeries, a Clean Coal Fund could be created. The sources of capital for such a fund could include international financing institutions, domestic banks and the state budget.

d. In some countries, environmental levies, or fines on plant operators for violating standards are used to fund environmentally desirable projects. This may be an appropriate system for India.

e. Among the many organisations and ministries involved in questions over using washed coal, the MOC should have the clear responsibility to co-ordinate and implement policy regarding coal washing.

5.2. Satpura Power Plant

The results of a study of NTPC's Satpura Thermal Power Station in 1985 using washed coal of 34 percent ash in one 210 MW unit:[72, 73]

a. PLF increased from 73 percent to 96 percent

b. Coal consumption reduced 29 percent (from 0.77 to 0.55 kg/kwh)

c. Reduction in Auxiliary Power Consumption (1.5 percent)

d. Reduction in down time of mills

e. No fuel oil support

f. Boiler efficiency improvement by 3 percent[74]

g. Coal mill power consumption (kWh) reduced by 48 percent reduction

h. Savings by using washed coal of Rs. 42.6 million/year or Rs. 0.024/kWh

5.3. Dadri Power Plant

The analysis of the National Thermal Power Corporation's (NTPC) Dadri Power Plant which used washed coal with around 34-35 percent ash from Central Coalfield Ltd's Piparwar washery revealed the following results.[75]

a. Increase in operating hours up to 10 percent

b. Increase in PLF up to 4 percent

c. Increase in PUF up to 12 percent

d. Reduction in breakdown period up to 60 percent

e. Increase in overall efficiency up to 1.2 percent

f. Increase in generation per day 2.4 Million units (MU or million kWh)

g. Reduction in support fuel oil 0.35 ml/kWh

h. Reduction in specific coal consumption of 0.05 kg/kWh

i. Increase in total units sent out per day about 2.3 MUs

j. Saving in land area for ash dumping 1 acre/year

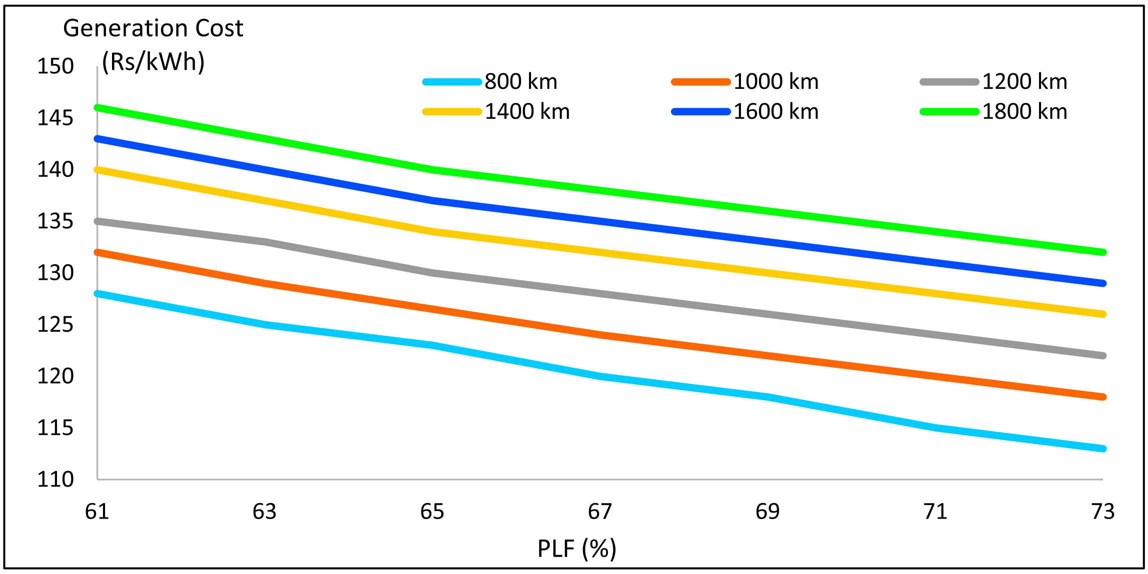
k. Reduction in CO_2 emissions (reduced transportations/coal combustion > 600,000 tonne/year).

l. Overall benefit resulting from using washed coal of Rs 119 million/year excluding the anticipated reduction in maintenance cost.

m. For the 4x210 plant, this represented a savings of Rs 0.02/kWh.

n. Savings in demurrage to railways about Rs 7/tonne of coal received

Chart 6: PLF Vs Cost of Generation at Different Load Levels



Source: R K Sachdev, Beneficiation of Power Grade Coals: Its Relevance to Future Coal Use in India, Urja Vol 32, No 1, July 1992

A case study carried out by CEA on the Dadri plant concluded that if beneficiated coal is used instead of ROM coal, the anticipated improvement in the PLF of the power plant would be of the order of 5 to 10 percent (even more in some cases). The same study also indicated that a mere 3 percent improvement in PLF would balance the additional cost of beneficiation of coal at the Piparwar project, which was located about 1,300 km from the plant site. The marked decrease in the cost of generation, with the improvement in the PLF for a given distance, is shown in chart 6.[76]

5.4. Dahanu Power Plant

The Dahanu Thermal Power Station (2X250 MW) reported the following results for use of 30 percent ash washed coal produced at the USAID/DIE sponsored Korba washery. The results included:

a. Ash generation reduced by 8.5 percent

b. PLF increased by 15.8 percent

c. Cost per unit reduced by approximately 10 percent

d. Plant availability increased by 6.5 percent

e. Specific oil consumption decreased by 65 percent

f. Aux power consumption decreased by 5.4 percent

g. Power generation increased by 16 percent

h. Savings Rs 0.28/kWh

The operator of the plant did not report generating cost, but the study estimated the savings/kWh from the value of the additional power generated (542 MU/yr) and other information as given below:

Table 17: Saving from the use of washed coal by Dahanu Power Plant

Cost Head	Cost	Assumption
Landed cost of ROM coal	Rs 1590/tonne	
Rail transportation cost	Rs 1070/tonne	assuming transport over 400 km from the mine site with the ROM coal price (FOB) at Rs 620/tonne
Washing costs	Rs 100/tonne	
Raw coal and clean coal transport and loading charges	Rs 45/tonne	
Total washing fee	Rs 145/tonne	
Washed coal landed cost	Rs 620/tonne	[ROM coal cost + washing fee of Rs 145]/tonne) / [average yield of 75 percent (yield at 30 percent ash) + rail transport costs Rs 2015]
Specific consumption of coal using raw coal	0.7 tonne/kWh	
Specific coal consumption using 30% ash coal	0.55 tonne/kWh	
Raw coal required to produce 3353 MU	2.35 MT	3353*0.7
Washed coal required to produce 3895 MU	2.14 MT	3895*0.55
Raw coal required to produce 2.14 MT of washed coal at 75 percent yield	2.85 MT	2.14/0.75
Landed cost of washed coal	Rs 4312 million	
total annual landed cost of raw coal	Rs 3786 million	
Cost for 542 MU of additional generation on using washed coal	Rs 526 million	Rs 4312 million - Rs 3786 million
Value of additional generation	Rs 1626 million	542 MU*Rs 3/unit
Net gain	Rs 1100	Value of additional units sold - cost of additional generation
Net savings per unit (kWh)	Rs 0.28	

Source: ADB, India: Implementation of Clean Technology through Coal Beneficiation, Technical Assistance Consultant's Report, 1998

5.5. Simulation Based Studies

The VISTA software based analysis was applied to two 500 MW power plants in India.[77] The first examined performance output provided by VISTA by comparing two domestic coals and considering how plant performance is impacted if ash quantity increases. The second used VISTA to determine whether coal washing is economical for the power plant.

5.5.1. Impact of Ash Content on Performance

The first analysis assumed the use of a low ash coal as the design parameter of the power plant, and simulated the decline in performance if coal ash was increased by 5 percent and 10 percent respectively. The predicted result for a 10 percent ash increase was reduction in plant availability of 2.0 percent. This equated to a loss of generation annually of 79 MU. At a value of Rs3/unit, a loss of Rs 0.068/unit was derived. Conversely, the use of better quality fuels was estimated to result in power generation costs that were lower by the same amount. The study suggested that maintenance and availability were strongly impacted by the ash content of the coal through four principal mechanisms:

a. As the ash content of coal increased and the calorific value of coal decreased, the mass of coal which must be burned increased. This impacted the coal receipt systems, conveyors, crushers, silos, feeders, pulverisers, pipes, and burners. The largest impact was on the pulveriser, where an increased throughput could not only lead to increased auxiliary energy requirements, increased maintenance, and potential limitations on the maximum achievable load, but also reduce the availability of the unit through more failures and a decrease in the maximum load that the unit can achieve if the pulverizer is out of service due to planned or unplanned maintenance.

b. As the ash content of coal increased and the fuel burn rate increased, the quantity of flue gas travelling through the steam generator increased. Coupled with the increase in ash content, this caused an increase in tube failures, impacting both maintenance and availability.

c. As the ash content of coal increased and the fuel burn rate increased, the quantity of ash that the bottom ash, fly ash, and precipitator or fabric filter systems must handle increased. The increased level of usage would lead to higher levels of erosion and more frequent cleaning and preventative repairs.

d. The quality of ash also impacted maintenance and availability of the power plant.

Coal ashes are made up of different levels of minerals and inorganic compounds, which can cause different levels of erosion throughout any part of the unit which must handle the coal, flue gas, or ash. In addition, differing levels of inorganic compounds contribute to very different levels of corrosion, especially in the high-temperature regions of the furnace.

5.5.2. Estimation of Value of Washing Coal

Raw ash content in coal of typically 41 percent was reduced to 32 percent, 28.64 percent, 25.48 percent and 22.60 percent respectively. In each case, the cost of coal, cost of transportation, cost of washing and the differential credits for lower maintenance, higher availability and lower auxiliary energy consumption were predicted. The results indicated that due to the difficulty of cleaning Indian coals and the low yields achieved with the lower ash products, coal between 32 percent and 28 percent ash provide a benefit while deeper cleaning to less than 28 percent ash was uneconomical. The average value of the benefit from washing was calculated at approximately Rs 30 million/year or a net savings of Rs 0.0085/kWh. The value was significantly lower than in other cases, due in part to the failure to include cost savings from reduced ash handling.

5.5.3. Savings on Account of Washing Coal: Ropar Power Plant

The British Department of Trade and Industry's Clean Coal Technology sponsored a study to assess the technical and financial feasibility of producing low (around 28 percent) ash coal for combustion in remote load centre power stations and capturing lost heat in coal preparation plant discard by generating electricity using fluidized bed based power plant.[78] A simulated product sample was prepared based on the coal preparation studies. This was analysed for combustion characteristics. These parameters were used to determine the change in performance and consequently the cost of generation at an existing power station. The Ropar power station (RPS) of the Punjab State Electricity Board (PSEB) provided detailed information about its boilers and auxiliary plant, and the data was analysed using VISTA computer simulation of coal fired boilers.

The results showed that the power plant could significantly improve its heat rate and lower its cost of generation. Three distinct studies were conducted:

(a) simulation of coal preparation methodology using LIMN software[79]

(b) an assessment of the economic and technical viability of using circulating fluidized bed (CFB) boiler technology for a waste coal based power plant in conjunction with the optimum coal washery design from the LIMN simulation and

(c) simulation using VISTA of the impact of burning lower ash fuel at the PSEB's 210 MW RPS.

The increases in heating value of the coal, resulting from upgrading the coal by beneficiation, and improvements in the fuel consistency, result in more efficient and controllable combustion. As a result, the thermal efficiency of both boilers and stoves increased and CO_2 emissions per unit of energy used were reduced.

VISTA predicted a savings of approximately $1.78 million per year in plant costs using washed coal (27 percent ash) compared with using unwashed coal (41 percent ash). The main effects of low ash coal included improved boiler efficiency and reduced coal burn rate (i.e. mass throughput). The reduced coal burn rate and lower ash levels resulted in significant maintenance cost savings, and reduced auxiliary power requirement and improved unit availability. In addition, the amount of bottom ash and fly ash requiring disposal is considerably lower, which also resulted in substantial cost savings. A further $0.244 million/year were estimated as savings in the cost of the coal supply, (assuming the price per kcal remained unchanged) because the boiler efficiency improvement meant that lower kcals need to be supplied to the unit for a given MW output. The resulting saving of Rs 83 million/year represented a savings of Rs 0.057/ kWh.

5.5.4. Study by US Department of Energy

The US Department of Energy's (DOE) National Energy Technology Laboratory performed studies on the economic analysis of coal cleaning in India using state-of the-art computer models. The simulations were on bituminous coal from the Talcher coalfield, with an ash content of 40 percent, typical of most Indian thermal coals.[80]

The computer models used were the ASPEN Technology Inc.'s Coal Cleaning Simulator (CCS) and the Electric Power Research Institute's (EPRI) Coal Quality Impact Model (CQIM). Both models were developed under DOE Initiatives. Data for the power plant simulations was obtained from three separate power plants: (1) NTPC's Rihand Super Thermal Power Station (2) Maharashtra State Electricity Board's Nasik Thermal Power Station, and (3) Tamil Nadu State Electricity Board's Tuticorin Thermal Power Station. The model evaluated the plants capabilities using the existing high ash coal and the simulation for lower ash coals.

a. These power plants placed a premium value of $0.55/tonne of coal for each percentage point reduction in ash content for coal transported 1000 km. The value was $0.46/tonne at 500 km. This is the value of the washed coal to the power plant relative to the ROM coal, not the cost of cleaning. The projected savings were derived from reduced maintenance costs within the power plant, increased plant availability, and reduced fuel transportation costs.

b. The washing costs were established at $3.03/raw tonne for coal of 32 percent ash. The 8 percent ash reduction, valued at $0.55 per percent ash reduction, equated to $4.40 allowable break-even washing cost. At $3.03/tonne paid for washing, a benefit of $1.07/raw tonne purchased and washed was derived from the reduction in the cost of power generation.

c. Based on the results of this study, using a heat rate of 2850 kcal/kW, a typical 500 MW plant would purchase 2.3 MT of raw coal for washing, and realize a savings of approximately US$3.02 million per year or a savings of $0.0007 (Rs.0287)/kWh.

5.6. Working Group Report of Planning Commission

In July, 2005, a committee was formed under the chairmanship of member (energy), planning commission and consisting of representatives from NTPC, BHEL, CEA, CIL, CMPDIL & GSECL.[81] The report of working Group on suitability of using washed Coal in thermal power plants was submitted in May 2006. Major findings are as listed below:[82]

Table 18: Integrated plant techno-economic analysis

Option	Fuel	Cost of Electricity (COE) Paise/kWh
A	40% ash ROM coal (Base)	154.99
A1	Washed to 34% ash + reject in FBC	161.17
A2	Washed to 30% ash + Reject in FBC	163.44
B	44% ash ROM coal (Base)	152.18
B1	Washed to 34% ash + reject in FBC	163.60
B2	Washed to 30% ash + reject in FBC	165.52

Integrated Plant Sensitivity Analysis showed that washing is viable in case of load centre power plants if washed coal is transported beyond break-even distance of 300-400 Km. Washing may be viable for pithead power stations also when use of washed coal led to substantial improvement of PLF and for power plants running at part load due to deterioration in coal quality.

Table 19: Washed coal breakeven cost analysis

Location of 2*500 MW power plant	COE Paise/kWh (Base value with 40% ash ROM coal)	Cost of 40% ash ROM coal (Rs/tonne)	Breakeven cost of washed coal with 30% ash (Rs/tonne)
Pithead	154.99	515.00	692
500 km from mine	194.63	1055.00	1347
1000 km from mine	231.63	1599.00	1962

Source (Table 18 & 19): Work shop on coal beneficiation in India, Presentation by Dr S. R. Ghosh, DIR (Engineering Services) CMPDIL, Ranchi, 2007

Washing may also be viable for pithead power stations when yield of washed coal is substantially higher. Though quantitatively not established, economics of an integrated plant was reportedly more favourable than the case when rejects were not being utilized.

Table 20: Break-even cost of washed coal with respect to PLF (30% ash coal based 2*500 MW pithead plant)

PLF %	Break-even cost of washed coal with 30% ash (Rs/tonne)	Remarks
80	692	Base case
81	714	Valid only for power plants where poor quality of coal is the sole reason for low performance of the plant
82	736	
83	757	
84	778	
85	799	

Source: Work shop on coal beneficiation in India, Presentation by Dr S. R. Ghosh, DIR (Engineering Services) CMPDIL, Ranchi, 2007

6 Status of Coal Washing In India

6.1. Brief Historical Background

The beginning of Indian policy on coal beneficiation goes back almost a hundred years. The Indian coal-washing committee, set up in 1925, concluded that Indian coal was not easily washable.[83] The difficulty in washing Indian coal in addition to 'selective-mining', which was the dominant mode of coal mining until early 1950s, meant that there was no real requirement for coal beneficiation in India. The first Indian coal washery was set up at West Bokaro in 1951 for coking coal, followed by a second one installed at Jamadoba in 1952, both by Tata Iron and Steel Limited (TISCO) based on conclusions of TISCOs detailed studies. This was followed by Hindustan Steel Limited (now Steel Authority of India Limited or SAIL) that set up one washery for coking coal. The Coal Board set up by the Government of India appointed a Coal Washeries Committee in 1953, which concluded that coking coal could be washed in steps to the extent necessary, to meet the needs of the steel industry.It further recommended that a more detailed study was required for washing non-coking coal. The Coal Board suggested installation of four central washeries at the railway marshalling yards—Dugda, Patherdih, Bhojudih and Kargali—during the Second Five-Year Plan.[84]

Private-sector steel-plant operators set up washeries for coking coal, based on their own studies. The third private-sector washery was established at Lodna colliery by Turner Morrison in 1955.A large washery in the public sector was commissioned at Kargali by National Coal Development Corporation (NCDC) in 1958. Five central washeries were set up by Hindustan Steel Limited on the recommendation of the Coal Washeries Committee during the period 1960–1968.[85] The Dudga washery, set up in 1962, was the first central washery in Jharia coal fields located on the western fringe near the railway marshalling yard, serving as the junction point between the eastern and the southeastern railways. The Durgapur washery of Durgapur Projects Limited (DPL) and Chasnalla washery of Indian Iron and Steel Company were installed in 1968.[86]

Around this time, more than 150 washability studies were conducted at the Central Fuel Research Institute (CFRI), classifying individual small private mines (generally underground ones) into high- and low-yielding groups.[87] Based on the results, the NCDC (now CCL) installed three pithead washeries at Kathara, Swang and Gidi for the upgrading of medium-coking coal in the 1970s.

Table 21: Coking-Coal Washeries 1950–1990

Washery	Year of installation	Owner
West Bokaro	1951	TISCO
Jamadoba	1952	TISCO
Lodna	1955	IISCO
Durgapur	1968	DPL
Chasnalla Washer	1968	IISCO
Kathara, Swang and Gidi	1970s	NCDC (now CCL)
SudamdihandMoonidih	1970s	
Barora (demonstration)	1984	BCCL
Rajrappa washery	1988	CCL
Nandan	1980s	WCF
Mahuda	1980s	BCCL
Bhetland	1994	TISCO
Madhuban	1990s	BCCL
Kedla	1990s	CCL

Source: R. V. Shahi, Indian Power Sector: Challenge and Response (New Delhi: Excel Books, 2006).

After nationalisation of coal mines in 1972, pithead washeries in the Jharia coalfield were set up at Sudamdih and Moonidih, each with a throughput capacity of 700 tonnes per annum (TPA). In 1988, the Planning Commission constituted the Ronghe Committee to study the issue of washing coal. The committee came to the conclusion that washing would be cost effective only if coal is transported over a distance of 1,000 km when the cost of beneficiation would more or less get neutralised by saving in the cost of transportation of additional ash in coal. The committee examined a number of options for beneficiation and suggested the following alternatives:

- Screening of raw coal of 200/250-00 mm at 30 mm;
- De-shaling or de-staining of 200/250-30 mm in HM;
- Draw by separator to produce de-shaled/de-stained coal rejects;
- De-watering and rinsing of de-shaled/de-stoned coal on de-watering and rinsing screen;
- Recovering fines through settling ponds; and
- Mixing of de-shaled / de-stoned 200/250-30 mm coal and recovered fines with raw 30 mm coal

Following the report on coal washing, non-coking coal washeries of capacity 14.6 MT were to be completed by 1989-90 and 45.15 MT of washing capacity was anticipated beyond 1989-90. As per the annual report of the MOC (1993-94), total clean coal production in 1992-93 was 12.5 MT.

Table 22: Washery Capacity in 1983-84

Status of Washery	Capacity (MT)
Existing washeries	32.16
Washeries under construction	7.46
Future washeries for coking coal	16.74
Proposed washeries for non-coking coal	59.75

The Rajrappa washery (CCL) was commissioned in 1988 to beneficiate medium-coking coals with the latest equipment and instruments. A demonstration plant of 100 TPA throughput capacity was set up in 1984 at Barora (BCCL) to beneficiate difficult-to-wash prime-coking coal. Two more washeries came into existence at Nandan (WCL) and Mahuda (BCCL) in the mid-1980s. Bhelatand washery of TISCO was commissioned in 1994. Two more washeries, Madhuban (BCCL) and Kedla (CCL), were installed in mid-90s for treating coking coals. Overall, the issue of washeries was primarily about coking coal until the 1990s.[88] The private sector took the lead and the public sector followed (Table 21).

Table 23: Washery Capacity in 1992-93

Company	Capacity (MT)
CIL	9.25
TISCO	1.93
ISCO	0.93

Source (Table 22 and 23): R. V. Shahi, Indian Power Sector: Challenge and Response (New Delhi: Excel Books, 2006).

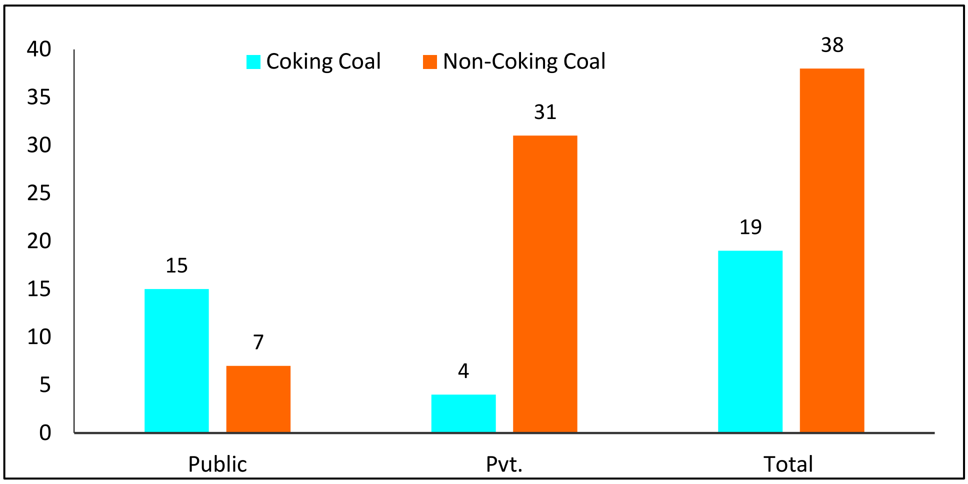
The first non-coking coal washery, Bina, was set up at Singrauli coalfield in 1999 to supply clean coal to NTPCs Dadri power plant near Delhi.[89] The plant was reportedly lying idle for a few years as NTPC could not decide the price of washed coal.[90] In the same period, with assistance from USAID, CIL installed a cyclone washery at Dipika, which is said to have paved the way for installation of cyclone washers for washing of non-coking coal in India. Increased production from lower seams, enhanced supplies from mechanical opencast mines, consisting of considerable proportions of free dirt, boulders and other lumpy extraneous materials, made washing a preferable option.[91]

Until the early 2000s, third-party investment (private sector) was the preferred mode for setting up of new washeries. In a major shift in policy in 2007, CIL decided to invest in a number of washeries in CCL and SECL. CIL also decided that all inferior quality coal (>34 percent ash), produced from future mines or expansion projects with a capacity of 2.5 MTPA or above and not linked to pithead power plants, should be washed.

6.2. Current Status

The installed capacity for washing thermal coal is estimated to be 110 MT in 2010-11 (including the private sector) and was expected to have increased by 250 MT by 2016-17.[92] All new open cast-mining projects of over 2.5 MT capacity that were not linked to pithead power plants were to have integrated washeries. The guidelines for the private sector to set up coal washeries on land owned by the public sector, based on Build-Own-Maintain, was issued in 2005.[93] CIL was to extend capital funding and other infrastructure facilities. Though some progress has been made, issues such as under-utilisation of coal washing capacity, mismatch between washing technology and coal type remain

Chart 7: Number of Coal Washeries (as on 31 March 2015)



Note: Installed capacity of non-coking private coal washeries is 87.2 MT and installed capacity of CIL's washery is 17.21 MT.

Source: Lok Sabha, Unstarred Question No. 552, answered on 23 July2015.

7 Policy and Regulatory Regimes

7.1. Evolution of Policy: Last Two Decades

Policymakers acknowledged the need for coal beneficiation in India's Five-Year Plans in the last three decades and identified some reasons for low capacity utilisation. For example, the 10th Plan (1997–2002) stated that washing capacity for coking coal is underutilised because the quality of coal in India made it uneconomical to wash. It also stated that existing coking-coal washeries were designed to beneficiate coking coal of relatively easy to moderately difficult "washability" characteristics but coal production had shifted to more "difficult to wash" coals. The Plan document attributed increased production from lower seams containing poor-quality coal, increased production from open-cast mechanised mines, and increased proportion of fines below 0.5 mm to a lack of proper facilities to process and handle, which adversely affected the performance of coking-coal washeries. The document also observed that the ash percentage in washed coking coal was being maintained at 18–20 percent and that yield of washeries had deteriorated from 51 percent in 1998 to 43 percent in 2002. It noted that in the Ninth Plan period, supply of washed coal was less than 50 percent of the anticipated quantity of 12.6 MT of washed coking coal from CIL as planned.

The 10th Plan also noted that, in the early 2000s, some of the coking-coal washeries converted to non-coking coal washeries, presumably in anticipation of the enforcement of the MOEF&CC directive, dated 19 September 1997, in Gazette Notification GSR 560 (E) and GSR 378 (E) dated 30 June 1998, which mandated the use of coal containing not more than 34 percent ash in power stations located 1,000 km from pitheads and those located in urban/sensitive/critically polluted areas, effective from June 2001. But the Plan document noted that the results were mixed and concluded that "washeries were uneconomical."

According to the Central Pollution Control Board (CPCB), only 20 percent of the total coal transported to power plants in 2000 was of superior grade, with ash content less than 24 percent, while the remaining 80 percent was of inferior grade, with ash content ranging from 24 percent to 45 percent. Based on estimates of the Joint Apex Committee constituted by the Ministry of Power (MOP) to consider various aspects of the directive from the MOEF&CC, the 10th Plan projected the need for 90 MT of washing capacity for non-coking coal while available capacity was only about 10 MT from seven washeries of CIL. The 10th Plan document observed that though setting up of washeries was open to the private sector, "there were no takers." It also observed that the proposal to supply blended coal to maintain 34 percent ash content had also not materialised. Despite these negative observations, the 10th Plan document identified improvement of environmental aspects and promotion of clean coal technologies such as beneficiation of non-coking coal and promoting washed coking coal with adoption of better technologies and making domestic products competitive for the steel sector, with a view to reduce imports as its "thrust areas."

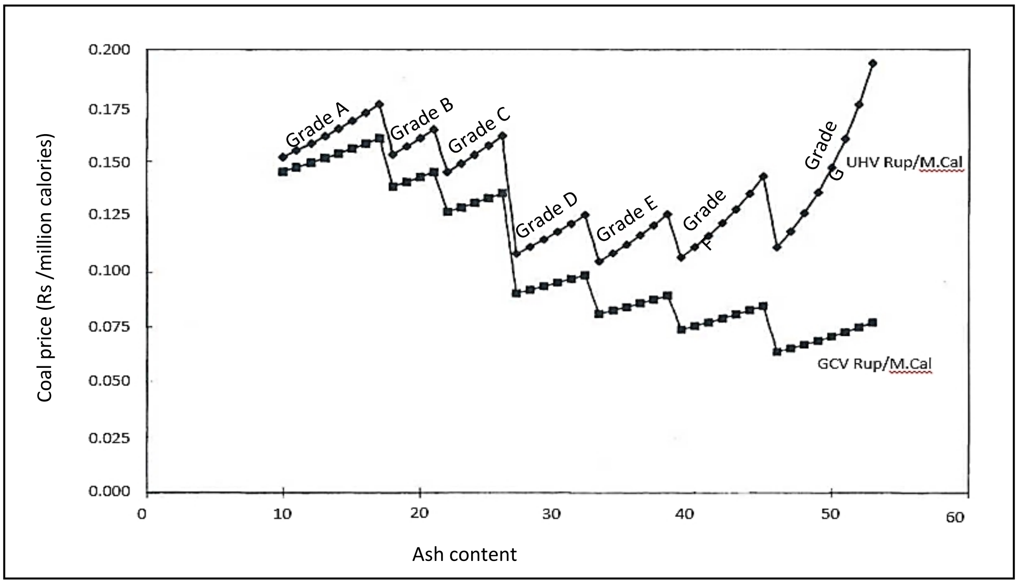
The 11th Plan (2007–12) too identified coal beneficiation as one of the prime clean-coal technologies. It observed that coal washing would ensure consistent fuel supply to conventional pulverised coal combustion (PCC) boilers and improve efficiency by 1 percent. It noted that coal beneficiation was necessary for improving thermal efficiency of energy conversion and for environmental performance. The Plan acknowledged that washed coal ensured consistency of coal quality and resulted in boiler-performance improvement by allowing units and auxiliaries to operate near design (optimum efficiency) points. It noted that power plants of higher capacity in the range of 800–1,000 MW were anticipated in the future and, therefore, it was desirable to use washed coal. According the 11th Plan, the use of washed non-coking coal had increased from 17.12 MT in 2002-03 to 55.24 MT in 2006-07. It projected that 243 MTPA washing capacity was required by 2011-12 and that an additional 140 MT washing capacity would be created. The document observed that "perfect" growth on coal washing could be realised if the Planning Commission's suggestion to price coal on fully variable Gross Calorific Value Basis (GCV) was implemented, as it would provide the right incentive to both the producer and consumer to improve the quality of coal. It cautioned that an increase in washing capacity would consequently increase the demand for raw coal, unless fines were used productively.

The 12th Plan (2012–17) noted that CIL had envisaged building 20 new washeries with a capacity of 111 MT in the 11th Plan but observed that this had not materialised due to delays in awarding contracts. As per the 12th Plan, coking-coal washing capacity was 29.88 MT in 2011-12 but output of washed coking coal was 7.03 MT with raw coal feed of 15.5 MT. Of this, the output of CIL washeries was only 3.89 MT, even though 22.18 MT of capacity (74 percent of coking-coal washing capacity) was with CIL. Non-coking coal washing capacity had increased to 96 MT, of which 17 MT was with CIL (17 percent of non-coking coal washing capacity). The overall washed coal output was only 36 MT with raw coal feed of 52 MT indicating suboptimal use of washery capacity. The 12th Plan anticipated coking-coal washing capacity to increase from 30 MT in 2011-12 to 49 MT in 2016-17 and non-coking coal washing capacity to increase from 96 MT in 2011-12 to 175 MT in 2016-17.

7.2. Coal Pricing

Until very recently, the GOI fixed grade-wise and colliery-wise price of coal under Section 4 of the Colliery Control Order 1945, which continued to be in force by the Essential Commodities Act, 1955. The price notification was amended between 1994 and 1996 to enhance the price differential between ROM, steam and slaking coal to accommodate the increased transportation charges and to provide additional prices for coal produced from certain mines.[94] The mining cost of a sample of mines estimated periodically was adjusted for inflation and used as the basis for price at which coal was sold to consumers. The concept of useful heat value (UHV) was used to differentiate between different grades of coal. While reports on the Indian coal sector prepared in the 1990s and early 2000s were critical of the concept of UHV, seen to be unique to India, there was a reasoned argument behind it.

Chart 8: Coal Price Per Unit under UHV and GCV System



Source: Implementation of Clean Technology through Coal Beneficiation, Technical Assistance Consultant's Report, ADB, India, 1998.

Note: The chart shows that for a given grade (say G) under UHV, the producer gets the highest price for the highest share of ash content. The GCV system minimises this differential.

In 1954, when the concept of UHV was proposed by the Coal Washeries Committee, power generators were using better grades of coal, the reserves of which were depleting fast. The objective of adopting the UHV concept was, therefore, to encourage and popularise the use of poor grades of non-coking coal by the power utilities.[95] The empirical formula developed by CFRI for UHV of coal—UHV = 8900 – 138 (A+M), where A is the ash content in percentage and M the moisture content in percentage—consisted of a 'discount' that increased with increase in the ash plus moisture content in coal.[96] This was a built-in incentive for a general shift towards usage of E, F and G grades of coal, with calorific value of about 4,000 kcal/kg (Table 24). The price of these coal grades for "million calories" was significantly lower compared to the superior coal grades A and B, with calorific value of about 5,800 kcal/kg. The Tariff Commission recommended UHV-based pricing in 1966, and it was adopted in 1979.[97] Under the UHV system of pricing, the coal producer had an incentive to produce coal at the highest ash level of a particular grade. It also allowed significant slippage of grade in delivered coal.

Table 24: Coal Grades as in the 1990s

Grade	UHV kcal/kg	Ash inpercent
A	6,200	<15
B	5,600–6,200	15–19
C	4,940–5,600	19–24
D	4,200–4,940	24–29
E	3,360–4,200	29–35
F	2,400–3,360	35–42
G	1,300–2,400	42–50

Source: Ministry of Coal

When the UHV concept was adopted, more than 95 percent of the coal was burnt on either fixed or moving grates, where the thermal efficiency dropped steeply with increasing ash content. Following the adoption of UHV, the consumption of inferior-grade coals increased, and it stood at about 119 MT in 1990-91. Power plants, whether located near the pithead of away from the coalfields, used ROM coal with ash content up to 47 percent.[98]

Following the recommendations of the Bureau of Industrial Costs and Prices (BICP), the GOI deregulated prices of all grades of coking coal and A, B and C grades of non-coking coal, which accounted for 40 percent of coal production in 1996. The price of deregulated coal grades rose shapely compared to grades whose prices were still under administrative control. However, the price increases for deregulated coal grades were thought to be less due to the imbalance between supply and demand and more due to the monopoly power of the supplier. Lower grades of coal (grades D to G) were used to generate power, but as power tariff was regulated, the price of these coal grades were not subject to 'deregulation'. These were the grades of coal that were expected to be processed through washing. The price rigidity embedded in policy leads to another plausible reason for the underutilisation of washing capacity for non-coking coal. Additional cost of washing cannot be accommodated in an inflexible price regime.

The GOI deregulated the price of soft coke, hard coke and D grade of non-coking coal in 1997, following the recommendations of the Committee on Integrated Coal Policy. CIL and SCCL were allowed to fix prices of E, F and G grades of non-coking coal once every six months by updating cost indices as per the escalation formula given in the 1987 report of the BICP. The pricing of coal was fully deregulated after the Colliery Control Order 2000 (CCO 2000) notified in January 2000 that it superseded the Colliery Control Order 1945. Under CCO 2000, the GOI has no power to fix the price of coal.[99]

Efforts of CIL to shift to GCV system in the late 1990s did not succeed due to protests from major consumer sectors such as power. Eventually, in January 2012, CIL shifted to benchmarking coal on the basis of GCV. A total of 17 slabs of 300 kcal bandwidth, starting from 2,200–7,000 kcal, replaced the seven-grade classification based on the UHV concept (Table 25 and 26). But customers from the power sector continued to receive discounts from 25 percent to 77 percent of the notified price under the revised price regime. In coal that was sold through e-auctions, the floor price was set 20 percent above notified price.

Empirical Formula for Indian Coals

GCV in kcal/kg = 85.6 x (100 – 1.1A – M) – 60M

A = Ash content, wt% M = equilibrated moisture content, wt%

– 40% ash, 10% M, GCV = 3,338 kcal/kg (6000 BTU)

– 30% ash, 10% M, GCV = 4,280 kcal/kg (7700 BTU)

1 tonne 40% ash coal = 0.78 tonne 30% ash coal

The price of thermal coal in India is technically deregulated, but this does not mean that it is market determined. The MOC has put on record reservations raised by the MOP over the deregulation of coal prices. According to the MOP, in the absence of a regulatory mechanism, price of coal could arbitrarily increase on account of the monopoly situation in coal production, which would affect electricity tariff, which in turn could directly affect the economy.

Table 25: Grades of Non-Coking Coal

Grade	Useful Heat Value (kcal/kg)=8900-138 (A+M)	Corresponding ash% + Moisture at 60% RH[100] & 40°C	GCV (kcal/kg) at 5% moisture level
A	> 6200	Not exceeding 19.5	> 6454
B	> 5600 but < 6200	19.6–23.8	>6049 but < 6454
C	> 4940 but < 5600	23.9–28.6	>5597 but < 6049
D	> 4200 but < 4940	28.7–34.0	>5089 but < 5597
E	> 3360 but < 4200	34.1–40.0	>4324 but < 5089
F	> 2400 but < 3360	40.1–47.0	>3865 but < 4324
G	>1300 but < 2400	47.1–55.0	>3113 but < 3865

Source: Ministry of Coal

Pricing regimes of coal across the world are designed to reduce the price per tonne of coal with higher ash content, for two reasons. The first and most important reason is that the calorific value decreases as ash content increases, and a correction is made for this effect. The second factor is that higher-ash coal has less value to consumers since it increases transport costs per unit energy; it leads to higher operational costs at the power station and higher ash-disposal costs. The element of the pricing regime correcting for these effects is designated "secondary ash penalty."[101] In general, international pricing of coal uses a reference price for coal of a specific quality (cost per unit energy) and a formula (or a set of rules) defining how the price of a particular batch of coal relates to the reference price. Secondary ash penalties are an example of this. There may also be penalties relating to consistency of quality, sulphur and so on.[102]

In India, where coal prices are not necessarily determined by market forces and most production is in the hands of a single company, price formulae have generally tried to reflect costs of production, but there is no built-in penalty for lack of consistency in coal quality. In some countries, direct consistency penalties have been introduced into pricing contracts. However, these are often complex and require extensive quality monitoring for application. Coal users contacted for this study cited the lack of consistency in coal quality as a major problem. Some experts suggested that under Indian conditions, coal washing could be used as a proxy for increased consistency.[103]

Table 26: Grades of Coking Coal

Grade	Ash content
Steel grade - I	<15%
Steel grade - II	>15% but < 18%
Washery grade - I	>18% but <21%
Washery Grade - II	>21% but <24%
Washery Grade - III	>24% but <28%
Washery Grade - IV	>28% but <35%

Source: Ministry of Coal

7.3. Coal Distribution

In the last three decades, the dominant system of allocating coal among users was a system of linkages between the producer and the consumer of coal, mediated by the GOI through the MOC. Coal linkages have evolved since their initiation. Now, coal linkages are not binding as in the past. They are only a means for obtaining coal in addition to other means such as e-auctions or imports. But the pattern of domestic physical coal flows has not changed significantly as these flows are constrained by the fixed railway system. Fuel supply agreements between CIL and its customers are linked to railway transport of coal. For non-core sectors, CIL has authorised its subsidiaries to formulate their own system for sale of coal. However, for core sectors such as power generation, sale of coal is guided by linkages and allocations. Consumers of coal from the power sector apply for linkage to the Standing Linkage Committee [Long Term] (SLCLT) through the CEA and the MOP.[104] The SLCLT has members from the MOC, CIL, SCC, CMPDIL, Ministry of Railways, Department of Industrial Policy and Promotion, CEA and MOP. The SLCLT decides the linkage of coal for source of supply, quantum of coal and mode of transportation and meets in March, June, September and December each year to review the coal supplies to the power and cement sectors in the quarter and to finalise the linkage to consumers in the next quarter. Going by statements on the website of the MOC, the GOI is of the opinion that the system of linkages "is the optimal system of allocating coal in a country with diverse sectors, diverse needs and diverse growth patterns."[105]

The system of linkages introduced layers of complexity in terms of cost and risk in the contract between the buyer (power, steel, cement and other sectors) and the seller (CIL and its subsidiaries). This was and continues to be a disincentive for coal beneficiation in the absence of no other specific quantifiable benefits offered to washeries. To address this concern, the option of washeries being set up on the BOOT (build, own, operate, trade) model was recommended by many agencies, but the absence of success stories indicates that this did not really reduce risks for investors to the extent desired.

7.4. Environmental Regulations

Regulations to address the environmental impact of mining, processing and combustion of coal were initiated about three decades ago by the MOEF&CC. These regulations continue to be strengthened as more information and knowledge on the nature of pollution and its impact become available. The enabling provision is the Environment (Protection) Act, 1986, (EPA 1986) that empowers the GOI to "take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing controlling and abating environmental pollution."[106]

With regard to ash content in coal, the MOEF&CC promulgated Gazette Notifications GSR 560(E), dated 19 September 1997, and GSR 378(E), dated 30 June 1998, on the use of beneficiated/blended coal containing ash not more than 34 percent, effective from June 2001 in power plants located 1,000 km from pithead and in power plants located in critically polluted areas, urban areas and ecologically sensitive areas. However, the response to these notifications were not adequate and continue to be lower than desired level even today as noted in earlier sections of the report.[107]

At the time the last notification was issued, most of the coking-coal washing plants in India were old and had capacity utilisation typically in the order of 50–65 percent. Of the 20 washeries in operation, only one had an annual output of over 1 MT of washed coking coal and three had individual outputs of less than 300,000 tonnes a year. It was reported that CIL found it difficult to maintain the contractual obligation of supplying coking coal with a maximum of 17 percent ash content, as demanded by SAIL.[108] About 60 MT of non-coking coal fell under the notification at this time and to address the projected demand for washed coal, 24 coal washeries, each with a capacity of 2.5 MTPA were to be set up.[109]

According to the CPCB, only 20 percent of the total coal transported to the power plants in 2000 was of superior grade with ash content 24 percent or less and the remaining 80 percent was of inferior grade with ash content ranging from 24 to 45 percent.

The MOEF&CC Gazette Notification (GSR 552 (E)), dated 11 July 2012, stated that with a growing concern over ambient air quality and public health, the use of cleaner coal and clean coal technologies is required. It further declared a revision in National Ambient Air Quality Standards (NAAQS) for 12 pollutants, which include SO_2, NO_2, particulate matter less than 10 micron (PM10), PM2.5, ozone, lead, carbon monoxide (CO), ammonia (NH_3), benzene (C_6H_6), benzo[a]pyrene ($C_{20}H_{12}$) (particulate phase), arsenic (As) and nickel (Ni), stipulated in November 2009.

The notification stated that transporting large amounts of ash wasted energy and created shortages of rail cars; shortage of port facilities; problems for power stations, including erosion in parts and materials; difficulty in pulverisation; poor emissivity and flame temperature; and excessive amounts of fly ash containing large amounts of unburned carbons.

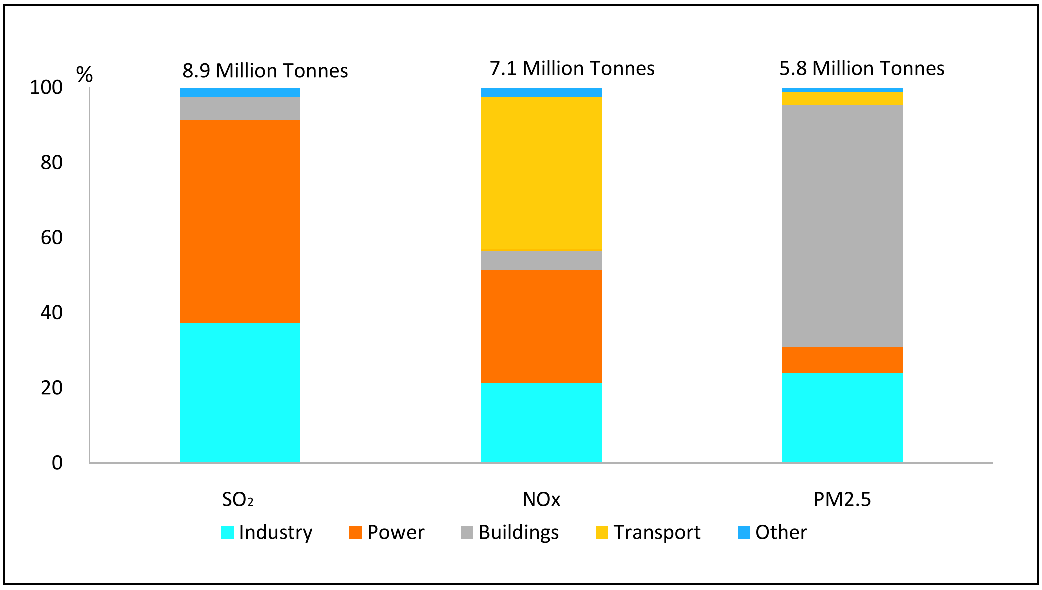
Box 4: Excerpts from Draft Rule (Notification)

In the form of a draft rule, the notification suggested that the following *power plants may use* raw coal or blended/beneficiated coal, with ash content not exceeding 34 percent and GCV not less than 4,000 kcal/kg on a *daily average* basis:

1. Stand-alone thermal power plants located beyond 500 km from pithead;
2. Captive installed capacity 100 MW or above, located 500 km from pithead; and
3. Any captive power plant above 100 MW or stand-alone thermal power plant located in urban areas or ecologically sensitive areas, as notified by the central government; or critically polluted industrial clusters or areas, irrespective of its distance from pithead, except any pithead power plant.

Thermal power plants using Circulating Fluidised Bed Combustion (CFBC) or Atmosphere Fluidised Bed Combustion (AFBC) or Pressurised Fluidised Bed Combustion (PFBC) or Integrated Gasification Combined Cycle technologies (IGCC) or any other clean technologies, as may be notified by the central government, were to be exempted from the rule.

Chart 9: Emissions by Air Pollutant and by Energy Sector in India in the New Policies Scenario



Source: Special Report on Emissions, World Energy Outlook, 2016.

Box 5: Excerpts from the Final Notification

The final Gazette Notification (G.S.R 02 (E)), dated 2 January 2014 by the MOEF&CC, contained some modification of the draft text. It stated that the following *power plants shall be supplied with* and shall use raw or blended/beneficiated coal with ash content not exceeding 34 percent on a *quarterly average* basis:

1. Stand-alone thermal plant of any capacity or captive thermal plant of installed capacity 100 MW or above, located 1,000 km from the pithead or in urban areas, ecologically sensitive areas or critically polluted industrial areas, irrespective of its distance from the pithead, except a pithead power plant;
2. Stand-alone thermal power plant of any capacity or captive thermal power plant of installed capacity of 100 MW or above, located 750–1,000 km from the pithead, effective from 1 January 2015; and
3. Stand-alone thermal power plant of any capacity or captive power plant of installed capacity of 100 MW or above, located 500–749 km from the pithead, effective from 5 June 2016.

It exempted thermal power plants using CFBC, AFBC, PFBC and IGCC or any other clean technologies, as may be notified by the central government, from the above-cited provisions.

The key difference between the draft and final version of the rule are:

a) the constraint of using coal of GCV 4,000 kcal/kg has been dropped in the final version;

b) the responsibility of coal beneficiation has been shifted to the supplier ("power plants shall be supplied with" rather than "power plants shall use" both [shown in italics text in Box 4 and 5]) in the final version;

c) the coal ash constraint limiting ash share to 34 percent is to be met on quarterly basis rather than on a daily basis, as suggested in the draft version (shown in italics text in Box 4 and 5).

Experts in the field see the shift in responsibility of washing coal from the user to the supplier as a positive move since the dominant coal supplier has access to vital resources such as land close to mines, railway linkages and quality testing facilities, which are inaccessible to third-party washery operators.

With regard to local pollution, the notification dated 7 December 2015 (SO 3305(E)) stipulates water consumption norms as well as norms for emission of local pollutants as follows:

Table 27: Emission Standards from Power Plants

Parameter	Standard
Thermal plants installed before 31 December 2003	
PM	100 mg/Nm^3
SO_2	600 mg/Nm^3 (for units <500MW)200 mg/Nm^3 for units > 500 MW)
NO_X	600 mg/Nm^3
Hg	0.03 (for units > 500 MW)
Thermal plants installed after 1 January 2003 and before 31 December 2016	
PM	50 mg/Nm^3
SO_2	600 mg/Nm^3 (for units <500MW)200 mg/Nm^3 for units > 500 MW)
NO_X	300 mg/Nm^3
Hg	0.03 mg/Nm^3
Thermal plants installed after 1 January 2017	
PM	30 mg/Nm^3
SO_2	100 mg/Nm^3
NO_X	100 mg/Nm^3
Hg	0.03 mg/Nm^3 mg/Nm^3

Source: Ministry of Coal

On the utilisation of fly ash, the notification dated 25 January 2016 (SO 254 (E)) stipulates the use of fly ash in its detailed provisions, some of which are captured below:

1. Every coal- or lignite-based thermal power plant (including captive and or co-generating stations) shall upload on their website the details of stock of each type of ash available with them and, thereafter, shall update the stock position at least once a month.
2. Every coal - or lignite-based thermal power plant shall install dedicated dry-ash silos, with separate access roads to ease the delivery of fly ash.
3. The cost of transportation of ash for road construction projects or for manufacturing ash-based products or use as soil conditioner in agriculture activity within a radius of 100 km from a coal- or lignite-based thermal power plant shall be borne by the particular coal- or lignite-based thermal power plant and the cost of transportation beyond the radius of 100

km and up to 300 km shall be shared equally between the user and the coal- or lignite-based thermal power plant.

4. Coal- or lignite-based thermal power plants shall promote, adopt and set up (financial and other associated infrastructure) ash-based product-manufacturing facilities within their premises or in the vicinity of their premises, so as to reduce the transportation of ash.
5. Coal- or lignite-based thermal power plants in the vicinity of cities shall promote, support and assist in setting up of ash-based product-manufacturing units so as to meet the requirements of bricks and other building construction materials and also to reduce the transportation.
6. To ensure that the contractor of road construction utilises the ash in the road, the authority concerned for road construction shall link the payment of contractor with the certification of ash supply from the thermal power plants.

The use of fly ash has been increasing progressively because of these enabling provisions. However, some experts in the field have observed that further increase in the use of fly ash may not be easy.

Though the environmental norms set by the MOEF&CC has had some positive impact, legal and economic experts have tended to be critical of the 'command and control' regime of environmental regulations in India, including those stipulating the use of washed coal.[110] Under such a regime, the penalties for non-compliance with regulations in general were thought to be disproportionate to the cost of compliance.[111] Drawing on the "polluter pays" principle, they proposed the use of an "economic instrument," namely an eco-cess on coal as an alternative means of achieving environmental outcomes. The argument behind it was that eco-cess should be set equal to the marginal damage caused by unwashed coal. As reliable information on the damage caused by high ash coal was not available, existing estimates of the cost of washing coal was used as a proxy for the damage caused.

Table 28: Eco-Cess Based on Beneficiation Costs as a Percentage of the Basic Price of ROM (NLF) Non-Coking Coal*

(CIL prices as on 17.8.2002)

Grade	Price of Coal		Eco-Cess as Percentage of Coal Price		Eco-Cess as Percentage of Final Price of Coal**	
	(Highest)	(Lowest)	(Highest)	(Highest)	(Highest)	(Lowest)
A	1628	912				
B	1447	819			-	-
C	1211	674			-	-
D	974	566	-	-	-	-
E	743	445	13.45	22.47	12.01	20:06
F	620	351	20-61	35.6	18.01	31.79
G	479	250	26.09	50.0	23.30	44.64

*Note: *For all grades of coal, price of steam coal and slack coal is equal to that of ROM coal plus INR 150 and INR 10 respectively.*

*** Final price of coal is taken to be 12 percent higher than the price of ROM coal*

Table 29: Eco-Cess Based on Beneficiation Costs as a Percentage of the Price of ROM Coking Coal

(CIL prices as on 31.1.2001)

Grade of Coal	Prices (INR)		Eco-Cess as a Percentage of Coal Price	
	Highest	Lowest	(Highest)	(Lowest)
SI	1695	1914	-	-
SII	1598	1416	-	-
WI	1385	1075	2.9	3.7
WII	1147	890	3.5	4.5
WIII	848	671	9.43	11.92
WIV	789	625	12.67	16.0
SCI	1360	1183	-	-
SCII	1126	907	3.55	4.4

Source (Table 28 and 29): Raja J. Chelliah et. al., eds., Eco-taxes on Polluting Inputs and Outputs (New Delhi: Academic Foundation, 2007).

The MOC, the CEA and some of the power generators opposed the introduction of an eco-cess as suggested by legal experts, on the grounds that it would (a) reduce competitiveness of domestic coal compared to imported coal, especially if duty on imported coal was halved as was proposed at that time; (b) increase demand for imported coal; (c) increase cost of power generation by about INR .10–.15 per kWh due to increase in price of E to G grades of ROM non-coking coal of the order 25–50 percent; (d) have an inflationary impact on the economy; and (e) make ash the only environmental externality of using coal while there were many others.

The issue of local environmental pollution (primarily PM, SO_x and NO_x) from power plants is likely to climb up in the list of Indian policy priorities, driven partly by demand for clean air from the articulate urban-rich and middle classes. The issue is important for India because (a) power plants are often located near cities and towns;[112] (b) India's population density is very high at 420 inhabitants/km^2 (12 times that of the US); and (c) around a quarter of the population lives near a power plant.[113]

7.5. Judicial Intervention

Poor compliance levels over the notification restricting ash content in coal transported over long distances has now led to the entry of judiciary in the domain. One interesting public interest litigation (PIL), filed by a resident of Nagpur in Maharashtra, alleges inaction by environmental regulatory authorities of the MOEF&CC, and the Maharashtra Pollution Control Board, regarding violation of the notification stipulating maximum ash content of 34 percent by coal-based thermal power plants of the Maharashtra State Power Generation Company Limited.

The order on the above PIL, issued in 2015 by the National Green Tribunal, Western Zone, stated that (a) the State Pollution Control Board (SPCB) and the CPCB shall incorporate the necessary condition for supply/use of required coal quality (standard) in the consent granted to coal mines/companies and coal-based thermal power plants; (b) the SPCBs and CPCB shall develop necessary capacity for sampling and analysis of ash content of coal at their respective laboratories as per the relevant Indian standards; (c) the CPCB shall provide all the technical assistance for such infrastructure development, provide training to scientific manpower and ensure the compliance of this direction; (d) till the automatic real-time online monitoring system is installed and operated by the coal companies and the thermal power plants, SPCBs shall take monthly samples for the coal ash content and ensure the compliance of notification.

The reaction to this order is mixed. While private washery operators see this development as a strong push for implanting the notifications of the MOEF&CC, restricting ash content in coal transported over long distances, power generators see this as a conclusion that is not balanced with financial constraints, under which they must operate.

Overall, the expansion of coal beneficiation capacity and the use of clean coal in India for greater energy security and environmental protection appears to be less of a technical or regulatory compliance problem and more of an economic problem. Coal washing increases the upfront cost of coal and, in the short term, also increases the cost of the output, such as electricity. In general, the cost of electricity from coal-fired power generation using clean coal was found to be lower only when all the plant costs associated with using unwashed coal are included in the longer term.

8 Under Utilisation of Capacity For Coal Beneficiation

The key message from the studies on coal beneficiation conducted in the past two decades was that coal users recognised other benefits (apart from savings in transport cost) of coal washing in principle, but they attributed very low monetary value to these benefits by the power stations. Savings in ash-disposal cost, for example, was estimated to be less than INR 5/tonne according to one study. The money price did not necessarily reflect the broad environmental benefit due to reduced land requirement; reduced handling and transport costs; and other social benefits such as reduced resettlement, reduced effects on the cultivation in the impact zone, and improved health and living conditions.

Moreover, studies in the past attributed technical mismatch between a particular type of washed coal and the specific design requirement of the boiler to the inability of power-plant operators to assess financial benefits accruing to the power stations. These financial benefits would be a result of greater plant availability, increased efficiency or better flame stability. The studies identified the use of beneficiated coal as the reason for the inadequate demand for washed coal. Most power stations reported that they were able to achieve the required standard for particulate emission; they did not anticipate a shortage of land for ash dumping because land was cheaply allocated to users who were essentially public-sector operators.

The current study, on which this report is based, revealed that though some aspects, such as the participation of the private sector, change in pricing of coal, and flexibility in coal-distribution linkages, have changed for the better, broader concerns remain the same.

There was overall consensus among stakeholders that washed coal is more desirable and that coal washing should be widely adopted. However, consumers of coal, especially those from the power sector suggested that among key reasons for underutilisation of capacity for washing coal was that the policy directive that influenced setting up of washeries prioritised environmental desirability over economic viability and did not take into account the cost of compliance. Some of the stakeholders felt that the directive was at variance with the growing influence of commercial and market forces on all segments of the coal-mining and power-generation value chain.

In the past, washeries of CIL or other users (such as those set up by some SEBs) were based on the policies of GOI that allowed washeries to be set up by the coal producer or consumer for their own captive use. The open policy of allowing private entrepreneurs to set up washeries—for their own use or for other users—has not been as successful as one may have hoped, since they were outside the system of existing linkages between coal production and consumption.

At a more granular level, washing and the cost of using washed coal for power generation differed depending on the type of coal, quality difference within each type, difference in distance between mine and power station, the technology used for power generation, and other parameters such as tariff structure in the particular state. This meant that the benefits of using washed coal could not be generalised across different users from the power sector. On the other hand, washery operators suffer from underutilisation of capacity for coal beneficiation because of poor enforcement of the directive limiting ash content in coal. Key reasons for the lack of momentum in coal washing, as far as washeries are concerned, were: overwhelming power of the monopoly supplier of coal, and its influence over regulation of the sector, including defining and monitoring of quantity and quality of coal as well as the transport of coal.

The contribution to energy security in terms of higher utilisation of domestic coal and the value of railway capacity released as key benefits of coal washing were acknowledged by both the power-sector consumers of coal as well as the washeries, but their observations suggested that these benefits need to be considered in a much broader context than coal washing. They are presently unquantifiable in precise terms because of masking by cross-subsidy in the tariff systems (both railways and electricity).

8.1. Realisation of Economic Gains

For power plants, variable quality was as much of a problem as overall poor quality in the coal supplied. Large-sized shales and stones in the coal supplied were reportedly creating problems in flame stability. Power plants thus desired coal of consistent higher quality. However, washed coal was not their first choice for higher quality coal on commercial grounds.

Key among first-order challenges in adopting coal beneficiation appeared to be that of high transaction costs of involving a third party (that of a washery) between the coal supplier and consumer, which included financial and non-financial costs. In an inflexible system of coal flow, sourcing of coal from one company and getting it washed through another agency skewed preference in favour of raw coal.

Among numerous second-order challenges pointed out by power generators was the fact that economic benefits of washing coal that were documented in theory were not realised in practice. For some users, the gains in heat value due to reduction in ash were often lost due to increase in moisture. The cost of rejects was charged to washed coal price, but this increase in cost of washed coal was often not compensated through economic gains, such as saving in transportation cost. For example, it was observed that the quantity of rejects varied from 18–20 percent for coal from Korba field to 30–35 percent for coal from Talchar or Ib Valley, when raw coal is washed to 34 percent ash. Plants that could not accommodate this loss were reported to prefer blending of domestic coal with higher quality imported coal. Some users pointed out that washing charges were not a "pass-through" item in power tariff when coal is washed by private player.

The loss of heat value in rejects and the absence of an arrangement to compensate for this loss were also among the foremost challenges identified by washeries in the private sector. Typically, for every 1 percent reduction in ash, the yield was reported to drop by 3.5 to 4.5 percent and for reduction of ash from 40 to 34 percent, the yield was in the range of 70–80 percent.

In this regard, two issues were highlighted. The first was the ability of the system to make up for the volume loss in terms of additional coal. Until 2015-16, indigenous coal was in short supply and coal was, therefore, not available to users outside the linkage system.Availability of domestic coal has improved substantially since then. If indigenous coal is available to make up for the loss from coal washing, power generators may opt for washed coal in the future.The second issue was the loss in heat value in rejects. Making use of the available residual heat content in rejects, using suitable type of combustion system was seen to be unavoidable to make washing economically feasible.

Among many second-order financial, commercial and transactional issues, which tend to increase the cost of using washed coal brought out by coal washeries, was the issue of penalty charged by power generators for short-lifting of raw coal as well as lower dispatch of washed coal in their work order. When coal companies failed to supply raw coal or railways failed to supply wagon capacity for dispatch of washed coal, washery operators were penalised, even though it was known that these issues were beyond the control of the washery operator. Another second-order challenge was that coal producers followed a 'cash and carry' system for consumers who obtained coal through washeries, but offered less rigid terms for consumers who procured raw coal directly. Those getting raw coal washed thus suffered a penalty in terms of interest payment loss due to advance payment to the coal company. This was said discourage consumers, especially financially constrained SEB-owned power companies, from using washed coal.

Overall, the realisation of economic gains in using higher-quality coal appeared to be undermined by skewed distribution of risks and rewards in the system that was biased against smaller parties in the value chain, who were not part of the broader public sector that dominated the system. The regulation of power tariff was also among the major constraints in adopting coal washing or any measure for quality improvement in the rest of the value chain.

The interactions with key coal users that there is awareness of the immediate extra costs that the use of washed coal will involve. Power generating companies know that there will be some countervailing savings on transport, but the breakeven distances (that is, when transport-cost saving equals washing costs) are assumed to be high. Some power plants seem to take only a limited account of savings in operational costs; in their view, these appear somewhat theoretical and untested. Some power plants claimed that potential benefits arising from savings due to coal washing cannot be realised. There appears to be a general belief that although lower ash coal will have benefits, these will not be sufficient to repay the costs of washing, especially in the short time cycles available for financial balancing.

8.2. Impact of the Regulatory Environment

The objective of environmental policy set by the MOEF&CC regarding coal beneficiation is to ensure the achievement of environmental standards, which is desired by all stakeholders.

However, the use of clean coal is seen as one of several possible ways of achieving this policy objective. Currently, coal users do not see this as the most economic means to achieve the environmental policy goal. Though no stakeholder stated this explicitly, more flexible approaches to achieving environmental policy goals—which take into account specific attributes of coal such as coal quality, transport distances, boiler technology—on a case by case basis may elicit greater compliance to the directive limiting ash content. The disadvantage of flexibility, as pointed out by one of the stakeholders, was that it would require judgements to be made locally, which in turn meant that local bodies such as the SPCB would require high-quality local monitoring capacity. Development of local monitoring capacity could be a policy priority in this regard.

8.3. Structural and Institutional Impediments

The inputs from washery operators suggested that the development and utilisation of coal washeries in the last few years suffered not only because the economic aspect was unfavourable but also because the flow of coal from the supplier to the consumer was mediated through a system of linkages administered by the government.The introduction of a third party (washeries owned by the private sector) in this relatively inflexible system did not favour washeries. Not only were washeries unable to obtain a firm commitment on the supply of requisite quality and desired quantity of raw coal from the supplier, they were also unable to enter into an agreement with public-sector power generators, who were reluctant to partner with the private sector. When power utilities did enter into an agreement, terms were often unfavourable to washeries, which had to bear a disproportionate share of risks. The environment of coal supply shortages in the last decade did not help the situation, as coal washeries were seen to be a conduit for diversion of scarce coal supplies into alternative markets.

Typically, coal was made available to washeries from a basket of mines (linkages granted company-wise and not mine-wise) producing coal of different washability characteristics. Washeries that were designed for coal with particular characteristics were at a disadvantage as they were penalised for slippage in ash content as well as slippage in GCV by the power companies. Issues such as availability of land for setting up washeries and land for disposal of washery rejects, access to infrastructure such as power, water and railway siding were also brought up as challenges for private washeries. As land adjacent to coal mines was in possession of the coal miner, washeries could not be put up in close proximity to the mines, which was critical from both economic and environmental perspectives. Other second-order challenges conveyed by coal washeries included access to rail wagons. When wagons were in short supply, priority was given to raw coal loading, which was seen to be influenced by power generators.

Grade slippage, the significant gap between quality of coal on paper and the quality of coal actually supplied, was a problem reported by coal washeries and coal users. Historically, grading of coal was carried out by the Coal Board, which was independent of the MOC and so, if consumers were not satisfied with the quality of coal as per declared grade, the Coal Controller, a statutory authority, re-assessed the quality of coal and downgraded the quality when necessary. Currently, grading of coal carried out by coal companies and the Controller is under the MOC. According to private washery operators, they are excluded from joint sampling of raw coal at the time of delivery of raw coal on behalf of the power plant and they often take inferior quality coal to comply with off-take obligations, even though this affects yield significantly. Overall, both washeries and power generators identified as challenges the dependence on a single supplier and the absence of an independent regulator to monitor quality. This problem may be addressed if the ownership of coal to be washed either remains with the coal supplier (CIL) or with the power generators owning the linkage.

In the larger context, benefits of using washed coal such as greater efficiency is primarily appropriated by the nation (in terms of lower investment in additional capacity and lower pollution levels) and are not perceived at the operating power-station level. Overall, savings directly perceived by the coal consumers constitute only a part of the true economic benefits of using washed coal.

9 Recommendations

The idea of washing coal, especially non-coking coal used for power generation, yielding economic and environmental benefits is not new. The Ronghe Committee report of 1988 acknowledged these benefits. Even today, there is little disagreement among stakeholders that benefits exist in washing coal, but they differ on quantification of the benefits. These benefits are not free, as costs are involved in coal beneficiation. Some are financial, such as the increase in the cost of fuel, and some are transactional, such as how the process of coal beneficiation can be accommodated in the established system of coal supply and distribution.

9.1. Structural Issues

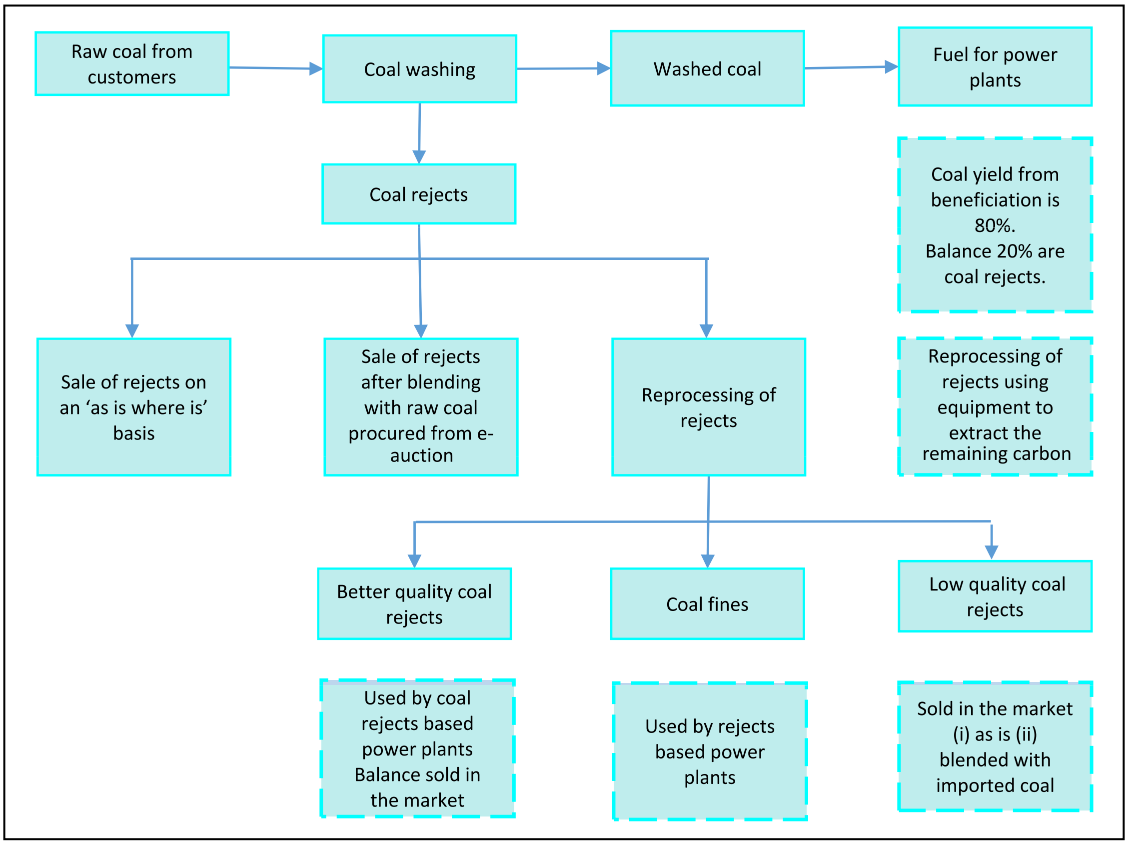
Ahead of further de-control in the coal sector, widespread introduction of long-term coal supply contracts to address some of the issues raised may be desirable to protect producer and consumer interests. Such contracts are likely to serve as the natural medium to govern the supply of washed coal. In the future, coal may be supplied from new private-sector miners. Should these private companies be required to produce washed coal, or otherwise see a customer demand for clean coal, they will build, own and operate such a plant themselves, following the general model adopted internationally for coal producers to wash coal.

As Indian coal is inherently difficult to wash, the loss in calorific value in rejects is often too high to disregard as 'waste'. Moreover, the rejects that contain combustible matter cannot be safely disposed due to problems of self-ignition. At the national level, the ideal situation will be for coal to be washed to the extent possible and the rejects used in an FBC boiler at the pithead. But this will involve additional incremental costs such as (a) additional mining of coal to make up for loss in the process of washing; (b) overall reduction in thermal efficiency in power generation; and (c) investment of capital in washeries and in the FBC plants.

The benefits include but are not limited to: (a) reduced transportation cost; (b) lower demand on rail capacity; (c) reduced operating cost at power stations; and (d) lower emission of pollutants. Economic benefits do not often translate into financial savings.

The environment could gain from coal washing, especially if pithead FBC generation is included. Land use and population displacement may also increase, both because of the plant operation and because of the additional mining necessary. Water use and emissions of dust and SO_2 could potentially be lower. CO_2 emissions will reduce without FBC, but emissions may increase with the FBC option for using rejects. There is a possibility that the value of freeing railway capacity may not be as high as presumed, since present tariff levels are very high and, often, the largest component in the price of delivered coal.

Chart 10: Flow Chart of Coal Washery



Source: Crisil

If some part of the savings that are expected from coal washing is passed on to coal suppliers (including washeries) it can create an incentive to produce washed coal. Benefits at national level could justify public support. Coal beneficiation offers a straightforward case for utilisation of the NCEF that is collected through a cess of INR 400/tonne of domestic coal production. The estimated NCEF collection for 2016-17 from CIL is about INR 239.44 billion (about $3.5 billion) out of which about a quarter is budgeted.[114] If the negative environmental externalities are internalised through environmental charges on power stations based on the 'polluter pays principle' it could attract private investment in washing. Free negotiation between the parties concerned may lead to a more optimum solution given that costs and benefits vary from case to case.

9.2. Environmental Issues

Policy on coal beneficiation that is anchored in both economic and environmental considerations is likely to have greater impact. It is well known that for coal flows across long distances, washing coal leads to lower overall costs, so that environmental benefits are thought to be effectively free. Savings in transport costs is one element, and it does not apply to all power plants. Other factors such as improvement in thermal efficiency, reduced land requirement for ash disposal or reduced support fuel must also be taken into account for other power plants.

A system of permits, fees and fines, as used in some coal producing and using countries, may be considered.[115] Taking the land requirement for ash disposal under this system, a power station receives a permit to dispose of a certain quantity of ash; the permit is case specific and needs a local environment enforcement agency to approve it. The fees are paid on actual disposals and is related to the environmental value of land used for dumping. It could also cover the future costs of full reinstatement of the lands used. Fines are paid on disposals in excess of permit. The permit limits are set at a high enough level to act as a deterrent so that the power stations avoid excess dumping by opting for washed coal. Environmental levies or fines imposed on plant operators for permits or for violating standards can be recycled to fund environmentally desirable projects.

Box 6: Macro-Economic Impact of Coal Washing: Experience from China

Overall, the prospects of coal cleaning are promising. Intuitively, the higher the heat value, the lower the emissions and lesser the transportation costs of washed coal. However, it may be useful to be aware that the outcome for the economy at the macro level may be different as illustrated by a macroeconomic simulation study of washed coal use in China.[116] Attractive properties of coal cleaning at the micro level turn out to have significant drawbacks at the macro level, such as increased energy use, higher energy intensity and rising CO_2 level.

When the price of washed coal falls (because of investment in capacity and consequent increase in supply of washed coal), users take into account composite benefit from higher heat value, lower transportation costs and reduced maintenance costs. The local government and citizens may take into account air quality and improved cleanliness in the working environment. However, the initial reduction in washed coal price due to higher productivity tends to increase the number of users that find clean coal attractive enough to switch. Clean coal demand increases correspondingly, until the price of clean coal increases sufficiently in relation to the raw coal price to re-establish equilibrium. The heat value gains following a switch to washed coal lead to reduced demand for raw coal and the ROM price of coal is lowered. Thus, the energy saving obtained by increasing the share of clean coal generates a feedback to all coal users as reduced coal prices in general.

The aggregate effect of many users' decisions to increase their shares of washed coal is that the total demand for transportation is reduced and so is the market price of transportation. Users assess the coal prices including transportation costs, and the transportation cost reduction generates a positive feedback to the coal demand in general, since coal use demands transportation.

Higher coal energy efficiency may simulate heavy industries as it will reduce energy costs, where large production units already have installed SPM cleaning measures. Therefore, particle emission effect in higher coal use in process industries may be mitigated to some extent. If the price of coal is deregulated, the use of washed coal increases significant, contributing to an increase in CO_2 emissions even though total SPM emissions reduce.

Key observations of the study are that coal beneficiation was a case for economic efficiency more than energy saving. The attractive energy efficiency gains stimulates energy use to an extent that dominates over the limited energy saving. The study concludes that coal washing is more efficient as a measure to reduce local air pollution than as an instrument of climate policy. Improvement in economic efficiency, including energy efficiency, created a slack in the capital constraint and allowed production to expand without being met by increasing costs. This should not discourage the use of washing coal in India as it might improve economic efficiency and increase GDP, which is a priority for a developing country such as India. As the thickness of the coal seam decreases, improving the quality of ROM coal through coal beneficiation can also add value and improve marketability of Indian coal even outside India.

Levies for ash disposal from a power station can also encourage the operator to sign a long-term clean coal supply contract with a potential BOOT company, giving that company the firm foundation to raise funds for the washing plant.

9.3. Investment in Coal Beneficiation

Widespread concern about the quality of coal delivered to power plants is evident. However, this does not unambiguously point to setting up of washeries. Rather, it points to an absence of quality assurance by the producers, an issue that can be addressed through policy and regulation. However, in most of the cases, the comprehensive balance of costs and benefits appears to justify coal beneficiation. At the power plant level, since only one part of the benefits (from freight savings) will be immediately visualised and other benefits (like improvement in plant availability and thermal efficiency) will be felt only in the long term, it is unlikely that demand for washed coal will materialise spontaneously without any push from policy.

Flexibility in choice between coal qualities will reflect a real option to users with widely different technologies. However, boilers currently in use may not be equally able to extract the final heat value of washed coal. Overtime, inefficient boilers are likely to be replaced, increasing the scope for maximising benefits of washed coal.

The MOC has oversight on coal sector regulation and the activities of the state-owned coal companies,it is most directly concerned with implementation of coal washing. Recent news reports suggest that the MOC favours increased beneficiation of coal. However, where public funding is involved, coal washing plants may be put at a lower priority than investment to rehabilitate and expand coal production. Further investment from the private sector, either for technology upgradation or for greenfield projects, is unlikely given the dire status of the private-washery sector. Unproductive washery assets of the private sector may be acquired by coal producers and utilised to the extent possible, as new capacity in washing will take some time to materialise. Alternative models for setting up coal beneficiation plants and their respective advantages and disadvantages are given in table 10.2 (Annexures).

Parameters that need to be ensured for washery project to become viable are (a) firm source of coal supply; (b) commitment on supply of evenly spread and defined quantity of coal over a reasonably long period say 15 to 20 years; (c) Commitment on quality of raw coal feed (size, ash, moisture etc.); (d) Land for setting up of washery; (e) Allowing backfilling of rejects into the mine; (f) Sharing of infrastructural facilities such as power, water, siding etc.;

Developing coal washery in a cost-effective manner is possible only if the coal washery is set up by the coal producer itself, wherein it can make the best use of sharing the common facilities. This will also eliminate risks associated with achieving the above-stated parameters through a contractual arrangement with the washery developer.

10 Annexures

10.1. Thermal Power Plants Required to Use Beneficiated Coal from June 2001

A) Existing

Name of Thermal Power Station	Capacity (MW)	Category	Estimated Annual Coal Requirement for 1,000–2,000 (MTPA)
Badarpur	705	UA	2.75
Indraprastha	278	UA	0.87
Rajghat	135	UA	0.58
Faridabad	165	UA	0.80*
Panipat (Units 1–5)	650	> 1000 km	3.60*
Bhatinda (Units 1–4)	440	> 1000 km	1.98
Ropar (Units 1–6)	1260	>1000 km	5.08
NCR Dadri	840	>1000 km	4.00
Harduaganj	425	>1000 km	1.06
Panki	274	UA	0.79
Paricha	220	>1000 km	0.89
Kota (Units 1–5)	850	UA	3.65
Sabarmati	410	UA	1.32*
Wanakbori (Units 1–6)	1260	>1000 km	6.06
Gandhinagar	660	UA	3.00*
Ukai	850	>1000 km	3.36*
Sikka (Units 1–2)	240	>1000 km	1.00*
Bhusawal	478	>1000 km	2.24
Koradi	1080	UA	5.50*
Nashik	910	>1000 km	3.60
Trombay	1150	UA	Oil/Coal
Dahanu	500	SA	2.01
CESC and Southern	190	UA	0.72*

Name of Thermal Power Station	**Capacity (MW)**	**Category**	**Estimated Annual Coal Requirement for 1,000–2,000 (MTPA)**
Tatagarh	240	UA	0.96*
DPL	390	CPA	0.49
Muddanur	420	>1000 km	2.37
Rayalaseema	630	UA	2.97
North (Chennai-1)	450	>1000 km	1.92*
Ennore	840	>1000 km	4.38
Raichur (1–4)	840	>1000 km	4.39
Mettur	1050	>1000 km	4.08*
Tuticorin (1–5)	820	CPA	1.84
Bokaro	350	CPA	1.00
Durgapur			
Sub-Total (A)	**20,000**		**79.05**

Source: Raja J. Chelliah et.al., eds.,Ecotaxes on Polluting Inputs and Outputs, (New Delhi: Academic Foundation, 2007).

B) Ninth Plan

Name of Thermal Power Station	**Capacity (MW)**	**Category**	**Estimated Annual Coal Requirement for 1,000–2,000 (MTPA)**
Bhatinda 5, 6	420	>1000 km	1.88*
Wanakbon7	210	>1000 km	1.00*
Gandhinagar7	210	>1000 km	0.95
Raichur 5, 6	420	>1000 km	2.14
North Chennai-II	1050	UA	IC
Mangalore	1000	>1000 km (Imported coal)	IC
Tranagallu	260	>1000 km	IC
Suratgarh-I	500	>1000 km	IC
Sub-Total (B)	**4070**		**5.97**

Note: Total coal consumption based on 1999–2000 data up to Ninth Plan was 87.14 MTPA.

**Revised based on the data provided by SEBs/Utilities; IC: Imported Coal; UA: Urban Agglomerates; CPA: Central Plan Assistance.*

Source: Raja J. Chelliah et. al., eds., Ecotaxes on Polluting Inputs and Outputs (New Delhi: Academic Foundation, 2007).

10.2. Alternative Models for Setting up Coal Beneficiation Plants

Model	Structure	Benefits	Challenges	Remarks
Washery of Power Generator	The power generator will own and operate coal washery.	It has the potential to meet coal quality standards of the user.	Power generators have limited understanding about coal washing. Coal-washing plant will be near the mine and not near the power station on economic considerations, which will reinforce their reluctance to get involved directly in coal washing.	Very unusual model, not practiced in any coal producing and consuming country.
Private Company Operated through BOO	Private company contracted to build, own and operate the washery by CIL..	Attract private capital for setting up washeries.	Requires the tradition of legal contracts, covering long-term coal supply agreement. Contractual complexity of finding the right balance between risk and reward is high. Contract will have to cover coal feed in, washed coal out, landuse, water, power, access, railways, rejects, financial stages and liquidated damages, which have to reviewed periodically. Penalties and compensation covering variations in quantity and quality of raw coal may be biased against private operator, given the disproportionate power of CIL. Magnitude of losses in the worst-case scenario is too great for the operator.	Model pursued in India in the last decade. The BOO model of Punjab SEB may not be ideal and may not be widely replicated because of the general reluctance of power companies to involve themselves with coal preparation.

Model	Structure	Benefits	Challenges	Remarks
Private Company BOOT Schemes	Contractor will build own, operate and trade in coal (purchase coal, wash it and trade washed coal).	Attract private capital for setting up washeries. Lower contractual complexity (no need to capture performance of the operators in the contract). Operator only requires raw coal purchase and clean coal sale agreements. Profit will be the motive for performance.	Cannot be accommodated under supply arrangements such as linkages.	Not commonly used in the rest of the world.
Joint Venture Schemes	Joint venture between CIL and private operator.	Attract private capital for setting up washeries. Will overcome primary shortcoming of BOO model, as CIL and the contractor will have a shared interest in the plant operating efficiently.		

ENDNOTES

1. India's financial year starts from April 1 of the year and ends on March 31 of the subsequent year.
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