A Case for Enhanced Use of Clean Coal in India:
An Essential Step towards Energy Security and Environmental Protection

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EXECUTIVE SUMMARY

India ranks third in world coal production, producing 407 million metric tons (mt) of coal in 2006. The majority of this production, approximately 85%, is used for thermal power generation. Electricity from coal currently accounts for 71% of India's total 67 gigawatts of power generated. Total power generation for coal is projected to increase to 161 gigawatts by 2030, with an associated projected increase in coal production to 750 mt. With a growing concern over energy security and sustainability, coupled with concerns about climate change and greenhouse gas emissions from coal combustion, the long term generation of coal-based thermal power by India will require the use of cleaner coal and clean coal technologies (CCT). Coal beneficiation (CB) is the first and most cost effective step toward satisfying this requirement.

Indian coals are of poor quality and often contain 30-50% ash when shipped to power stations. In addition, over time the calorific value and the ash content of thermal coals in India have deteriorated as the better quality coal reserves are depleted and surface mining and mechanization expand. This poses significant challenges. Transporting large amounts of ash-forming minerals wastes energy and creates shortages of rail cars and port facilities. A low-quality, high-ash coal also creates problems for power stations, including erosion in parts and materials, difficulty in pulverization, poor emissivity and flame temperature, low radiative transfer, and excessive amounts of fly ash containing large amounts of unburned carbons. On the other hand, the benefits of using beneficiated coal are well documented and include reductions in erosion rates and maintenance costs in power plants, and increases in thermal efficiencies and reduction in CO_2 emissions. Further, if IGCC or supercritical PCC is used in the future, the thermal efficiency can be further increased resulting in even greater GHG reductions. However, use of these state-of-the-art technologies requires consistent supply of clean coal to achieve the maximum overall thermal efficiencies. Even fluidized bed combustors (FBC), which are capable of burning lower-grade coals, would operate more efficiently with higher-grade coals.

In light of the many benefits associated with the beneficiation of coal, considerable interest has been given in recent years to the development of processes capable of improving the quality of coals produced and used in India. The US Government, through several bi- and multi-lateral mechanisms with the Government of India, including the US Department of Energy's Energy Dialogue and the Asia-Pacific Partnership on Clean Development and Climate are focusing on coal beneficiation as part of a broad fossil energy agenda, and is reaching out to US industry engagement with India. Activities are aimed at addressing the energy security needs of India while utilizing the technical expertise and clean coal technologies from the US. These efforts include (1) improving the visibility of U. S. firms and their products by technical exchange visits, workshops, etc., (2) strengthening interagency coordination of federal programs pertinent to these activities, and (3) improving existing programs and policies for facilitating the transfer of coal-related technical assistance and technologies abroad.

India has been slower than other countries in embracing coal beneficiation as part of normal operating practices in thermal power generation. Reasons cited for the slow acceptance include the lack of stringent emission standards and the misleading perception that coal beneficiation adds to the cost of electricity generation. This paper characterizes the benefits derived from using cleaner coal to produce thermal power utilizing case studies from India and highlights the existing challenges to enhance coal beneficiation capacity and the use of clean coal in India.

INTRODUCTION

The International Energy Agency (IEA) predicts that world energy demand will grow approximately 60% over the next 30 years, most of it in developing countries such as India which has substantial quantities of coal reserves. India ranks third in the world both in terms of coal production (407 million tones) and coal consumption (around 425 million tonnes). India, along with China, account for 70% of the projected increase in world coal consumption. Strong economic growth is projected for both countries (averaging 6% per year in China and 5.4% per year in India from 2003 to 2030), and much of the increase in their demand for energy, particularly in the industrial and electricity sectors, is expected to be met by coal.[1]

In India, almost 70 percent of the growth in coal consumption is expected to be in the electric power sector and most of the remainder in the industrial sector. In 2003, India's coal-fired power plants consumed 5.0 quadrillion Btu (1.26 quadrillion kcal) of heat from coal, representing 69 percent of the country's total coal demand. Coal use for electricity generation in India is projected to grow by 2.7 percent per year, to 10.3 quadrillion Btu (2.6 quadrillion kcal) in 2030, as an additional 94 gigawatts of coal-fired capacity (net of retirements) is brought on line. As a result, India's coal-fired generating capacity more than doubles based on *IEO2006* projections, from 67 gigawatts in 2003 to 161 gigawatts in 2030.[2] Currently, India's government is targeting the completion of more than 50 gigawatts of new coal-fired capacity during its eleventh plan period (April 2007-March 2012).[3]

Coal will remain the dominant fuel in India's energy mix through 2030. Demand is projected to grow from 407 Mt in 2006 to 758 Mt in 2030, at an average rate of growth of 2.4% per year. The power sector will be the chief driver of Indian demand. Currently, 71% of India's electricity is generated from coal.[4] Total coal supplied to the power utilities in 2005–06 was 317 million tonnes; the steel and cement sectors are second and third largest consumers respectively.[5] India's coal needs will be largely met domestically. India has 92.4 billion tonnes of proven coal reserves, 9.3% of the world total.[6] Coal is located mainly in the center and east of the country, far from the main consuming areas (Figure 1).[7] As a result, large quantities of coal are transported by rail over long distances.

Although India has significant quantities for coal, the quality of the coal is poor and often contains 30-50% ash when shipped to power stations. Over time, the caloric value and the ash content of thermal coal had deteriorated as the better quality coal reserves are depleted and surface mining and mechanization expands. Most coal power plants burn coal without any prior cleaning. Transporting large amounts of ash-forming minerals wastes energy and creates shortages of rail cars and port facilities. Burning low-quality, high-ash coals also creates problems for power stations, including erosion, difficulty in pulverization, poor emissivity and flame temperature, low radiative transfer, excessive amount of fly ash containing large amounts of unburned carbons, etc.[8, 9] The use of beneficiated coal can reduce erosion rates by 50-60% and maintenance costs by 35%.[10, 11] In addition, the use of beneficiated coals could increase thermal efficiencies by as much as 4-5% on existing PC boilers with an accompanying reduction of CO_2 emissions by up to 15%. Further, if IGCC or

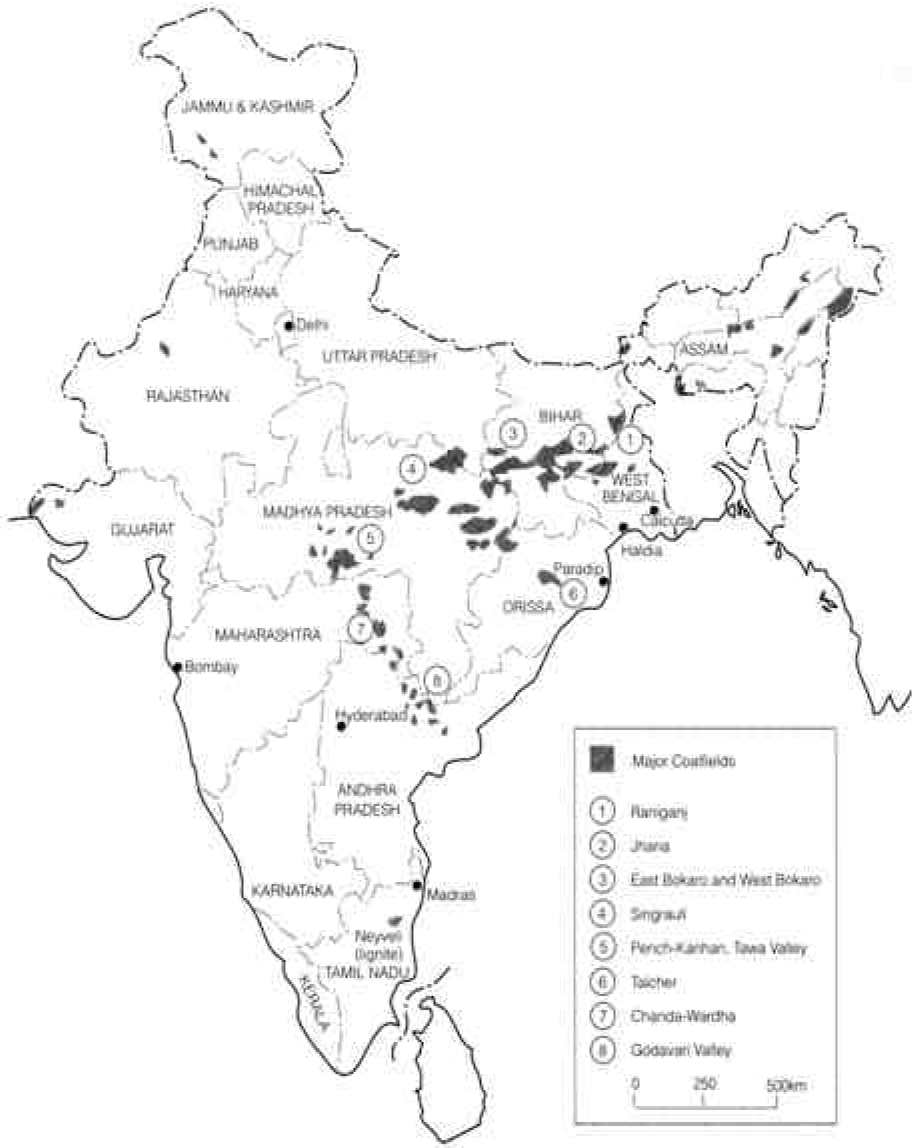


Fig. 1 Major Coal Fields of India
(Ref: IEA Coal Research Report "Major coalfields of the World," CCC/32, 2000)

supercritical PCC is used in the future, the thermal efficiency can be increased from 30 to 45%, which will make more substantial GHG reductions. However, use of these more advanced technologies will require a consistent supply of high-quality coals to achieve these maximum overall thermal efficiencies. Even technologies that are designed to use lower grade coals such as fluidized bed combustors (FBC) would operate more efficiently with higher-grade coals.[12, 13] Thus, the development of processes capable of improving the quality of coals mined and consumed in India is a critical need.

The US Government, through several bi- and multi-lateral mechanisms with the Government of India, including the US Department of Energy's Coal Working Group and the Asia-Pacific Partnership on Clean Development and Climate's Coal Mining Task Force recognize the need for improved coal processing in India.[14] Activities of these groups are aimed at addressing the energy security needs of India while recognizing the critical role that US technology can play in addressing these challenges. The need to produce clean coal in India creates international market opportunities for U. S. technology suppliers, developers, architect/ engineers, and other U. S. firms that can share the advantages gained through coal beneficiation experiences from US coal and power production. Through these international mechanisms, the US Government and industry have formed a partnership, and efforts are underway to: (1) improve the visibility of U. S. firms and their products by technical exchange visits, workshops, etc., (2) strengthen interagency coordination of federal programs pertinent to these activities, and (3) improve existing programs and policies for facilitating the transfer of coal-related technical assistance and technologies abroad.

Among the many activities being pursued among these international activities, are efforts to enhance the effective utilization of India's coal resources through the advancement of coal beneficiation and the use of clean coal. The focus of this paper will be on highlighting the costs and benefits of coal beneficiation, as well as the true costs of using dirty coal and its impact on human health, transportation costs, power plant efficiency and maintenance. This type of information will provide government decision makers with a balanced assessment of the value and need to expand coal beneficiation capacity and the use of clean coal in India.

GENERAL DISCUSSION

GOVERNMENT ROLE IN COAL

Coal reserves and the right to mine coal in India are controlled by the Government of India (GOI). The nationalization of coking coal reserves occurred in 1971-72 and all other coal reserves in 1973. At present India's coal industry is dominated by government owned companies. Coal India Ltd, a Central Government company, is the biggest producer of coal (84.4%) followed by Singareni Colliery Company Ltd. (8.9%), a joint venture company of Central and State Governments.[15] Some other smaller public undertakings exist for meeting their captive requirement. In the private sector, TISCO and Jindal Power and Steel (JSPL) are major coal producers. The present statutory and regulatory provisions allow captive mining in the private sector for approved end users including power, iron, steel and cement. A large number of coal blocks have been allocated under this dispensation. These allocates may form a subsidiary or joint venture company to carry out mining activities subject to specific conditions. For captive consumption and washeries, 100% foreign direct investment (FDI) is permissible in coal mining. The captive mines are expected to add substantially to coal production of the country.

COAL PRODUCTION

Due to the geology; India depends primarily on open cast mining (85%) to meet growing demand. These mines are characterized by low stripping ratio (typically less than 1:1) with the mining zones comprised of several seams banded together that are typically 30 to 70 meters (100 to 200 feet) in total thickness. Indian coals are predominantly high in ash. Run of mine (ROM) product ash quality is generally greater than 30% ash on an 'as-mined' basis with the current average being 36-38%. These coals are from the Gondowana geological formation.

Mass production technologies like draglines, electric and hydraulic shovels, and large capacity dump trucks are being used. In underground mines, continuous miners and longwalls are beginning to be adopted. New mining technology initiatives are needed to address coalfields that lie in remote areas and occur in hillside tracts (steep seam mining) to achieve improved production performance and extraction percentage. The trends in coal production are listed in Appendix 1 for the prior three year period.

COAL BENEFICIATION

A cost-effective and significant step toward improving power plant efficiency and reducing the GHG emissions from the coal-fired power plants in India would be to increase the availability of clean beneficiated coals using appropriate beneficiation technologies. Coal beneficiation (or cleaning) is widely viewed as the lowest-cost option for India to address these goals. According to IEA reports, increasing the quality of coal is an essential step toward the deployment of the state-of-the-art Clean Coal Technologies (CCTs) in India. Coal beneficiation is a low-cost solution that can (i) produce higher-quality coals that can be burned more cleanly and with greater efficiency, (ii) reduce the amounts of emitted fly ash and associated hazardous air pollutant precursors, (iii) minimize capital, operating and maintenance costs associated with coal fired power generation, (iv) lower costs and free up capacity on the overburdened saturated network of Indian railways; (v) reduce the need to import higher-quality coals; and (vi) improves health and safety and mitigates environmental degradation.[16]

Beneficiation of thermal coal is a relatively new development in India. Much of the new cleaning capacity was installed in response to regulations promulgated in 2001 by the Ministry of Environment and Forrest (MEF). These regulations mandate that raw coals be cleaned to less than 34% ash if transported more than 1,000 km or if burned in environmentally sensitive areas.[17] This legislation does not apply to power plants located near mine sites, which can still burn raw coals without cleaning. Even for those coals that are being cleaned, the extent of beneficiation is minimal since the current requirements dictate only 2-3% ash reduction in many cases.

In India, the coal beneficiation process generally consists of several steps.[18] Washing plants are typically preceded by single or two-stage crushing to reduce the raw coal to a top size of 100, 75 or 50 mm. The smaller fraction of raw coal (-13, -10 or -6.5 mm) that typically contains low ash (20-30%) is usually not washed. The specific size selected for washing or direct consumption would depend upon the ash content and effectiveness of screening. The coarser fraction is washed by jig, heavy medium bath or heavy medium cyclone to the extent that the combined ash of the washed coarse coal and the unwashed small (<10 mm) and fine (<3 mm) coal is within the stipulated limit. In some washery plants, inefficient barrel washers and spirals are used for small and fine coal, respectively, in which case the fraction finer than approximately 0.5 mm would normally be discarded. In some cases, the extent of coarse coal cleaning is limited to rock removal by hand picking, which is labor intensive and highly inefficient.

At present, the capacity for the beneficiation of thermal coals is estimated at 70 million tonnes per annum, with an additional 20 million tones per annum under proposal/expansion on CIL's land.[19] These are listed in Appendices 2 and 3. For the year 2005-06, India produced 380 million tonnes of thermal coals, of which only 17 million tonnes were beneficiated coals. Assuming an average yield of 80% for beneficiation, the 17 million tonnes of clean coal would represent approximately 22 million tonnes of feed coal. Thus, approximately 5% of the coals burned for electricity generation were beneficiated coals. The beneficiation plants in India were operating at approximately 44% of the design capacity, despite the fact that beneficiation offers a number of economic and environmental benefits. Power plants in India have been slow to utilize washed coal because of several reasons including the perception that traditional coal washing adds to the already high cost of supplied coal. However, there is a tremendous need to implement high efficiency CB plants using modern technology, and to better characterize not only the costs, but the benefits of employing cleaner coal.[20] Typically, the true costs of using dirty coal and its impact on human health, transportation costs, power plant efficiency and maintenance, etc. are being ignored thereby posing a problem for greater market penetration of coal cleaning technologies.

ECONOMICS OF COAL BENFICIATION

In the mid 1990's, the price for providing washed coal was being projected at $3.75 (Rs150 at exchange rate of Rs40/$) per raw ton inclusive of raw coal delivery (trucking) to the washery, and clean coal delivery and loading into the wagons. The average rate considered for washery services excluding raw and clean coal handling would be $2.50 (Rs100) per raw ton. The typical line item costs for coal washing in India are listed in Appendix 4. These are projected averages and do not account for penalties. As can be seen, little margin for profit beyond the investors return on investment is likely. This is however an attractive minimum 15% and typically 16% by the norms for government sanctioned projects. An investment by foreign investors is generally allowed to 49% in most areas and majority shareholding (greater than 51%) is permitted in captive mining ventures. India taxes on dividends paid outside of India are paid by the company and have generally been around 40%. India has a bi-lateral tax agreement with the US and investments are covered by international investment codes as well as Indian law.

In the last three years, because of intense competition by coal transporters and agents, the bid price for coal washing services (inclusive of all handling charges) has been as low as Rs105 ($2.56 at exchange rate of Rs41/$) per raw ton. This 30% reduction in washing fees has resulted from the lack of diligence on the part of washed coal users to insist on the use of high efficiency washery equipment by the washery operators and has also been fueled by the supposed revenue from the sale of rejects.

ADVANTAGES OF USING BENEFICIATED COAL

The advantages of using beneficiated (washed) coal have been proven through their increasing use in thermal power stations throughout the USA, Europe and other countries. These advantages are numerous, ranging from purely economic savings to environmental benefits. Within India, the use of washed coals is gaining momentum as the impact of poor quality fuels is becoming apparent.[21] The general impacts and benefits of using washed coal (both direct and indirect) within the power generation process are given here:

a. Plant efficiency effects
b. Equipment system capacity
c. Auxiliary power equipment requirements
d. Propensity for slagging or fouling
e. NOx, SOx, particulate and opacity emissions
f. CO2 emissions
g. Maintenance costs
h. Emission Fees or taxes
i. Replacement power costs resulting from unit availability and capability
j. Fuels and transportation costs

CASE STUDIES AND FINDINGS

Significant research has been done to determine the beneficial results of using lower ash coals in Indian thermal power plants. The following six case studies have been chosen to demonstrate the qualitative and quantitative benefits of coal beneficiation.

Study One - Satpura Thermal Power Station, National Thermal Power Corporation

The National Thermal Power Corporation performed a study at its Satpura TPS using washed coal of 34% ash in one 210 MW unit.[22] The results include:

- PLF increased from 73% to 96%
- Coal consumption reduced 29% (from 0.77 to 0.55 kg/kwh)
- Reduction in Auxiliary Power Consumption (1.5%)
- Reduction in down time of mills
- No fuel oil support
- Boiler efficiency improvement by 3%
- Coal mill power consumption (kwh) reduced by 48% reduction
- Savings by using washed coal of $1.04 million (Rs42.6million) per year or $0.0006 per kW (Rs0.024/kW).

Study Two – Simulation by National Energy Technology Laboratory, US DOE

The US Department of Energy's National Energy Technology Laboratory (formerly known as Pittsburgh Energy Technology Center, PETC) performed studies on the economic analysis of coal cleaning in India using state-of the-art computer models.[23] The simulations were on bituminous coal from the Talcher coal field, with an ash content of 40%, typical of most Indian thermal coals.

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. The CQIM Model, now marketed by Black and Vetch, Engineers and Architects is referred to as "VISTA". Data for the power plant simulations was obtained from three separate power plants: (1) National Thermal Power Corporation'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 effectively evaluated the plants capabilities using the existing high ash coal and the simulation for lower ash coals. These power plants placed a premium value of $0.55 per ton of coal for each percentage point reduction in ash content for coal transported 1000km. The value was $0.46 at 500km. This is the value of the washed coal to the power plant relative to the run-of-mine 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. The washing costs were established at $3.03 per raw ton for coal of 32% ash. The 8% ash reduction, valued at $0.55 per percent ash reduction, equates to $4.40 allowable break-even washing cost. At $3.03 paid for washing, a benefit of $1.07 per raw ton purchased and washed is derived from the reduction in the cost of power generation. Based on the results of this study, using a heat rate of 2850 kcal/kW, a typical 500 MW plant would purchase 2.3 million tons 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) per kW.

Study Three - Dadri Power Plant (4x210 mw), National Thermal Power Corporation.

The analysis of the National Thermal Power Corporations Dadri Power Plant which uses washed coal with around 34-35% ash from Central Coalfield Limited's Piparwar washery revealed the following results:[24]

- Savings in demurrage to railways; $0.22 per tonne of coal received
- Increase in operating hours; up to 10%
- Increase in PLF; up to 4%
- Increase in PUF; up to 12%
- Reduction in breakdown period; up to 60%
- Increase in overall efficiency; up to 1.2%
- Increase in generation per day; 2.4 MU's
- Reduction in support fuel oil; 0.35 ml/kwh
- Reduction in Sp. Coal consumption; 0.05 kg per kwh
- Increase in total units sent out per day; 2.3 MU's (approx.)
- Saving in land area for ash dumping; 1 acre per year
- Reduction in CO2 emissions (reduced transportations/coal combustion; > 600,000 ton/yr.
- Overall benefit resulting from using washed coal of $2.9 million (Rs119 million) per year excluding the anticipated reduction in maintenance cost. For the 4x210 plant, this represents a savings of $0.0005(Rs0.02) per kW.

Study Four – BSES (currently Reliance Natural Energy's) Danahu Thermal Power Station

Similar results were recorded at the Danahu Thermal Power Station (2X250MW) as that reported for use of 30% ash washed coal produced at the USAID/DIE sponsored Korba washery.[25] The results include:

- Ash generation reduced by 8.5%;
- PLF increased by 15.8%
- Cost per unit ($/kwh) reduced by approximately 10%
- Plant availability increased by 6.5%
- Sp. Oil consumption decreased by 65%
- Aux Power consumption decreased by 5.4%
- Power generation increased by 16%

BSES did not report generating cost. An estimate savings per kWh can be derived from the value of the additional power generated, 542 MU per annum, and other information. BSES reported a landed cost of ROM coal as $38.80/ton (Rs1590). We assumed rail transportation costs of $26.10/ton (Rs 1070) for coal over the 400km from the mine site with the ROM coal price (FOB railcar) being $15.12 (Rs 620). Washing costs were $2.44 (Rs100) plus raw coal and clean coal transport and loading charges of $1.10 (Rs45) for a total washing fee of $3.54 (Rs 145) per raw ton of coal. The cost of using washed coal is the difference between the total washed coal landed cost and the original total raw coal landed cost. Washed coal landed cost will be the sum of the ROM coal cost of $15.12 (Rs620) plus washing fee of $3.54 (Rs145) divided by the average yield of 75% (yield at 30% ash) plus the rail transport costs ($18.66/.75 plus $26.10) or $49.15 (Rs2015). The specific consumption of coal using raw coal was 0.70 tons per kWh and reduced to 0.55 tons per kWh using 30% ash washed coal. From the above figures, to produce 3353MU required 2.35 million tons of raw coal (3353 time 0.70) as compared with producing 3895MU using 2.14 million tons of washed coal (3895 times 0.55). A total of 2.85 million tons of raw coal were required to produce the 2.14 million tons of washed coal at 75% yield (2.14 divided by 0.75). The total annual landed cost of washed coal is 2.14 million times $49.15 or $105.18 million (Rs4312 million) and the total annual landed cost of raw coal would be 2.38 million times $38.80 or $92.34 million (Rs3786 million); a difference of $12.84 million (Rs526 million) additional costs to generate an additional 542 Mkwh. The value of additional generation can be estimated as $0.073 (Rs3) times 542 Mkwh or $39.566 million (Rs1626). The net gain between additional units sold and additional cost of generation is a savings of $26.73 million (Rs1096 million) or $0.0069 (Rs0.28) per kWh of total generated power.

Study Five – "Estimating the Cost of Coal-Fired Generation, An Application of VISTA"

Two examples using the VISTA model applied to 500 MW power plants in India are summarized below.[26] The first examines performance output provided by VISTA by comparing two domestic coals and considering how plant performance is impacted if ash quantity increases. The second uses VISTA to determine whether coal washing is economical for the power plant.

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 the coal ash was increased by 5% and 10% respectfully. The predicted results for the 10% ash increase indicate a reduction in plant availability of 2.0%. This equates to a loss of generation annually of 79 Mkwh. If a value of $0.073 (Rs3 per kWh) is assumed as the sale price, a loss of $0.0016 (Rs0.068) per kWh is derived. Conversely, the use of better quality fuels would result in power generation costs being lower by this amount.

The study suggests that maintenance and availability are strongly impacted by the ash content of the coal through four principal mechanisms:

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

2. As the ash content of the coal increases and the fuel burn rate increases, the quantity of flue gas traveling through the steam generator increases. Coupled with the increase in ash content, this causes an increase in tube failures, impacting both maintenance and availability.

3. As the ash content of the coal increases and the fuel burn rate increases, the quantity of ash that the bottom ash, fly ash, and precipitator or fabric filter systems must handle will increase. This increased level of usage will yield higher levels of erosion and more frequent cleaning and preventative repairs.

4. The quality of ash will also impact maintenance and availability of the power plant. Coal ashes are made up of different levels of minerals and inorganic compounds, which can yield 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.

The second analysis was a prediction of the value of washing Indian coals to increase the unit heat content. Coal having a typical raw ash content of 41% was reduced to 32%, 28.64%, 25.48% and 22.60% 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, that coal between 32% and 28% ash provide a benefit while deeper cleaning to less than 28% ash was uneconomical. The average value of the benefit from washing was calculated at approximately $0.73 mil (Rs30 million) per annum or a net savings of $0.0002 (Rs

0.0085) per kWh. This value is significantly lower than the first case due in part because it fails to include cost savings from reduced ash handling.

Study Six - Technical Economic Feasibility of Low Ash Power Station Fuel in India
The British Department of Trade and Industry's Clean Coal Technology reported on the technical economic feasibility of low ash power station fuel in India.[27] The objective of the study was to assess the technical and financial feasibility of producing low (around 28%) ash coal for combustion in remote load center power stations and capturing lost heat in coal preparation plant discard by generating electricity using fluidized bed based power plant. A simulated product sample was prepared based on the coal preparation studies. This was analyzed 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 in Punjab provided detailed information about its boilers and auxiliary plant. Powergen Ltd. applied the plant data and coal analysis, to the VISTA computer simulation of coal fired boilers. The results showed that the existing power plant could significantly improve its heat rate and lower its cost of generation. The authors undertook three distinct studies, a) simulation of coal preparation methodology using LMIN, b) an assessment of the economic and technical viability of using 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 Ropar PS.

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 is increased and CO2 emissions per unit of energy used are reduced.

VISTA predicted a savings of approximately $1.78 million per year in plant costs using washed coal (27% ash) compared with using unwashed coal (41% ash). The main effects of the low ash coal include improved boiler efficiency and reduced coal burn rate (i.e. mass throughput). The reduced coal burn rate and lower ash levels result in significant maintenance cost savings 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 results in substantial cost savings.
A further $0.244 million per year are saved in the cost of the coal supply, (assuming the price per GJ remains unchanged) because the boiler efficiency improvement means that less GJ need to be supplied to the unit for a given MW output. The resulting saving of $2.024 million (Rs83 million) per year represents a savings of $0.0014 (Rs0.057) per kWh.

Summary of Economic Benefits from Case Studies
The case studies support the economic rationale for pursuing coal beneficiation and challenge the misleading perception that coal beneficiation adds to the cost of electricity generation. These studies characterize the benefits derived from using cleaner coal to produce thermal power utilizing case studies in India. A summary of the benefits as characterized by the case studies are presented in Appendix 5

and 6. On average, the use of washed coal resulted in a 2% reduction in the cost of electricity generation with savings averaging $0.0008 (Rs0.035) per kWh of generated power. In all cases, the efficiency of the boiler improved resulting in additional units of power being generated from the same total units of heat. The availability of the power plant and the PLF increased allowing for the additional generating capacity. Total generated power output increased an average of 10% with the use 10% lower ash coal.

EXTRAPOLATION OF CASE STUDIES TO NATIONAL BENEFITS

To assess the national implications of the use of clean coal, information from these six specific case studies and related information was used to extrapolate to the national cost and benefits of coal beneficiation and the importance of expanding coal washing capacity and the use of clean coal in India.

HIGHER QUALITY FUEL

One of the most significant problems for the Indian thermal power generators is the lack of sufficient high quality coal from the as-mined sources. As noted in the introduction, coal production in India is expanding with the growth of open-cast mines but the quality of the surface mined reserves has deteriorated. By washing these coals, a higher quality fuel of consistent heat value can be made available. Many benefits are derived from the use of washed coal.

REDUCED FUEL QUANTITY REQUIREMENTS

By having a fuel which contains higher heat content per unit weight (kcal/kg or BTU/lb), the volume or tonnage of bulk material both handled and transported is reduced for the same heating value thus lowering unit cost.

ENHANCED UTILIZATION OF INSTALLED CAPACITY

Generation from the existing installed capacity of 70,682 (as on 30.04.07) is at 71%.[28] Using washed coal can increase this by a minimum of 10% to provide an additional 5,018MW of capacity utilization. In addition to the annual revenue of over US$2940 million (Rs120,000 million) from the increase in units generated, the equivalent capital expenditure (estimated US$1.5 million (Rs 60 million) per MW) of US$9,000 Million (Rs369,000 million) or approximately twelve new 500MW power plants is realized.

REDUCTION IN CAPITAL FUNDING REQUIREMENTS

The mandatory use of cleaner fuel in new power plants and also in refitted older plants would result in lower capital and operating costs per kilowatt power generated. Based on the studies presented, the benefit of washed coal will result in significant improvements, 10% increase in generation and a 2% reduction in total cost of generation as compared to using higher ash ROM coals. A reduction of up to 8% in the overall capital cost has been reported for every 10% reduction in ash in the feed coal. Assuming an average capital cost per installed MW of $1.5 million (Rs60), the investment in the planned

50,000MW increase during the Eleventh Plan could be reduced by as much as $6000 million (Rs246,000 million) or over $1.0 billion dollars (Rs 4100 crores) per year.

TRANSPORTATION CAPACITY AND COST REDUCTION

Within India, the principal means of coal transport is by rail, with 95% of the coal used for thermal power generation transported greater than 500 kilometers. The major rail transport routes are currently saturated and the rapidly growing demand for additional thermal power will require significant expansion of railway infrastructure which is expensive. Assuming a generalized yield of 80% for washed coal, Bhattacharya and Maitra, 2007 estimated a savings in cross country transport of 55Mt or the equivalent of 42 trains per day.[29] If rail transported only washed power coal in 2011-12, the revenues from the excess capacity as transport costs are projected to be sufficient to finance the construction of 467 km of track every year. A critical component to the planned growth of adding 50,000 MW of coal fired power generation during the Eleventh Plan will be the concurrent growth in coal production and the ability to transport the additional tonnage. Coal production in 2011-12 is planned to increase from 345Mt to 501 Mt. An estimated 276 Mt will be transported greater than 500km, up from 191 Mt in 2006 on the railways arms of the Golden Quadrangle based on continued consumption of ROM coals. While the washeries will average an 80% yield, the net change in the quantities dispatched by rail will not be 20% reduction. By calculating the power plants coal requirements on the basis of total energy units (BTU's or Kcal's) required to produce the projected quantity of electricity, (i.e. Heat Rate times Units Generated divided by Heat Content of Washed Coal, see Appendix 6), we arrive at the net quantity of washed coal (adjusted to include both the heat required for the original power generation and the additional capacity noted above). The net quantity (by weight) of washed coal required will be 92.5% of the original ROM quantity (ex. 2.18Mt divided by 2.35Mty). The railways will be able to carry an additional 7.5% as compared to shipping ROM coals. With the railways currently being able to ship 191 Mt per year of ROM coal, if washed coal is used by all power plants receiving coal by rail at a distance greater than 500km, an additional 14.3 Mt per year of washed coal could be dispatched to new plants without making any investment for expansion. This 14.3 Mt per year would available for delivery to new power plants. Based on washed coal values and respective heat rates, this would represent 6.5% of the Eleventh Plan growth or 3280MW being serviced by rail without any cost to the railways. By reducing the quantity of coal shipped yet maintaining the net heat content, the benefits to direct shipping coats, indirect capital costs for infrastructure growth and environmental benefits can be significant.

PRE-COMBUSTION VERSUS POST-COMBUSTION ASH HANDLING BENEFITS

Annual fly ash production in India in 2004 was approximately 100Mt and expected to rise to 175Mt by the year 2012. Fly ash utilization is less than 25% of the total fly ash produced despite Government efforts to encourage the use of this material for manufacture of cement, concrete blocks, bricks and tiles, and for construction of road, dams, embankments, etc.[30] By reducing the ash content of the coal pre-combustion, the deleterious effects caused by the ash are reduced. The removal of stones and other debris from the material being handled by the conveyors and crushers results in much less downtime and wear and tear. The amount of ash generated by a power plant will decrease significantly with use of lower ash coal. It is estimated that over 65,000 acres of land is covered by ash ponds in India and that by 2015 the disposal of ash will require 1000Km^2. Coal washing not only decreases the ash, but increases the calorific value. Using washed coal at a plant would extend a given ash disposal site by 12-20%.

CO2 EMISSIONS

The effect of improvements in power plant efficiency through use of clean coal can have significant benefits it terms of reductions in GHG emissions.[31] For example, a change in efficiency from, 28% to 33%, would result in a reduction in CO2 emissions of up to 15%, or some 190 g/kWh generated. If the average efficiency is raised from 33% to 38%, a further reduction of some 175 g/kWh is achievable. With the widespread application of the state-of-the-art technologies such as supercritical steam PCC or of IGCC, which also benefit from the use of upgraded coals, average efficiencies might be brought up to nearer 43%.[32]

There are two quite separate aspects to the impact of coal upgrading. One is the possible short-term benefits including reductions in CO2 emissions which result from using upgraded coals in existing power plant boilers. Refer to Figure 2. The other is the longer-term benefits arising from the use of advanced clean coal technologies which may demand the use of upgraded coal anyway in order to realize their potential for increased thermal efficiency.

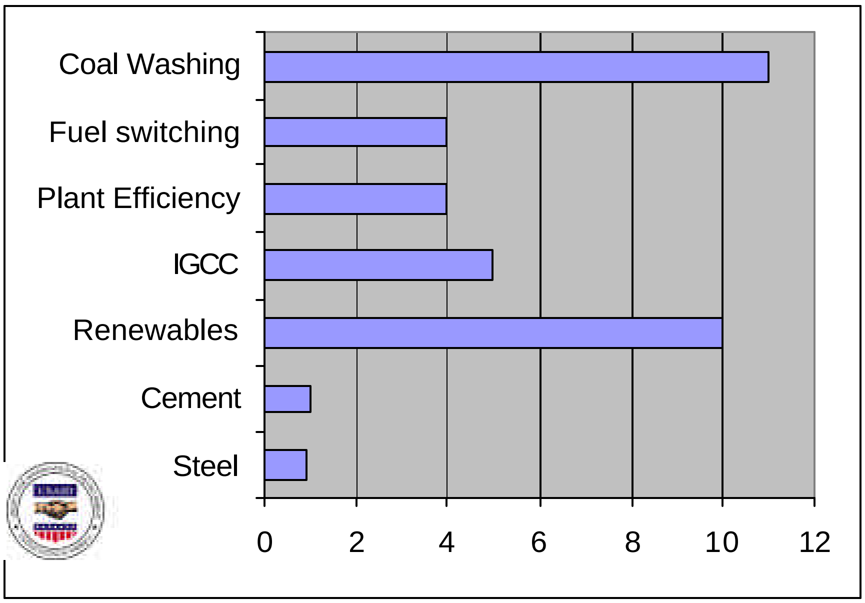
The studies on efficiency improvements from using washed coal indicate marked reductions in carbon emissions as the efficiency of the plant increases. Test results have demonstrated carbon dioxide emissions in the range of 1.11 kilogram per kW generated are reduced by 6.5% to 1.045 kilograms per kW when using 30% ash coal versus 42% ash. At an efficiency increase from 28% to 33% in the boiler, total carbon reduction is expected to be 15% or 190 g/kW. At these levels of performance, the combined use of washed coal and improved technology in the development of the planned 50,000MW expansion would reduce carbon emissions by 7.5 million tons per year. In the existing plants having an installed capacity of 70,000MW, the use of washed coal having 10% less ash than currently burned would result in a reduction in carbon emissions of 13.2 million tons per year.

There are other process implications of coal upgrading, but they are mainly second order effects in terms of boiler efficiency. For example, reducing the ash content of a 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 a washed coal.

SUMMARY AND CONCLUSIONS

This brief paper covers the impact that washed coal has on power plant operation. Although coal washing increases the upfront cost of coal, in general the cost of electricity from coal fired power generation using clean coal will be less, when all the plant costs associated with using unwashed coal are included. The economic benefits of using clean coal include: (1) fewer tons of coal handled reducing the transportation costs; (2) less abrasive coal product used in power plant; (3) increase in mill capacity; (4) reduction in ash deposit formation; (6) increased plant efficiencies; (7) higher unit availability and capability (8) reduction in tube failures; (9) lower maintenance costs; (10) reduction in auxiliary power consumption; (11) improved ESP performance; (12) less particulate emissions; (13) lower sulfur emissions; and (14) less ash to dispose. In addition, other significant benefits will arise from using washed coal that have not been addressed in this paper, including the benefits to human health from reduced atmospheric emissions.[34]

Figure 2. Comparison of Coal Washing with Other GHG Emissions Reduction Opportunities[33]



Annual GHG Mitigation Potential in India (Million tons)

- Typical Emissions using raw coal (42%) in a standard Indian coal fired power plant.
  - Carbon Dioxide – 1.11 kilograms carbon dioxide per kilo watt hour of commercial power
- Typical Emissions using washed coal (30%) in a standard Indian coal-fired power plant
  - Carbon Dioxide – 1.045 kilograms carbon dioxide per kilo watt hour commercial power

Viewed in the context of India's overall economic growth and increasing demand for electricity, the incentives for the use of cleaner washed coal in the existing and future power plants are:

1. **Increased power generation without investment or lag time** – By improving efficiency and availability, using washed coal can increase generation from existing plants by a minimum of 10% to provide an additional 5,018MW of capacity utilization. The equivalent of approximately fourteen new 500MW power plants.

2. **Sustainable, highly efficient power generation**- The mandatory use of cleaner fuel in new power plants and also in refitted older plants would result in lower capital and operating costs per kilowatt power generated. The investment in the planned 50,000MW increase during the Eleventh Plan could be reduced by as much as $6000 million (Rs246,000 million) or over $1.0 billion dollars (Rs 4100 crores) per year.
3. **Increased rail way transport capacity** –With washed coals, the railways will gain an additional 7.5% of net capacity as compared to shipping ROM coals to deliver the same energy content to the power plant.
4. **Lower pollution emissions** - The combined use of washed coal and improved technology in the development of the planned 50,000MW expansion would reduce carbon emissions by 7.5 million tons per year. In the existing plants having an installed capacity of 70,000MW, the use of washed coal having 10% less ash than currently burned would result in a reduction in carbon emissions of 13.2 million tons per year.

The expansion of coal beneficiation capacity and the use of clean coal in India, and achieving this significant potential benefit to energy security and environmental protection, is not fundamentally a technical problem. Policies need to be adopted that address the institutional barriers preventing widespread adoption of coal beneficiation in India. Necessary changes will require the coordination of various ministries that influence the coal mining, preparation, transportation and use, including the ministries of coal, oil and gas, and power, and environment and forest. This will be required to promote coal beneficiation and reduce the transport of useless ash and rock that is currently overloading an already overburdened rail freight system. Progress is being made. For example, recent Indian government regulation requires that coal transported more than 1000 km must have ash content of below 34%. However, challenges remain. For example, the current coal pricing structure, based on grades of coal with band widths that are quite wide, rather than on a fully variable systems based on gross calorific value (GCV) as done in the rest of the world, provides no incentive to encourage additional upgrades since coal quality is not effectively considered in the cost.

Expansion of the current washery infrastructure will require a balanced approach involving government, public and private sector investment. The potential market opportunity for equipment, engineering services and operations and maintenance for coal beneficiation in India exceeds US$4billion. Domestic investment alone may not be adequate to meet the potential requirements. India will need to establish appropriate regulatory and market based systems that can assure investors of the viability of their potential investment. Implementing policies and practices that increase the opportunity of the private sector in building, owning and operating coal washeries can augment government investment. The Government of India is liberalizing its economic policies, including the introduction of several incentive systems such as tax holidays and tax reductions. Additional changes in policies that lower the duties on capital goods imported for coal preparation are needed to put them at par with duties on imports for other energy sectors. These changes will stimulate domestic as well as international participation. Global solicitations or tenders will require the bidders to have experience in the design, construction, commissioning and operation or washeries and international mining companies such as those in the US can bring needed high quality experience and expertise in coal cleaning to India.

In addition to changes in financial policies, new environmental performance standards that are consistent with the capabilities of existing and advanced clean coal technology systems are needed in order to protect the health of India citizens, if future use of coal is to expand as projected. These could include restrictions on the generation and disposal of fly ash.

The US Department of Energy's Coal Working Group and the Department of State's Asia-Pacific Partnership on Clean Development and Climate's Coal Mining Task Force recognize the need for improved coal processing in India. Activities sponsored by these groups have included technical exchange visits, workshops and transfer of information on coal beneficiation. Planned activities for 2007-2008 include a coal preparation workshop in India, with experts to discuss best practices and address technical and institutional progress and challenges. In addition, specific coal preparation demonstration projects are planned that will include the transfer of coal-related technical assistance and technologies. Through these efforts, the US Government and industry are assisting India to produce clean coal and accelerate the development and deployment of clean energy technologies in a manner that ensures economic, environmental and energy security benefit.

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APPENDIX 1
TRENDS IN INDIAN COAL MINING

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TRENDS IN INDIAN COAL MINING

Domestic Coal Production	2003-04	2004-05	2005-06
Open Cast	298.5	320.3	345.7
Underground	62.7	62.3	61.3
Total	360.2	382.6	407.0
Coal Import			
Coking	13.0	16.9	17.1
Non-coking	8.7	12.0	19.7
Coke	1.9	2.8	2.6
Total	23.6	31.7	39.4
Coal Export			
Coking	0.16	0.11	0.00
Non-coking	1.50	1.18	1.33
Coke	.20	0.15	0.00
Total	1.86	1.44	1.33

APPENDIX 2
DETAILS OF NON-COKING COAL WASHERIES IN OPERATION IN INDIA

APPENDIX 2

DETAILS OF NON-COKING COAL WASHERIES IN OPERATION IN INDIA[35]

	NON-COKING COAL			
1	Dugda-I, CIL	1.00	Jharkhand	TPS
2	Lodna, CIL	0.48	-do-	TPS
3	Madhuban, CIL	2.50	-do-	TPS
4	Gidi, CIL	2.50	-do-	TPS
5	Piparwar, CIL	6.50	-do-	TPS
6	Kargali, CIL	2.72	-do-	TPS
7	Bina, CIL	4.50	UP	TPS
	(A) CIL	20.20		
8	Dipka, Aryan Coal Beneficiation Pvt. Ltd.	5.0	Chhatissgarh	RSEB,GEB,PSEB,KPCL,MSEB,Cement, etc.
9	Gevra, -do-	6.0	-do-	-do-
10	Chandrapur, -do-	2.0	Maharashtra	MSEB, KPCL
11	Adilabad, Aryan Energy Private Ltd.	2.0	AP	KPCL
12	Talcher, Aryan Energy Private Ltd.	3.0	Orissa	Sponge Iron
13	Wani, Kartikay Coal Washeries Pvt. Ltd.(Aryan)	2.0	Maharashtra	TPS
14	Korba, Spectrum Coal and Power Ltd. (formerly ST-CLI)	5.0	Chhattisgarh	BSES, GEB, Cement
15	Ramagundam, Gupta Coalfield & Washeries Ltd.	2.5	AP	KPCL, Cement, Small industries
16	Sasti, Gupta Coalfield & Washeries Ltd.	2.5	Maharashtra	RPTS, KPCL
17	Wani, Gupta Coalfield & Washeries Ltd.	2.5	Maharashtra	MSEB
18	Umrer, Gupta Coalfield & Washeries Ltd.	0.75	-do-	Cement
19	Bhandara, Gupta Coalfield & Washeries Ltd.	0.75	-do-	Sunflag Iron & Steel Co. Ltd.
20	Parasia, Gupta Coalfield & Washeries Ltd.	0.75	-do-	Cement
21	Bilaspur, Gupta Coalfield & Washeries Ltd.	1.2	Chhattisgarh	Sponge Iron
22	Ghugus, Gupta Coalfield & Washeries Ltd.	4.0	Maharashtra	MSEB
23	Talcher, Global coal Mining (P) Ltd.	2.0	Orissa	Sponge Iron
24	Wani, Bhatia International Ltd.	3.0	Maharashtra	MSEB
25	Chandrapur, Bhatia International Ltd.	1.0	Maharashtra	Industries
26	Raigarh, Jindal	2.5	Orissa	Steel
27	Wani, Indo Unique Flame Ltd.	0.5	Maharashtra	Sponge Iron
28	Chhattisgarh Power & Coal Beneficiation Ltd.	1.2	Chhattisgarh	Power & Cement
	(B) Private	50.15		
	TOTAL (A+B)	70.35		

APPENDIX 3

WASHERIES UNDER PROPOSAL/EXPANSION ON CIL'S LAND

APPENDIX 3 WASHERIES UNDER PROPOSAL/EXPANSION ON CIL'S LAND[35]				
Sl. no.	Washery & Operator	Capacity (MTY)	Location	Consumer
1	Kalinga, Spectrum Coal and Power Ltd. (formerly ST-CLI Coal Washeries Ltd.)	11.0	Orissa	APGENCO
2	NK area (CCL), Monnet Daniels Coal Washeries ltd.	3.5	Jharkhand	PSEB
3.	Dipka, Aryan Coal Beneficiations Pvt. Ltd.	5 to 7 (expn.)	Chhattisgarh	TPS & Cement

APPENDIX 4

COST COMPONENTS OF 3.0 MTPA BUILD–OWN-OPERATE WASHERY IN INDIA

APPENDIX 4

COST COMPONENTS OF 3.0 MTPA BUILD–OWN-OPERATE WASHERY IN INDIA

	Activity	Cost (US$/ raw ton)	Cost (Rs[a]/raw ton)
1.	Raw Coal Trucking (5km)	$0.49	Rs20
2.	Direct Washing Costs	$1.37	Rs56
3.	Rejects Handling	$0.17	Rs 7
4.	Clean Coal Transport (8km)[b]	$0.63	Rs26
5.	Rail Loading[b]	$0.17	Rs 7
6.	Debt Service (Based on Rs400 million capital cost)	$0.44	Rs18
7.	Overhead and Administration	$0.24	Rs10
8.	Return on Investment (16% on 30% equity)	$0.15	Rs 6
	TOTALS	$3.66	Rs150

[a] US$1 = Rs41 [b] Clean coal costs have been adjusted to costs per ton raw coal

APPENDIX 5

SYNOPSIS OF TYPICAL BENEFITS OF USING WASHED COAL

APPENDIX 5

SYNOPSIS OF TYPICAL BENEFITS OF USING WASHED COAL

(Note: Effects as shown are typically for washed coals having 30% ash at equilibrated moisture and have been extrapolated from the case study data where washed coals of higher ash where tested.)

Area of Influence		Effects
Transportation		
	Reduction in transportation costs	Depends on distance and ash reduction (e. g. 1000km. Distance and ash reduction from 41% to 30% results in savings of 7.5%)
	Reduction in CO2emissions due to reduced fuel consumption in transportation	Depends on distance and ash reduction (e.g., 1000 km. Distance, ash reduction from 41 to 30% results in 15% reduction in CO^2 for the same delivered heating value.
Power Plant Site		
	Decrease in auxiliary power	10% decrease for every 10% reduction in feed coal ash
	Decrease in auxiliary fuel	50% reduction when using washed coal (present avg. is 4ml/kwh) having 10% reduction in ash.
	Improvement in thermal efficiency	3.0% improvement for every 10% reduction in feed coal ash
	Improvement in plant load factor	10% improvement for every 10% reduction in feed coal ash
	Reduction in O&M Costs	2% cost reduction for every 10% reduction in feed coal ash
	Reduction in capital investment for new power projects	8% reduction in capital investment when using coal with 30% ash instead of 41%
Environmental		
	Reduced land requirement for ash disposal	12% reduction in land requirement when using coal with 30% ash instead of 41%
	Reduced water consumption for ash disposal	12% reduction in water consumption when using coal with 30% ash instead of 41%
	Reduction in CO2 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%

APPENDIX 6

ESTIMATED BENEFITS BY USING WASHED COAL [500MW TPS]

APPENDIX 6

ESTIMATED BENEFITS BY USING WASHED COAL [500MW TPS]

The following table is a comparison of the estimated costs and benefits from utilizing washed coal with progressively lower ash contents, i.e. 38%, 34% and 30%. The influence of cleaner coal on the entire energy delivery and use cycle is multidimensional. For example, as the ash content of the fired coal is reduced, its effect on the boiler efficiency is a function of several factors such as the rate of slag forming on the tubes, fouling of the air flow, lost heat to the ash, etc. By improving any of these (not all beneficial effects have been listed), the boiler efficiency will improve as a result of improved heat transfer. Based on the results fom the case studies reviewed in this paper, the expected impact on the operating efficiencies and cost are presented. To provide a common representation, a 500MW plant is illustrated. The following assumptions are used:

1) The based plant has a PLF of 79% when operated on raw coal of 38% as-received ash (PLF value is taken as the average performance of existing Indian pulverized coal thermal plants),
2) Heat rate of base plant is 2745 kilocalories per kW,
3) An exchange rate of US$1 = RS41 is used,
4) Cost of "E: Grade raw coal is (US$15.12) Rs620 per raw ton FOB rail car or road dispatch location,
5) Rail transportation rate is calculated using a fixed rate of Rs0.76 per ton-kilometer
6) Selling price of electricity per kW is Rs3.00,
7) Cost for flyash disposal is Rs35 per ton of ash produced,
8) Washing charges are Rs145 per raw ton and includes trucking and handling between mine and up to placement in the rail car.

Sl. No.	Particulars	Raw Coal (38% ash)	Washed Coal (34% ash)	Washed Coal (30% ash)
1	Each TPS Capacity (MW)	500	500	500
2	Ave. Raw Coal Price (per ton - "E" grade)[36]	$15.12 (Rs620)	$15.12 (Rs620)	$15.12 (Rs620)
3	Freight from pithead to TPS (1400km)	$26.10 (Rs1070)	$26.10 (Rs1070)	$26.10 (Rs1070)
4	Power selling price (Rs per kwh)	$.0732 (Rs3.00)	$.0732 (Rs3.00)	$.0732 (Rs3.00)
5	Overall efficiency improvement (%)	-	1.00	1.50
6	Increase in PLF (%)	-	4.00	7.00
7	Increase in generation hours (%)	-	6.50	11.60

APPENDIX 6 (con't)				
8	Washed coal yield (%)	-	80	75
9	Ash disposal saving (Rs per ton)	-	$0.84 (Rs35)	$0.84 (Rs35)
10	Washing charges (Rs per ton of raw coal)	-	$3.54 (Rs145)	$3.54 (Rs145)
11	Raw coal linkage from SECL per unit "E" Grade	2.38 MT	2.85 MT	2.91 MT
12	Ash (%)	38	34	30
13	GCV (kcal/kg)	3810	4200	4460
14	Sp. Coal consumption (Te)	0.71	0.64	0.59
15	Generation (Mkwh) per year	3352	3563 (82% PLF)	3695 (85% PLF)
16	Total Clean Coal required (MT)	2.38	2.28	2.18
17	Coal price (landed) per ton ([2/8]+3+[10/8]0	$41.22 (Rs1690)	$48.66 (Rs1995)	$50.12 (Rs2055)
18	Coal Cost (Millions, M)	$98.10 (Rs4022)	$110.94 (Rs4549)	$109.27 (Rs4480)
19	Extra cost for using washed coal (M)	-	$12.84 (Rs526)	$11.16 (Rs458)
20	Additional generation (M kwh)	-	210	343
21	Additional O&M Cost (M)	-	$0.18 (Rs7.5)	$0.34 (Rs14)
22	Addl. Expenditure for addl. Generation (M) (8+12)	-	$13.07 (Rs534)	$11.50 (Rs472)
23	Total expenditure (M)	$98.10 (Rs4022)	$123.96 (Rs5083)	$120.77 (Rs4952)
24	Addl. Units for sale (M kwh)	-	200	326
25	Value of addl. Units sold (M)	-	$14.62 (Rs600)	$23.83 (Rs977)
26	Savings in auxiliary power (M)	-	$0.63 (Rs26)	$0.90 (Rs37)
27	Savings in O&M Cost (M)	-	$0.20 (Rs8.2)	$0.41 (Rs17)
28	Savings in fuel support (M) (@0.35ml/kwh)	-	$0.19 (Rs7.8)	$0.28 (Rs11.5)

APPENDIX 6 (con’t)				
29	Savings in ash disposal (M)	-	$0.16 (Rs6.40)	$0.26 (Rs10.60)
30	TOTAL GAIN (16+…+20) (M)	-	$15.80 (Rs648)	$25.69 (Rs1053)
31	NET GAIN (M Rs) (21-13) (M)	-	$2.78 (Rs114)	$14.18 (Rs581)
32	NET GAIN , $ (Rs) per kwh)		$0.0008 (Rs0.032)	$0.0038 (Rs0.157)

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