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A Resource and Technology Assessment of Coal Utilization in India

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Executive Summary

Electricity production in India is projected to expand dramatically in the near term to energize new industrial development, while also easing the energy shortages throughout the country. Much of the new growth in electricity production will be fueled by domestic coal resources; however, there is worldwide concern about increased coal use, as greater carbon dioxide (CO_2) emissions from coal combustion will exacerbate climate change. At the same time, there are now a number of different existing and emerging technological options for coal conversion and greenhouse gas (GHG) reduction worldwide that could potentially be useful for the Indian coal-power sector. This paper, part of a series of Pew Center White Papers exploring strategies for reducing CO_2 emissions from coal-powered electricity, reviews coal utilization in India and examines current and emerging coal power technologies with near- and long-term potential for reducing greenhouse gas emissions from coal power generation.

According to the Ministry of Coal, India is currently the third largest producer of coal in the world, with a production of about 407 million tons (MT) of hard coal and 30 MT of lignite in 2005–06. India has significant coal resources, but there is considerable uncertainty about the coal reserve estimates for the country. Without improvements in coal technology and economics, the existing power plants and the new plants added in the next 10–15 years could consume most of India's extractable coal over the course of the plants' estimated 40- to 50-year lifespans. Indian coal demand, driven primarily by the coal power sector, already has been outstripping supply; over the past few years, many power plants have restricted generation or have partially shut down because of coal supply shortages. Hence, heavy investments in the coal sector, particularly in underground mining, will be needed to increase the pace of domestic coal production. Coal imports are also projected to increase significantly over the next 20 to 25 years, with important implications for the Indian coal industry, as well as for the national and financial security of the country.

The demand for coal in India's power plants has rapidly increased since the 1970s, with power plants in 2005–06 absorbing about 80% of the coal produced in the country. Other key coal consumers are the steel and cement industries. A large fraction of India's coal is transported using railways, and the future development of coal is linked to greater investments in coal transport infrastructure. The demand for coal in India is expected to increase rapidly in the future, dominated mainly by the power sector. It is projected that about 47 gigawatts (GW) of new coal-based power plants will be installed during the 2007–2012 period; total consumption of coal in the power sector is expected to be about 550 MT by 2012.

Nearly all Indian coal power plants rely on one technology for converting coal to electricity: steam-based subcritical pulverized coal (PC). While the unit size and efficiency of Indian coal power plants have improved over the years, the basic technology has remained the same for nearly three decades. Bharat Heavy Electricals Limited (BHEL) is the main manufacturer of power plants in India; the company's technology is used in about 70% of power plant units, accounting for more than 50 GW of installed coal-based capacity in the country. The current "standard" is the BHEL 500 MW subcritical PC unit with assisted circulation boilers

and turbo-driven boiler-feed-pumps. Currently, more than 25 of these units are in operation with an average designed gross-efficiency of 38% and net operating efficiency of 33%.

Although the efficiency of coal-based power plants in India has improved in recent years, the average net efficiency of the entire fleet of coal power plants in the country is only 29%. The poor efficiency in India is blamed on a variety of technical and institutional factors such as poor quality of coal, bad grid conditions, low plant load factor (PLF), degradation due to age, lack of proper operation and maintenance at power plants, ineffective regulations, and lack of incentives for efficiency improvements. Studies have indicated that there is ample scope to improve the efficiency of existing power plants by at least 1–2 percentage points.

Key environmental concerns in the coal-power sector in India include air pollution (primarily from flue gas emissions of particulates, sulfur oxides, nitrous oxides, and other hazardous chemicals); water pollution; and degradation of land used for fly ash storage. Furthermore, the poor quality of Indian coal, with its high ash content and low calorific values, has led to increased particulate pollution and ash disposal problems. Regulations that limit pollution from power plants are focused mainly on particulate matter emissions and ambient air quality standards for sulfur oxides (SO_x) and nitrogen oxides (NO_x), although the enforcement of these regulations has been weak. The demand for electricity is so great that plants that violate the norms are not shut down, despite legal obligations to do so. With the projected increase in installed capacity, a key challenge for the government is to effectively enforce and tighten its existing regulations.

India's CO_2 emissions have been increasing at an average annual rate of 5.5% from 1990 to 2000, with coal accounting for about 70% of total fossil-fuel emissions. Although India is now the fourth largest emitter of CO_2 emissions worldwide, its total emissions are still about one-fifth and one-third of emissions from the United States and China, respectively; measured on a per capita basis, India's carbon emissions are almost one-twentieth those of the U.S. and less than half those of China. Options to reduce CO_2 emissions from coal-based power plants include: a) increasing efficiency of energy conversion by increasing the efficiency of existing power plants and switching to new, higher-efficiency technologies; b) using less carbon-intensive fuels or mixtures of fuels (such as coal-biomass mixtures); and c) capturing and storing CO_2 from power plants.

Many advanced power-generation technologies are under consideration for the Indian power sector, including supercritical PC, circulating fluidized-bed combustion, and integrated gasification combined cycle (IGCC). There is already one plant based on supercritical PC technology under construction in India, and many more are being planned, although a large fraction of the new plants continue to be based on subcritical PC technology. Gasification of Indian coal is not practical with standard entrained flow gasifiers because of the high ash content and high ash-fusion temperature of most Indian coals. Consequently, the less advanced fluidized-bed gasifier technology is being considered for use with Indian coal.

Carbon capture with amine scrubbers in Indian power plants would require low pollutant levels in flue gas in order to be technologically and economically viable, as pollutants would bind with the amine and reduce its absorptive capacity. Carbon capture using scrubbers also would result in lower capacity and efficiency, and high generation costs. As a result, India would need higher-efficiency power plants as a precursor to any possible retrofitting for carbon capture. There is, however, plenty of projected geological storage capacity, although detailed geological assessments of specific storage sites needs to be done. Early demonstration of storage also could be combined with CO_2-based enhanced oil and gas recovery.

Finally, it is far from clear what the appropriate technology choices might be for India, as all of the current and emerging technologies worldwide have their strengths and limitations. Therefore, it is critical not only to consider and implement technologies that meet the near-term needs of the country but also to set the coal-based power sector on a path that would allow it to better respond to future challenges, including the challenge of reducing GHG emissions. It will be necessary for India to undertake a systematic analysis of the various technical options best suited to the country's unique characteristics, and an analysis of the best approaches for deployment.

Introduction

Coal was the key energy source for the industrial revolution, which has provided amenities that most of us take for granted today—including electricity, new materials (steel, plastics, cement and fertilizers), fast transportation, and advanced communications.[1] Coal replaced wood combustion because of coal's abundance, its higher volumetric energy density[2] and the relative ease of transportation for coal.

However, the use of coal also has many negative impacts. Coal mining historically has been a dangerous occupation, with workers toiling under often inhuman conditions.[3] Mining has leached hazardous chemicals into water sources and destroyed forests and habitats. Even entire mountains have been lost due to strip mining.[4] Coal use has severely degraded air quality and human health because of high particulates and sulfur dioxide (SO_2) emissions. While regulations on power-plant emissions have reduced air pollution significantly (particularly in Europe and the United States), there is now a much bigger, global threat from increased coal use. Emissions of carbon dioxide (CO_2) from coal combustion have been identified as a primary culprit in increasing atmospheric CO_2 concentrations, strongly affecting the world's climate (IPCC, 2001a). Mitigating climate change will require deep reductions in global CO_2 emissions, especially from coal use.

The need to reduce CO_2 emissions from coal has become an important issue just when populous developing countries, such as India and China, are rapidly industrializing. Following the development pattern of industrialized countries in Europe and North America, these newly developing countries intend to utilize their significant coal resources to further their economic development goals and to increase the standard of living of their citizens. The OECD countries are mainly responsible for the current high CO_2 atmospheric concentrations.[5] However, due to accelerating growth in emissions from China and India, these countries likely will have to engage in reducing CO_2 emissions from their energy sectors as well, despite the fact that these countries are expected to continue to have lower per-capita emissions than the OECD countries over the next several decades. Furthermore, new technologies such as clean coal technologies, carbon capture and storage, and other low-emission technologies are likely to be developed and deployed first in industrialized countries. Key challenges for subsequent transfer and deployment of these technologies in developing countries include adapting the technologies to specific developing country circumstances, building indigenous capacities, and addressing issues of cost and financing. How advanced technologies are developed and who

[1] As Nicolls (1915) writes, "With Coal, we have light, strength, power, wealth, and civilization; without Coal we have darkness, weakness, poverty, and barbarism." (as quoted in Freese (2003)).

[2] The energy density of coal is 32 MJ/kg and 42 GJ/m^3, by weight and volume, respectively; similarly, energy density for dry wood is15 MJ/kg and 10 GJ/m^3 (Sorensen, 1984). These numbers will vary depending coal rank and wood quality.

[3] See, for example: Freese (2003); U.S. OTA (1978) and references therein.

[4] See, for example: Reece (2006).

[5] It takes between 50–200 years for 50% of a CO_2 pulse to disappear from the atmosphere (IPCC, 2001b). The long lifetime of CO_2 implies that emissions from OECD countries are primarily responsible for the current high atmospheric concentrations of CO_2. In 1971, the OECD countries emitted 9,400 million tons of CO_2 (66% of world total of 14,100 million tons). By 2003, OECD countries emitted 12,800 million tons (51% of world total of 25,000 million tons) (IEA, 2005).

pays for their deployment will continue to be crucial questions in many international forums, including the ongoing climate negotiations to reduce greenhouse gas (GHG) emissions.

This White Paper reviews the Indian coal and coal-power sectors against the backdrop of the broader effort to reduce GHG emissions from a growing power sector throughout the world. A complementary Pew Center White Paper, *Policy Options for Carbon Mitigation in the Indian Coal Power Sector*, discusses policy approaches and suggestions for deploying advanced cleaner coal-power technologies. Both papers are part of a series of Pew Center White Papers that explore strategies for addressing CO_2 emissions from coal-based power generation.

Coal in India

Exploration, development, and sale of coal and lignite resources in India are completely under the oversight of the Indian Government, through the Ministry of Coal. The Ministry of Coal effectively determines all matters relating to the production, supply, distribution and sale price of coal. The Ministry is in administrative control of major coal-producing companies including Coal India Limited (CIL), Singareni Colliery Company Limited (SCCL),[6] and Neyveli Lignite Corporation (NLC). After nationalizing the coal mines between 1972 and 1973, the Government of India held the rights to nearly all coal mines in the country, and CIL was the public-sector holding company for these mines. CIL has seven coal-mining companies as its subsidiaries; the eighth subsidiary, Central Mine Planning and Design Institute Limited (CMPDIL), provides technical support in planning, exploration, mine development, and research and development in coal technologies.[7] More than 90% of coal and lignite produced in India is from the CIL, SCCL, and NLC mines, as only a small amount of captive coal mining is allowed for private steel, power and cement companies. The Geological Survey of India (GSI), the Mineral Exploration Corporation (MEC), SCCL, and CMPDIL map India's coal resources by undertaking prospecting surveys in areas with potential coal resources. The GSI and MEC are under the jurisdiction of the Ministry of Mines. The Coal Ministry also is in administrative control of the Coal Controller's Organization, which, among others, gives grants for opening new seams/mines, collects and publishes data on the coal sector, collects excise duties, and monitors progress in captive mining (Ministry of Coal, 2006a).

In addition to the Ministry of Coal, the Ministry of Power plays a key role in recommending coal linkages to power projects and in recommending coal block allocations for captive mining. A similar role is played by the Ministry of Steel for the steel sector. The Planning Commission of India sets the long-term vision and priorities for the government and provides overall policy guidance and sectoral growth targets for all government ministries through its national plans. The Power and Energy Division of the Planning Commission also provides support to an Energy Coordination Committee under the chairmanship of the Prime Minister that addresses all key energy sector issues.

Among the other government entities involved in coal, the Ministry of Environment and Forests plays a key role in regulating the environmental impacts of mining and in providing clearances for mining in forest lands. The Ministry of Mines (through the GSI and MEC) also facilitates coal resource exploration. The Directorate General of Mines Safety, in the Ministry of Labor, helps protect occupational health and safety of mine workers in India through legislation, examinations, inspections and investigations.[8]

[6] SCCL is a joint sector ownership between Government of Andhra Pradesh (which controls 51% of equity capital) and the Government of India (49% of equity). See: http://www.coal.nic.in/sub1.html

[7] CIL also directly controls the activities of the North-Eastern Coalfields (NEC), which is focused on coal production from the northeastern states of India.

[8] See: http://www.dgms.net/

RESOURCES

Figure 1: Major coalfields and mining centers

Source: IEA, 2002.

Although India has significant domestic coal resources, estimates of coal reserves are uncertain. India has an estimated 22,400 square kilometers (sq. km) of potential coal-bearing area, of which GSI has systematically explored only about 45% (10,200 sq. km) (Ministry of Coal, 2006b).[9] Indian coal deposits generally occur in two main geological horizons: a) the Lower Gondwana sediments (Permian); and b) the early Tertiary sediments (Eocene). Most of the major coal deposits are Gondwana coals in the eastern and southeastern parts of India; the Tertiary coals are located in Assam and other northeastern states, as well as Jammu and Kashmir (see Figure 1). Indian coal is primarily bituminous and sub-bituminous; there are nearly 36 gigatons (GT) of lignite resources in Tamil Nadu, Gujarat, Rajasthan, Jammu and Kashmir (Ministry of Coal, 2006a).

GSI, MEC, and CMPDIL engage in preliminary exploration using wide-spaced drilling in the coal-bearing regions under the regional/promotional exploration program.[10] Based on these explorations, coal resources are categorized according to borehole spacing into "inferred" (borehole spacing greater than 2 km) and "indicated" (spacing between 1 and 2 km) resources. Depending on the projected coal demand and the judgment of coal companies, certain areas are identified for detailed drilling (with borehole spacing less than 400 m) to define more precisely the coal seam properties (thickness and quality) and to make more accurate estimate of resources. Resource estimates from these more detailed drillings are called "proved reserves."[11]

As of January 2005, Indian coal resource inventory stood at 248 GT (see Table 1). Coal resources in the "proved" category were only 93 GT (38% of total resource). Coking coal constituted only about 18% of proved resources, of which only a quarter was of prime coking coal quality. Of the proved non-coking coal resources, superior grades[12] (namely, A, B, C & D) constituted about a third; the rest were inferior coal (grades E, F & G), which is typically used for coal power plants. Overall, the proved resources of inferior non-coking coal (i.e., coal that is used for thermal power generation) accounted for about 20% of the total coal resource inventory.

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[9] It is estimated that about 143 GT of coal resources exist in the remaining 55%. In addition, about 67 GT of coal are expected to lie deeper than 1200 m in the Cambay basin. These 210 GT of "prognosticated resources" are not included in the official coal inventory (Ministry of Coal, 2006b).

[10] The regional exploration program is funded by the Ministry of Mines for GSI, and the Ministry of Coal funds the promotional exploration program for GSI, MEC, and CMPDI (Ministry of Coal, 2006b).

[11] This nomenclature of "proved reserves" is not accurate, nor is it directly equivalent to the more commonly used term "proven reserves," as is discussed further in this section.

[12] Indian coal is priced according its grade, which is based on a range of useful heat values (UHV) of coal. UHV is determined by the ash content and moisture in coal, and it correlates with the coal's gross calorific value. Since grades are assigned to wide ranges of UHV, pricing is not directly proportional to calorific value of coal.

There are, however, several problems with the Indian coal resource assessments:

- Detailed drilling and analysis of coal resources seems to be more dependent on the coal industry's views on extraction, rather than on independent assessments of total coal resources, including those at deeper depths (Ministry of Coal, 2006b). For example, Chand (2005) has noted that most of the recent drillings have been limited to 300m (62% of the explored coal resources is located within 300m depth), which is the depth accessible through opencast mining.

- The coal inventory includes reserves that are already depleted due to mining and resources that cannot be mined due to mining, surface, and geotechnical constraints,[13] as well as resources that cannot be mined using current technology (Ministry of Coal, 2006b).

- Classifying resources according to borehole density does not take into account geological complexities and coal seam heterogeneities. In many cases, drilling does not even extend to the basement of coal basins, but is limited to arbitrary depths (Ministry of Coal, 2006b).

- Technical terms such as '*resources*' and '*reserves*' are often misused, with geological resources being treated as '*reserves*' (Chand, 2005). The Indian classification system is primarily based on geological evaluations without assessing the quality, mineability, or extractability of deposits. In contrast, the United Nations Framework Classification (UNFC, 2004) denotes reserves as the part of the remaining resources that is economically mineable, technically extractable, and geologically proven.[14]

Thus, there is considerable uncertainty about the actual amount of proved coal reserves in India. A recent report from the Ministry of Coal (2006b) notes that "there are conflicting views among experts about the level of availability of coal." Although reserves should ideally be defined for each coal field based on techno-economic-geological analysis, CMPDIL has made tentative estimates of extractable resources (i.e., reserves) by making various assumptions about extractability and confidence levels for established coal inventory. These estimates are shown in Table 1. According to CMPDIL, only 52 GT (56%) out of 93 GT of proved resources are considered extractable[15]—this is only *one-fifth* of the total resources in the country. Furthermore, at least 8 GT has already been depleted due to past mining, leaving only about 44 GT as a tentative estimate of coal reserves in India (Chand, 2005). These tentative estimates of extractable resources (see Table 1) need to be strengthened through better analysis.

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[13] Mining constraints include coal left in pillars, roofs and floors of coal seams during underground mining, and coal left in mining benches for open-cast mining. Surface constraints include water bodies such as rivers and lakes, railway lines, transmission lines, road highways, villages, towns and cities. Geotechnical constraints include faults, dykes, thickness of coal seam, occurrence of dirt bands within coal seams, and gaseous seams that can catch fire (Ministry of Coal, 2006b).

[14] Proved reserves are the economically mineable part of a recoverable quantity assessed by a feasibility study or actual mining activity usually undertaken in areas of detailed geological exploration. It includes diluting materials and allowances for losses which may occur when material is mined and milled. Appropriate assessments of these reserves, which include feasibility studies, require inclusion of realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. The assessments must demonstrate, with a high degree of confidence at the time of reporting, that extraction is justified. Detailed geological exploration includes detailed three-dimensional delineation of a known deposit achieved through closely spaced sampling. The samplings must establish the size, shape, structure, grade, and other relevant characteristics of the deposit with a high degree of accuracy (UNFC, 2004; Chikkatur and Sagar, 2007).

[15] A more recent estimate indicates an estimated range of 56–71 GT of extractable coal reserves, of which 33 GT are in the "proved" category (Planning Commission, 2006).

Nonetheless, one can safely state that India still has a substantial amount of coal reserves,[16] although it is likely to be smaller than what has been assumed by many international bodies (Chikkatur and Sagar, 2007).[17]

Table 1: Tentative estimates of extractable coal reserves in India

	Geological Resources				Tentative Reserves		
Area	Proved (GT)	Indicated (GT)	Inferred (GT)	Total (GT)	Extractable (GT)	% of Proved Resources	% of Total Resource
Coal India Ltd.	68	19	5	92	30	44%	33%
Rest of Country	25	98	33	156	22	88%	14%
Total	**93**	**117**	**38**	**248**	**52**	**56%**	**21%**

The term “extractable reserves” is almost equivalent to UNFC’s proved reserves—however, it also includes depleted reserves.

Source: Chand, 2005; Ministry of Coal, 2006b.

Depending on the rate of domestic coal production and use, current Indian coal reserves might last anywhere from 30 to 60 years (Chikkatur, 2005; Ministry of Coal, 2006b).[18] Without improvements in coal technology and economics, the existing power plants and the new plants added in the next 10 to 15 years might consume *most* of the currently estimated extractable coal in the country over the course of their 40- to 50-year lifespans.[19] The relatively short lifetime projected for India’s coal reserves is in sharp contrast to the general assumption that Indian coal will last more than 200 years[20]—an assumption predicated on extracting all of the resources without accounting for technology or economics (Chikkatur, 2005). The amount of coal reserves, and the lifetime of these reserves, can be increased through more extensive geological surveys, large technological and financial investments in the coal sector, reduced demand for domestic coal, and higher costs for consumers (especially power plants).

Better energy planning and policies require a good understanding of domestic coal reserves, and therefore it is important to reduce existing uncertainties about Indian coal by making better reserve assessments. It is likely that much of the uncertainty could be reduced when the current coal resource inventory is reclassified according to the UNFC categories.[21] Furthermore, uncertainty about domestic coal resources will impact India’s long-term energy supply trajectory, which in turn has significant implications for India’s GHG emissions.

[16] India’s 44 GT would make it the country with the sixth largest coal reserves in the world—a small drop from being the fourth largest if it had 93 GT (assuming that the coal reserve data for other countries are reliable).

[17] See, for example: IEA (2002); BP (2006); EIA (2006); IEA (2006)

[18] This relatively short lifetime results primarily from a rapid exploitation of current reserves to satisfy the increasing coal demand for power generation (Chikkatur, 2005). Many mines already are being mined unsustainably to cope up with increased demand from power generation (Personal communication. S.K. Chand, 2006). A recent estimate indicates that the current coal reserves would be depleted in 45 years, assuming an extraction rate of 5% (Planning Commission, 2006).

[19] Existing plants consume about 300 MT of coal annually; at this rate, they would consume about 12–15 GT of coal over their lifetime (assuming that the older power plants get replaced with other similar coal plants). Over the next 10–15 years, more than 100 GW of new coal power plants could be installed. These plants would consume about 500 MT annually (assuming a specific coal consumption of 0.75kg/kWh and 75% plant load factor), and 20–25 GT of coal over their lifetime (See Chikkatur and Sagar, 2007).

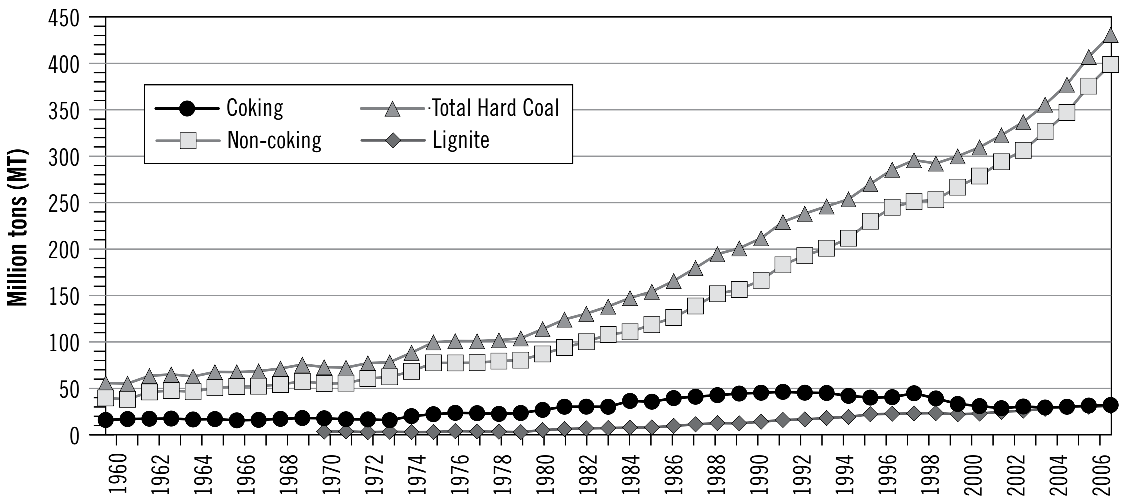
[20] See, for example: BP (2006); Shahi (2003); Sagar (2002), and http://www.cslforum.org/india.htm.

[21] While the Ministry of Coal has already accepted the UNFC system as the new national standard, the reserves are yet to be fully reclassified.

PRODUCTION

Coal mining in India is dominated by opencast extraction; mining in the country has grown with a 4% average annual growth rate over the past decade. Coal has been mined in India for more than 230 years. Prior to nationalization of coal mines (1971–73), most of the coal mines were in the private sector. Nationalization was aimed at bringing about the coordinated, optimal and scientific development of the coal industry, and a massive and rapid increase in coal production (Gupta, 1979). Since nationalization, coal production has increased more than fivefold, with the production in 2004–05 at 377 MT (see Figure 2). Much of the production since nationalization has been from the seven state-owned collieries of Coal India Limited and Singareni Collieries Company Limited; about 95% of current coal production is from CIL and SCCL. In addition, coal production has been dominated by non-coking coal, as coking coal reserves in the country are quite limited (see Figure 2). The increased production of non-coking coal is mainly due to increasing demand from the power sector. In addition to coal, the production of lignite also has been increasing—albeit at a much slower rate (see Figure 2)—with NLC dominating lignite production in the country.[22]

Figure 2: Coal production in India (1960–2006)



Hard coal production excludes lignite production.

Source: The coal data is from Ministry of Coal Annual Reports (1999–00, 2003–04, 2005–06, 2006–07). Data for lignite is from MOSPI, 2008.

Generally, there are two main methods for extracting coal: opencast (surface) mining and underground mining. In opencast mining, the coal is mined in an earth-moving operation by excavating the overburden up to the coal seams and then removing the coal using draglines, shovels, and dump trucks. Opencast mining is advantageous because of greater recovery of in-situ resources, high productivity, low costs and labor intensity, and better workplace conditions (Ward, 1984; Buchanan and Brenkley, 1994). Typically, opencast mining is used for coal seams within 300m of depth, although deeper mining is possible.[23] However,

[22] About two-thirds of lignite production is from NLC and the rest from the mining companies in Gujarat (Ministry of Coal, 2007a).

[23] The cost of opencast mining increases proportionally with the overburden ratio, which is ratio of overburden thickness to the coal seam thickness and relative density (Ward, 1984).

opencast mining has enormous environmental impacts including large-scale land use, overburden disposal, disturbance of hydrology and run-off, increased erosion, acid mine drainage, noise, and possible destruction of entire ecosystems (Buchanan and Brenkley, 1994).

In contrast, underground mining, which typically is used for extracting very deep coal seams, involves constructing a vertical shaft or slope mine entry to the coal seam and then extracting the coal using bord-and-pillar[24] or longwall techniques (Ward, 1984). Underground mining is relatively more labor-intensive and it is not possible to extract all of the coal—anywhere between 50 to 90% of the coal can be extracted depending on particular geological characteristics. Some of the problems with underground mining include poor workplace environment, explosions, subsidence, aquifer disturbance, minewater disposal, and methane emissions (Buchanan and Brenkley, 1994).

Although underground mining was dominant in the early years of coal production in India, much of the increased production since the 1970s has come from opencast mining; nearly 83% of total production in 2003–04 came from opencast production (CMIE, 2005). Underground mining has essentially stagnated over the past decade, with annual production decreasing to below 65 MT in recent years (CMIE, 2005). The increased emphasis on opencast mining has led to a faster production rate and reduced mining losses; however, it also has reduced coal quality as shale and other materials often get mixed with coal.

In addition to traditional mining, new options such as coal bed methane (CBM) extraction and underground coal gasification (UCG) are now being considered for unmineable coal seams in India. Coal seams generally contain gaseous methane adsorbed within the coal bed, and this methane can be extracted from seams through boreholes. CBM—which can be used for a range of industrial purposes, including power generation—is actively being considered in India by various public and private sector companies, including the Oil and Natural Gas Corporation (ONGC) and Reliance Industries—two of the country's largest oil and gas exploration and production companies. Exploration and extraction of CBM is under the administration of the Ministry of Petroleum and Natural Gas; the Directorate General of Hydrocarbons (DGH) is the nodal agency for promoting CBM in India. Coal blocks already have been allocated for CBM exploration and production. Production and sale of CBM has already commenced (since July 2007) in West Bengal fields, and more production is expected from ONGC and Reliance wells.[25]

UCG gasifies coal in-situ by injecting oxygen and water into coal seams, thereby converting the coal into a low-energy synthetic gas, in a process similar to surface coal gasification (see section on Power-Generation Technologies). The produced syngas can then be burned in a combined-cycle gas turbine, or used for other purposes. There are significant environmental advantages of UCG: it eliminates coal mining and its attendant environmental damages; much of the ash remains underground; and it produces very little SO_x and NO_x (DTI, 2004; Friedmann, 2005). Furthermore, the commercial use of deeper coal seams would significantly increase the amount of coal usable for energy purposes in the country, although better assessment of deeper coal resources is necessary before undertaking UCG activities. UCG, however, is not yet a fully commercial technology, although several commercial-scale plants have been proposed worldwide. As of now, both public and private oil and natural gas companies in India are interested in pursuing UCG testing in the country.

[24] Also known as room-and-pillar and pillar-and-stall. Bords are underground roadways by which coal is extracted, and pillars are made of coal that is left to support the overburden on top. The deeper the coal seam, the thicker the pillar size (Chikkatur and Sagar, 2007).

[25] Business Standard, "India begins tapping gas from coal bed," July 14, 2007. See: http://www.geecl.com/news/clip-1.pdf.

Recently, the Gas Authority of India Limited (GAIL) linked up with Ergo Exergy Technologies to undertake pre-feasibility studies for a 5 MW pilot-scale UCG in deep lignite mines in Rajasthan.[26] In 2004, ONGC linked up with a Russian institute to conduct feasibility studies, followed by pilot plants, in deep lignite and coal seams in Rajasthan, Tamil Nadu, and Gujarat. Private oil and gas companies, such as Reliance, also are interested in developing UGC.[27] The results from the first few pilot plants are crucial for assessing the feasibility of large-scale use of UCG technology for Indian coals.

CONSUMPTION

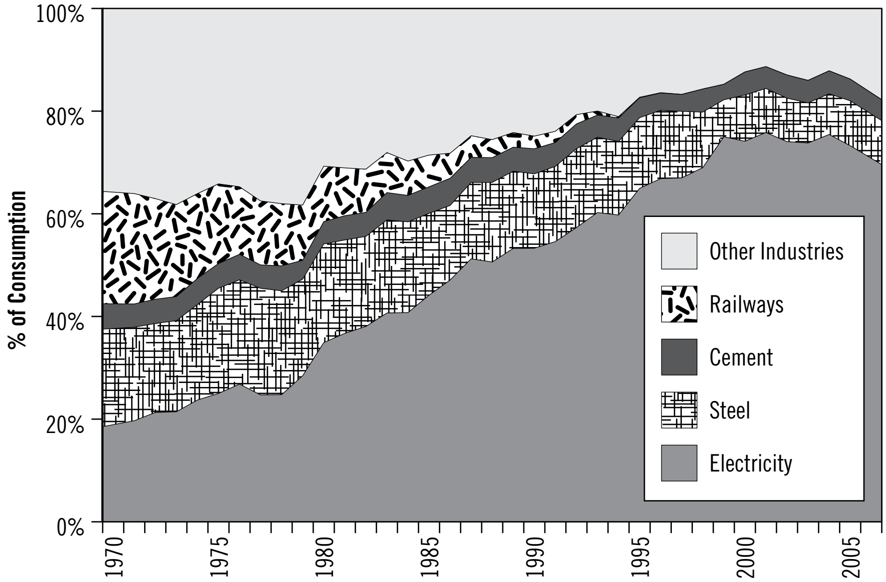
Coal consumption and demand have grown enormously in India, primarily dominated by the electricity sector. Starting in the 1970s, coal-based thermal power plants were installed at a rapid pace, and demand for thermal coal increased accordingly. In 1970, electricity generation consumed about 13 MT (less than 20% of total coal consumption); it consumed about 280 MT in 2003 (nearly 75% of total consumption) (see Figure 3).

Other major coal-consuming sectors include rail transport, iron and steel production, and cement production. Coal consumption by the railways has decreased steadily; in fact, direct coal consumption by the railways ended by the mid-1990s, as rail transport became entirely based on electricity and diesel. The iron and steel industry, which primarily consumes coking coal and some high-grade non-coking coal, is the second largest consumer of domestic coal, although its consumption has decreased from 20% of total consumption in 1970 to about 8% in 2003. Much of India's coal imports are being used by the steel industry as domestic coking coal supply has declined since the mid-1990s (see Figure 2). The third largest consumer of coal in India is the cement industry, which accounts for 4 to 5% of total consumption. Other smaller consumers include the fertilizer industry (consuming nearly 4–5 MT of coal per year since the 1980s; (CMIE, 2005)); the textile industry (including jute and jute products); the paper industry; and the brick industry.

[26] See: "Underground coal/lignite gasification tech — GAIL gets board nod to get license from Canadian firm," Richa Mishra, Hindu Business Line, Feb 18, 2006. http://www.thehindubusinessline.com/2006/02/18/stories/2006021803170200.htm

[27] See: "Reliance plans underground coal gasification projects," Ambarish Mukherjee, Hindu Business Line, December 7, 2005. http://www.thehindubusinessline.com/2005/12/07/stories/2005120704210100.htm

Figure 3: Coal consumption by sector (1970–2006)



"Other industries" includes paper, textiles, jute, bricks, coal for soft coke, colliery, fertilizers & various other small industries.
Source: MOSPI, 2008

Long-term and short-term supply of coal to "core" consumers (power and cement industries) is determined by a "Standing Linkage Committee" in the Ministry of Coal, which decides the provision of supply linkages (mode and quantity) from specified mines to individual power and cement plants.[28] The supply to large, "non-core" consumers is based on another linkage committee. The brick-kilns, domestic consumers, and other small industrial units are left without any formal supply linkages. As a consequence, they readily buy coal from the black-market at high prices.[29]

Current transport from mines to consumers relies primarily on the railways, although road and merry-go-round systems (for industries located close to pitheads) are other key transport mechanisms. Nearly 50% of coal transport currently is handled by the railways; rail used to handle more than three-fourths of the country's coal transport in the mid-1970s (TERI, 2005).[30] Road transport of coal accounts for about 20% of total coal transport, and merry-go-round systems also have become an important transport mode, as power plants increasingly are located near pitheads (Chikkatur and Sagar, 2007). Transport by sea is also important—major Indian ports handled more than 50 million tons of coal in 2003–04 and 2004–05—with coal accounting for nearly 14 to 15% of all port traffic (TERI, 2005).

[28] The standing linkage committee has the Additional Secretary in the Ministry of Coal as the Chairman, and representatives from CIL, SCCL, CMPDI, Railways, Planning Commission, Central Electricity Authority, Ministry of Power, and the Ministry of Industry. The Committee decides the linkage of coal for source of supply, quantum of coal and the mode of transportation. See: http://coal.nic.in/linkage.html.

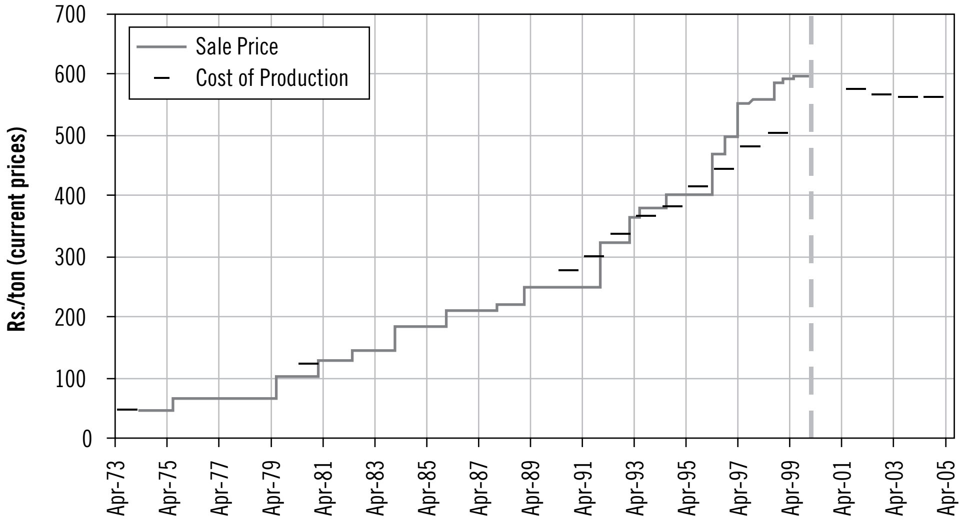
[29] Recently, CIL has set up an electronic-marketing system, whereby small non-core consumers can purchase coal through an e-auction system (Ministry of Coal, 2006a).

[30] Coal accounted for about 44% of overall railway freight traffic and 40% of overall freight revenue in 2005–06. See: http://www.indianrailways.gov.in/deptts/stat-eco/05-06/ST-13.pdf.

COST

The average cost of coal production in India has steadily increased since the 1970s, despite increases in productivity. The productivity of opencast mining in CIL from 1975 to 2003 has gone up from 0.9 to 6.6 tons/man-shift (TERI, 2004), with the percent of production from opencast mining increasing from about 25% to 80% in the same period. Nonetheless, the average cost of production in CIL has increased from about Rs. 45 to Rs. 560 per ton in the same period (see Figure 4).[31] Although the production cost of opencast mining is about 3 to 4 times cheaper than underground mining, the high cost of production in underground mines has led to higher average production costs. For example: in 1993–94, the cost of underground mining in CIL was about Rs. 710/ton ($22.5/ton), in contrast to Rs. 240/ton ($7.6/ton) for opencast mining. The weighted average cost for CIL mines in 1993–94 was Rs. 360/ton ($11.4/ton) (CMIE, 1995).

Figure 4: Average cost of production and average sale price of CIL coal



The average cost of producing of ton of coal is shown as dashes that extend from April 1 to March 31 of any particular year. The sale price of coal was determined by the Ministry of Coal and revised periodically (as shown). Since January 2000 (marked by dashed line), the MoC is no longer setting prices.

Source: Chikkatur and Sagar (2007); CIL production cost prior to 1993 is from CMIE (1995), from 1993 to 1998 is from Ministry of Coal Annual Report 1999–00, and from 2001 to 2004 is from CIL website (http://coalindia.nic.in/perf8.htm). The sale price for CIL coal from 1974 to 1986 is from CMIE (1995), and from 1987 to 1999 is from TERI (2005).

In line with the high average production costs, the average sale price of coal also has been increasing since the 1970s (see Figure 4). The sale price of coal has always been (and continues to be) a contentious issue in India. The Colliery Control Order 1945 allowed the government to fix coal prices; prior to nationalization in 1973, coal prices were administratively set low in comparison to production costs (Gupta, 1979; TERI, 1986)—leading to losses for coal mining companies. To allay some of these losses, the government set up the Bureau of Industrial Cost and Prices in 1970 to recommend the appropriate price of coal, based on

[31] The historical exchange rate of Indian rupees to U.S. dollars is as follows: From 1970 to 1980, the rupee remained fairly constant at an exchange rate of about Rs. 8 per U.S. dollar (fluctuating within a band of Rs. 7.5 to 9); from 1980 to 1990, the rupee deflated gradually from about Rs. 8 to Rs. 17; and from 1990 to 2002, the rupee deflated dramatically from Rs. 17 to a peak of Rs. 49 per U.S. dollar in 2002. Since then, the rupee has slowly appreciated and it is now around Rs. 40 per U.S. dollar. See: eh.net for more information.

production costs. The prices initially were based on an average of production costs of all mines, which led to problems for coal companies with high production costs and allowed for inefficient mining practices to continue (TERI, 1986).

In 2000, a new Colliery Order was passed deregulating the price of all grades of coal. The Ministry of Coal no longer sets the price of coal. Rather, each coal company is allowed to set its own sale price based on prevailing market prices. Nonetheless, the prices fixed by the coal companies still are perceived to be "guided" by the government (Ministry of Coal, 2006b). One issue is that coal consumers do not directly participate in price setting, nor are there any negotiations between consumers and producers (Ministry of Coal, 2007b). Furthermore, there is very little price elasticity for coal—i.e., coal is always in demand regardless of its price[32]—especially since the electricity sector consumes nearly 75% of domestic coal and electricity is in constant demand, even at high prices. Hence, resolving price issues has been a key reason for the push towards having an independent regulatory agency for the coal sector.

The cost of transportation is also a significant part of the final cost of delivered coal to consumers. For example, the cost of coal for power plants in 2005 was estimated to be under $20/ton ($5/million kilocalories), including royalty and tax; however, the cost of delivered coal is about $48 to $64 per ton, as freight and handling add about $28 to $44/ton, depending on distance and mode of transport (Ministry of Coal, 2006b).[33]

QUALITY

The quality of Indian coal is poor and has gotten worse over the past decades. Indian coal has the general properties of the Southern Hemisphere Gondwana coal, whose seams are interbanded with mineral sediments (IEA, 2002). Run-of-mine coals typically[34] have high ash content (ranging from 40–50%), high moisture content (4–20%), low sulfur content (0.2–0.7%), and low calorific values (between 2500–5000 kcal/kg) (IEA, 2002). A comparison of Indian coals to Ohio and Chinese coals indicates the key differences (see Table 2). Selected coals from the U.S. and China have about twice the calorific value and carbon content of Indian coals. The low calorific value implies more coal usage to deliver the same amount of electricity. Indian coal, however, has lower sulfur content in comparison to other coals, although it has relatively high amounts of toxic trace elements, especially mercury (Masto *et al.*, 2007).

[32] Expert Committee on Coal Reforms (Ministry of Coal, 2006b) points out that the price inelasticity exists not only in power generation but also for consumers of high-grade coal, such as iron and steel industries and cement industries. Only small-scale brick-kilns and industrial consumers are truly price sensitive and they are willing to pay high costs, as they generally depend on the grey-market, as they are not provided specific coal supply linkages.

[33] The freight charge of $7–$11 per million kilocalories ($28–44 per ton) was for distances between 1000 to 2000 kilometers from coal mines. In contrast, the price of imported coal was about $13 per million kilocalories at coastal locations (Ministry of Coal, 2006b). The assumed average calorific value of coal was 4000 kcal/kg.

[34] In contrast, the Tertiary coals in Assam have low ash, high sulphur and higher calorific values (Krishna, 1980).

Table 2: Typical coal characteristics in selected Indian power plants, compared to selected Chinese and U.S. coals

Details, %	Kahalgaon	Simhadri	Sipat	US (Ohio)	China (Long Kou)
Carbon	25.07	29.00	30.72	64.2	62.8
Hydrogen	2.95	1.88	2.30	5.0	5.6
Nitrogen	0.50	0.52	0.60	1.3	1.4
Oxygen	6.71	6.96	5.35	11.8	21.7
Moisture	18.5	15.0	15.0	2.8	11.0
Sulphur	0.17	0.25	0.40	1.8	0.9
Ash	46.0	46.0	45.0	16.0	7.7
Calorific Value, kcal/kg	2450	2800	3000	6378	6087

Ultimate analysis of non-coking (thermal) coal from three power stations (Kahalgaon, Simhadri, and Sipat) is shown along with analysis of Ohio coal of the United States and Long Kou coal from China.

Source: Visuvasam *et al.*, 2005.

Ash is generally well intermixed into the coal structure and hence coal washing using physical methods is difficult, although it might be necessary for industrial use. The high ash content also leads to technical difficulties for utilizing the coal, as well as lower efficiency and higher costs for power plants. Some specific problems with the high ash content include high ash disposal requirements, corrosion of boiler walls and fouling of economizers, and high fly ash emissions (IEA, 2002). The high silica and alumina content in Indian coal ash is another problem, as it increases ash resistivity, which reduces the collection efficiency of electrostatic precipitators and increases emissions.

The ash content in Indian coals has been increasing over the past three decades, primarily because of increased opencast mining and production from inherently inferior grades of coal (Ministry of Coal, 2006b). Current practices have limited coal resource assessments to within 300m, which implies that opencast mining is expected to dominate production over the next 20 to 30 years; thus, coal quality might not improve much without additional washing and beneficiation.[35] Furthermore, the current grading system of coals in India does not provide a proper pricing signal for coal producers to improve coal quality. Nevertheless, there is already some washing of power plant-grade coal in India as power plants aim to meet the environmental regulations on coal-ash content. The regulations require that power plants must use coal with less than 34% ash if they are located more than 1000 km from the mine-sites or are located in critically polluted areas, urban areas, and ecologically sensitive areas (CPCB, 2000).

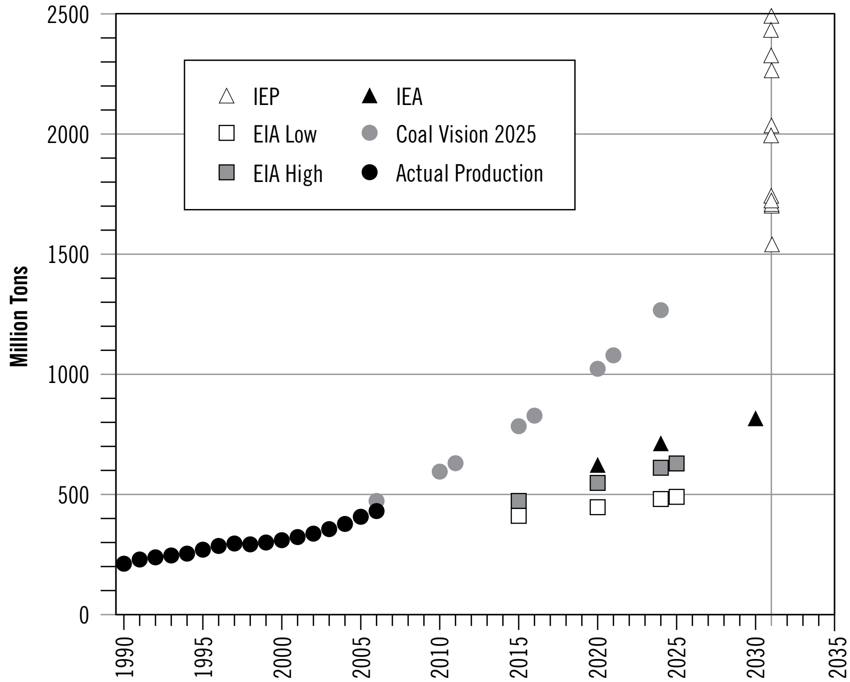
PROJECTED FUTURE DEMAND

Coal is projected to be the main resource for power generation in India in the short to medium term (see section on Future Growth and Continued Reliance on Coal), despite projected increases in natural gas, nuclear, and renewable capacity in the country. Hence, coal demand is expected to rise with increasing electricity demand—and the growth in coal demand is not likely to be met by domestic production alone. Recent pro-

[35] Coal washing and beneficiation has been practiced in India for coking coal for a long time. Recently, washeries for non-coking coal are also being constructed.

jections of coal demand in the power sector indicate that coal consumption could be as high as 550 MT by 2012 (CEA, 2007b). Longer-term scenarios from the Integrated Energy Policy Committee indicate that the total coal demand may vary anywhere between 1.5 and 2.5 GT, assuming a coal calorific value of 4000 kcal/kg and 8% GDP growth (Planning Commission, 2006—see Figure 5).[36] The Committee believes that by 2030, annual coal demand will be about 2 GT. Coal demand projections by various other agencies also are indicated in Figure 5.

Figure 5: Projected future demand for coal in India



Projections from Indian agencies (Coal Vision 2025 from the Ministry of Coal and the Draft Integrated Energy Policy (IEP) from the Planning Commission, both assuming 8% GDP growth) project higher coal demand than the projections from international energy agencies (IEA and EIA). Coal demand based on various scenario projections from the IEP report are shown above (open triangles), assuming coal calorific value of 4000 kcal/kg.

Source: Planning Commission, 2006.

In contrast to these demand projections, domestic production of coal and lignite is expected to be about 480 MT by 2012 (CEA, 2007b); the projected production rises to about 1.4 GT by 2031–32, assuming an annual growth rate of 5.5% (Planning Commission, 2006). Already, coal demand—driven primarily by demand in coal power plants—has been outstripping supply.[37] Recently, many power plants, including National Thermal Power Corporation (NTPC) plants, have pulled back on generation and have partially shut down because of coal sup-

[36] Coal demand of 2.5 GT occurs in a scenario where coal is the dominant fuel of choice; the 1.5 GT occurs in a scenario where nuclear, hydroelectricity, gas, and renewables resources are forced and demand-side management, coal use efficiency, transport efficiency are all increased (Planning Commission, 2006).

[37] Over the two decades, demand for coal has increased at an average annual rate of 5.7%, while production has only increased at 5.1% (Planning Commission, 2002).

ply shortages and critically low coal stock levels.[38] The Mid-Term Assessment for the Tenth Plan (2002–2007) projected an annual growth rate for coal demand of 6.1%, whereas the production growth rate was expected to be only 5.7% (Planning Commission, 2005). Hence, there is an acknowledged gap between coal demand and supply in India—a gap that is projected to increase in the short term (Ministry of Coal, 2006b).

The increasing demand for coal has forced an acceleration of coal production in the country; however, the rate of future coal production might be limited. Socio-environmental damage from opencast mining (displacement of people, and the destruction of forests, top soil, water resources, etc.) is a key constraint for the future. The unreliability of extractable reserve estimates might also inhibit developers to take up projects without better data (Ministry of Coal, 2006b). Many analysts have called for more investments and planning in underground coal production in the country (Chand, 2005; Ministry of Coal, 2006b). While the current coal shortages might be temporary—a result of strikes, low productivity in domestic coal mines, and a slowdown in commissioning of new mines at CIL—the coal shortages might also be harbingers of a future where domestic coal supply is indeed limited (Chikkatur and Sagar, 2007).

In order to meet the projected demand, imports of coal are likely to increase significantly over the next 20 to 25 years—to anywhere between 11% to 45% of total coal demand (i.e., coal imports of 70 to 450 million tons of oil equivalent (Mtoe)) (Planning Commission, 2006). Today, imported coal is only about 6% of consumption.[39] The high level of coal imports will have many implications for the Indian energy sector. For example, it might induce the Indian coal industry to become more efficient and to produce coal with better quality. On the other hand, increased coal imports, along with increased imports of oil, could have a strong negative impact on Indian national security and its financial situation.

REGULATION AND REFORMS

Recently, there has been a significant push towards reforming India's coal sector (consistent with the broader trend of reforms and restructuring in various parts of the energy sector) and creating an independent regulator for coal. The two main drivers for independent regulation are a desire for better coal pricing and increasing competition. There are strong concerns that the coal sector does not have enough competition and that government overly controls and influences the sector. Recently, the coal ministry has opened up the coal sector by allocating coal blocks to private players and public-sector corporations for captive mining. However, there are no comprehensive laws requiring the licensing, set-up and operations of a coal mining company or coal trading company (Ministry of Coal, 2007b). Thus, given the strong interests of existing industries, it is better to have an independent regulatory agency work with the various stakeholders to determine the new laws necessary for increasing competition.[40] Furthermore, the Competition Act of 2002 will affect future coal sector agreements. This Act prohibits agreements that decrease competition or that enable abuse of an

[38] For example, see: "Coal shortage: NTPC units in critical stage" Hindu Business Line, March 19, 2005; "Thermal plants' coal shortage worsening" Hindu Business Line, April 4, 2005; "Power crisis likely to continue — Coal, gas shortage results in 2 b units loss" Hindu Business Line, May 4, 2005; "Shortage of coal hits power generation at RTPS" The Hindu, May 7, 2005.

[39] Current imports are primarily for coking coal that is used in the steel industry, although the power sector has recently been importing more coal to mitigate coal shortages. In 2003–04, a total of 24 MT of coal was imported from Australia, Indonesia, South Africa, and China (IEA, 2002; Ministry of Coal, 2004).

[40] Ministry of Coal (2007b) has provided a range of suggestions on this issue.

enterprise's dominant position in terms of pricing, reducing production, limiting market access, or pursuing certain anti-competitive mergers (GoI, 2003).

The government has received plenty of suggestions regarding how to regulate the coal sector in India. A major source of these suggestions is the Expert Committee on Coal Sector Reforms (Ministry of Coal, 2006b; 2007b). For example, the Committee has recommended the creation of an Office of the Coal Governance and Regulation Authority with five directorates:

- Coal Resources Management
- Safety, Health, and Employment
- Prices, Taxes, Royalty, Value Added Tax, Property Tax, and Salary of Workers
- Environment Management
- Policy—Legal, Public Relations, Statistics, and Dispute Resolution

The Committee also has suggested setting up an advisory body (National Coal Council) to enhance the participation of all stakeholders and to help the government periodically in understanding the state of economics, technology, environmental and social aspects of coal production and usage.

Coal Power

BACKGROUND

The current power sector in India is dominated by coal-based generation and remains largely under government control. India's generation of electricity using coal began as early as 1899, with the 1 MW Emambaugh Lane power station in Calcutta. Just after India's independence, there were 65 projects, nearly all in the private sector. These projects generated electricity using coal-fired steam generators for public supply with an installed capacity of 1 GW, which accounted for 60% of total capacity (CWPC, 1951; Planning Commission, 1952).

After India's independence, state ownership and planning were key tools used by the Indian government. As a result, rigid control of electricity by the government was considered essential for meeting the country's objectives.[41] Electricity consumption was considerably higher in urban areas compared to other parts of the country. Concerned about the inequities this entailed,[42] the government aimed its policies at providing cheap electricity to villages and rural areas. One of the government's principal objectives was to provide electricity for irrigation and village-based small-scale industries (Planning Commission, 1952). Accordingly, State Electricity Boards (SEBs) were created to construct new power plants; arrange for transmission, distribution and sale of electricity to consumers in the state; and administer regional grid systems (GoI, 1948a). A Central Electricity Authority (CEA) was also created to coordinate and plan power development activities.

In the 1950s and 1960s, the government plans centered on co-developing irrigation and power sectors, and there was greater emphasis on hydroelectricity.[43] Meanwhile, the growth in the coal-power sector was dominated by imported power plants with unit sizes less than 100 MW. By the early 1970s, the power sector had to rely much more on indigenous coal, especially since the global oil crisis made the use of indigenous coal relatively cheaper. This forced the government to emphasize coal usage in many energy-intensive sectors, including electricity generation (Chakravarty, 1974; Pande, 1980). To consolidate the generation of electricity using coal and to ensure adequate supply to the various power plants and industries, the government nationalized the coal mines between 1971 and 1973. India began to locate coal-based power plants at pithead locations to reduce the costs of transporting coal to power plants. A new centrally owned public sector corporation—National Thermal Power Corporation—was established in 1975 to accelerate the installation of pithead coal power plants, and to provide additional thermal power capacity to the regional grids.[44] Power plant manufacturing capability in the country was consolidated with the formation of the Bharat Heavy

[41] Private companies were deemed to be ineffective for providing nationwide access to electricity, since their profit motivation would have led to a focus on areas with greatest demand—cities and urban areas—and neglect rural areas where they would get meager return on their investments (Datta, 1961).

[42] In 1950, 56% of the total public utility installations served only about 3% of population in six large towns (Govil, 1998).

[43] See Chikkatur and Sagar (2007) for more details.

[44] Many critics suggest that the World Bank played a crucial role in the creation of NTPC in order to protect its investments in the Indian power sector, since corporations backed by the central government would provide lower credit risks and greater borrowings than the SEBs (Govil, 1998; Rao, 2002).

Electricals Limited, which began to supply indigenously manufactured power plants in 1970 (Chikkatur and Sagar, 2007).

Largely due to these efforts, electricity generation in the country grew at a high rate in the 1980s, buttressed by a rapid increase in coal-based capacity. The installed capacity of coal power grew at an average annual rate of 8% in the 1970s and at 10% in the 1980s. Nearly 200 new coal power plant units (mainly 110 and 210 MW sizes) were installed between 1970 and 1990, in contrast to only about 75 units (less than 100 MW sizes) in the previous two decades (see Table 3). Since the 1990s, the growth of coal-power capacity slowed slightly as the power sector was more focused on institutional issues.[45]

Table 3: Size and vintage of coal-based units in India

Age	Installed Capacity (up to end of 2005)					Installation Year
Unit Size	**<100**	**100/110/120/140/150**	**200/210/250**	**500**	**Total**	
< 5 years		490	3165	4500	**8155**	2001–2005
5–10 years	75	740	5280	2000	**8095**	1996–2000
10–14 years	205	120	8060	3500	**11885**	1991–1995
15–19 years	332	890	8370	5500	**15092**	1986–1990
20–24 years	540	1670	8270	500	**10980**	1981–1985
25–29 years	120	2640	3290		**6050**	1976–1980
30–34 years	460	2710			**3170**	1971–1975
35–39 years	2210	720			**2930**	1966–1970
40+ years	1466	430			**1896**	< 1965
Total	**5408**	**10410**	**36435**	**16000**	**68253**	

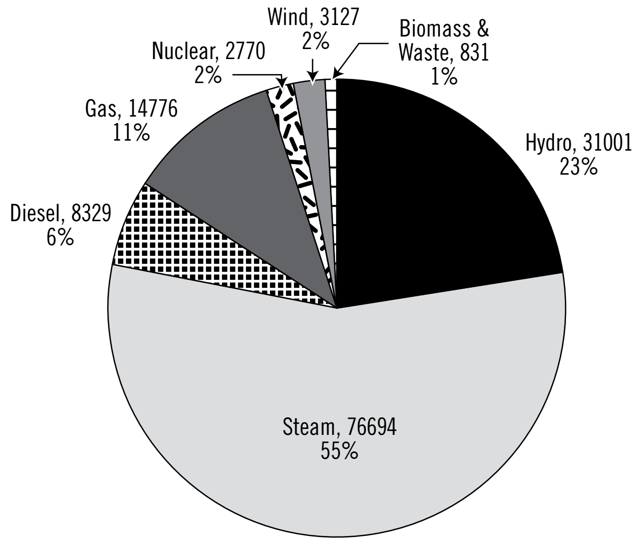
The unit size and vintage of current installed capacity of Indian coal and lignite power plants up to the end of 2005 is shown in five-year periods.

Source: Chikkatur and Sagar, 2007.

As of March 2005, there was about 77 GW of coal and lignite-based installed capacity (68 GW in utilities and 9 GW in non-utilities), accounting for nearly 56% of total installed capacity (see Figure 6). Coal and lignite-based generation accounted for about 80% of total generation (425 TWh—utilities; 45 TWh—non-utilities) (CEA, 2006). In 2004–05, these coal-power plants consumed about 280 MT of coal (with average calorific value of 3800 kcal/kg) and 25 MT of lignite (with average calorific value of 2700 kcal/kg) (CEA, 2006), making the power sector the largest consumer of domestic coal.

[45] For a broader discussion of institutional issues, see Chikkatur and Sagar (2007).

Figure 6: Installed capacity for power generation (March 2005)

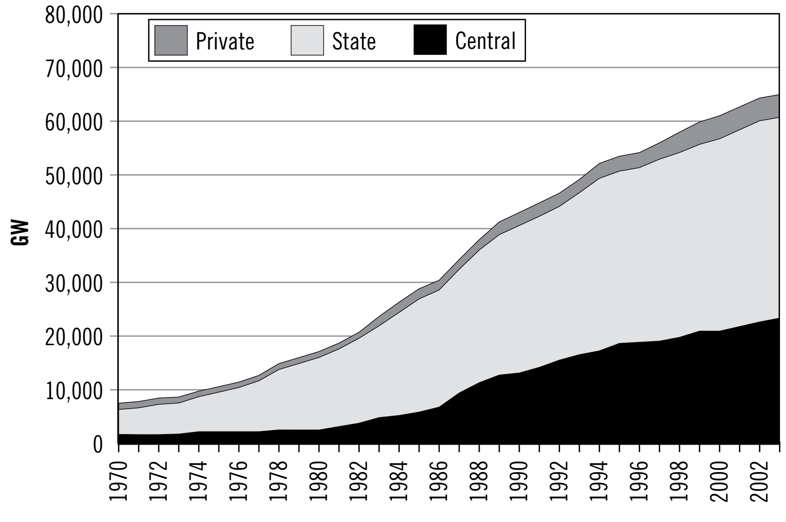


Data includes both utilities and non-utilities.

Source: CEA, 2006.

As of 2003–04, the State Electricity Boards and departments owned nearly 57% of the installed capacity, and about 36% was owned by central government corporations (CMIE, 2005). The remaining 7% (~4 GW) of privately-owned utilities were concentrated around urban centers (see Figure 7). Hence, the coal power sector is dominated by the government and its policies.

Figure 7: Ownership of installed capacity of coal-based power plants (1970–2003)



The state category also includes plants owned by local municipal bodies. The central category also includes DVC-owned plants.

Source: CMIE, 2005.

Despite government control, the sector has undergone dramatic structural changes over the past decade, particularly in the state sector. The SEBs, which owned most of the coal-based generation capacity, became financially insolvent by the late 1980s. The distribution network in the country became inefficient, with very high transmission and distribution losses, as well as commercial theft. Hence, the SEBs had to rely on state government subventions, cross-subsidies and other accounting manipulations to meet their financial obligations (Tongia, 2003). In order to improve their financial situation, the SEBs in India underwent significant institutional restructuring throughout the 1990s. Supported by the World Bank, SEBs in several states unbundled generation, transmission and distribution into separate entities, introduced independent regulation of the sector, and encouraged privatization of distribution. The central government formally restructured the entire power sector with the Electricity Act of 2003. The new Act required all SEBs to unbundle and privatize, while introducing wholesale competition and trading, with independent regulation (Chikkatur and Sagar, 2007). Essentially, the Act has introduced a market-driven system by which electricity became a commodity. This is a dramatic shift from the past, when electricity was viewed as a tool for social progress that requires active state participation (Purkayastha, 2001).[46] With these new changes, coal power generation has been effectively freed from many controls, with two exceptions: environmental regulations, which are governed by the Ministry of Environment and Forests; and tariff setting, which is governed by independent state and central regulators.

FUTURE GROWTH AND CONTINUED RELIANCE ON COAL

Much of the expected growth in electricity in India over the next few decades will likely be based on coal, particularly domestic coal. The demand for utility-generated electricity is projected to more than double from about 520 TWh in 2001–02 to about 1300 TWh by 2016–17, with an annual growth rate of about 6–7% (CEA, 2000). Longer-term scenarios indicate demand to be around 3600–4500 TWh by 2031–32 (Planning Commission, 2006). The short-term electricity demand is expected to be met with nearly 100 GW of new capacity in the 10th and 11th Plan periods (2002–2012)—an investment of nearly Rs. 8 trillion ($160 billion) (Ministry of Power, 2001). The Planning Commission (2006) notes that the installed capacity (including captive power) needs to be about 800–1000 GW by 2031–32, depending on GDP growth.[47]

This projected rapid growth in electricity generation is expected to be met by using coal, since other resources are uneconomic (as in the case of naphtha or liquefied natural gas (LNG)), have insecure supplies (diesel and imported natural gas), or are simply too complex and expensive to build (nuclear and hydroelectricity) to make a dominant contribution in the short to medium term (Chikkatur and Sagar, 2007). Liquid fuels such as heavy oils have limited use in the power sector for economic and environmental reasons; for example, distillates such as naphtha, high-sulfur diesel and other condensates are either too expensive or too polluting for large-scale use. Although use of natural gas and regasified LNG in the power sector is increasing, particularly in the private sector, the long-term availability and costs of gas are uncertain. Existing

[46] Nonetheless, the government still has a strong focus on providing power to the poor, as illustrated by its continued rural electrification activities.

[47] Other researchers also generally corroborate the government's projections showing rapid growth of installed capacity and electricity generation in India. Gupta *et al.* (2001) have used a RAINS-ASIA model to predict that the overall generation of electricity in India needs to quintuple in 30 years from 1990 to 2020. Shukla and collaborators have made longer predictions up to 2100, when they expect India to be generating more than ten times as much as electricity compared to 1995—4300 TWh in 2100 from 420 TWh in 1995 (Rajesh *et al.*, 2003).

gas-based power plants are experiencing low load factors because of paucity of supply.[48] Furthermore, the high cost of importing natural gas and of constructing LNG handling facilities is another crucial factor that might limit the growth of gas-based power generation.[49] A comparison of the cost of generated electricity in existing plants indicates the high price of gas-based generation (see Table 4).

Table 4: Comparison of power plants[50]

	Coal	Gas	Hydro
Capital Cost ($/kW)	650–1100[a]	650–950[b]	700–1650[c]
Construction time (years)	2–4	2	5–10
Cost of Generation (¢/kWh)[d]	3.2	5.6	3.5
	(1.6–4.8)	(2.5–8.9)	(1.4–6.8)

Sources:
[a] Chikkatur and Sagar, 2007.
[b] Sathaye and Phadke, 2006.
[c] Data from ongoing central-sector hydroelectric projects in the 10th Plan and beyond (CEA website).
[d] 2003–04 cost data based on existing central-sector power plants (CERC, 2004).

India has significant hydroelectricity resources, and the government aims to increase hydroelectricity generation. However, there are a number of problems with developing hydroelectricity in India, including shortage of funds, inter-state water use conflicts, lack of suitable transmission infrastructure, long gestation periods, geological uncertainty in the Himalayan regions, high environmental impacts, and problems of rehabilitation (CEA, 1997). The potential for nuclear power development is also not high in the short to medium term, because of limited domestic natural uranium resources and various international restrictions that have held back the Indian nuclear power industry (Gopalakrishnan, 2005).[51] Electricity from renewable sources, such as biomass (combustion and gasification), micro- and pico-hydroelectricity, solar photovoltaics, and urban and industrial waste, are relatively small and used mainly in niche applications; even wind power, which has grown significantly in the last decade, is concentrated in a few states where commercial-scale wind resources exist, wind contributes only about 0.5% of the total power generation in the country. Although the increased use of renewable sources is necessary and important, they are unlikely to play a significant role in the power sector in the short to medium term (Chikkatur and Sagar, 2007).

Hence, coal is likely to remain dominant for at least the first half of this century. Nearly 50 GW of new coal-based projects are currently under consideration for the 11th Plan (2007–2012), and overall coal consumption in the power sector is expected to reach 550 MT by 2012 (CEA, 2007b). Based on the Planning Commission (2006) scenarios, coal-based capacity of utility power plants is likely to be in the range of

[48] For example, see: "NTPC opts for liquid fuel to meet gas shortage" Business Standard May 5, 2005; "Gail asks AP-based IPPs to look for alternate fuel" Financial Express May 9, 2005; "CAG raps govt for power generation mess" Business Standard May 20, 2006.

[49] For example, see: Mamata Singh, "Gas cost to fuel power price" Business Standard May 7, 2005.

[50] Table includes the non-weighted average and range (in parenthesis) of generation costs for existing power plants. The range in generation cost is primarily due to wide variation in installation times. Older plants have much lower fixed costs than newer plants. The cost of generation for hydroelectric plants is based only on the fixed costs. See Chikkatur and Sagar (2007).

[51] The recent U.S.-India nuclear accord, if ratified, might ease the dependence of the Indian nuclear power sector on indigenous fuel supply and technologies. India could get access to the worldwide uranium markets and technologies. However, there is considerable debate regarding the accord's benefits (or lack thereof) to the Indian nuclear industry and its potential growth (Chikkatur and Sagar, 2007).

200–400 GW in 2030,[52] up from about 68 GW in 2005. EIA projections for growth in coal-based capacity in India is lower—160 GW by 2030—with an average annual growth of 3.3% (EIA, 2006). In contrast, EIA (2006) projects a much higher growth for China (4.3%)—790 GW in 2030, up from 240 GW in 2003. With the large number of coal-based thermal power plants expected to come online, coal consumption in the power sector is expected to be in the range of 380–500 MT (6–8 exajoule (EJ)) by 2011–12 and 1–2 GT (17–33 EJ) by 2031–32 (CEA, 2004a; Planning Commission, 2006). EIA (2006) projections indicate a lower coal consumption rate for power generation in India—5 to 11 EJ from 2003 to 2030. In comparison, China's coal consumption in power generation for the same period is projected to rise from 17 to 53 EJ; the projected increase in the United States is from 21 to 32 EJ.

Thus, the role of coal in the Indian power sector—in both the present and the future—cannot be understated.

COAL UTILIZATION TECHNOLOGY

Before India's independence, not only the technology for generating electricity, but also the materials and equipment necessary for construction, had to be imported. The earliest power plants were based on stoker water-tube boilers that were directly imported from Britain.[53] By the 1950s, pulverized coal boilers[54] had been installed in India, although the technology was available worldwide by the 1920s. PC boilers produce steam at higher pressures and temperatures, thereby increasing the efficiency of the steam turbine and overall electricity generation—initially, the steam parameters were kept below the critical point of water,[55] and hence this technology is generally referred to as "subcritical pulverized coal" technology.[56] By the late 1960s and early 1970s, larger units of varying sizes were imported from the U.S. and the U.S.S.R (see Table 3).

The Indian government in the 1960s began to establish indigenous manufacturing industries for heavy electrical equipment, as post-independence industrial polices precluded the private sector from manufacturing utility-scale power plant equipment.[57] In 1973, a new holding company, Bharat Heavy Electrical Limited, was formed to take over the management of these industries to coordinate the manufacturing of power plant equipment. BHEL soon became the sole indigenous manufacturer for power plants in India. Currently, most power plants installed in India are indigenously manufactured.

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[52] Assuming PLF of 75% and specific consumption of 0.75 kg/kWh.

[53] Coal-based electricity generation is, in essence, as follows: first, the carbon in coal is completely burned in a boiler and the generated heat from combustion is used to heat water/steam in tubes that encase the boiler. The energy of the hot and pressurized steam is then converted to rotary mechanical motion in a steam turbine. The rotating steam turbine, in turn, is connected to an electromagnetic generator that produces electricity. In stoker boilers, coal was burned on a grate, and the resultant hot flue gas was directed towards water-tubes (Singer *et al.*, 1958; Miller, 2005).

[54] In pulverized coal technology, coal was no longer burned on stoker grates, but was pulverized into a fine powder and introduced into the burners with pressurized air. The pulverization allowed for a hotter, more efficient, controlled burning of coal. For a more detailed description and technical details, please refer to Merrick (1984), Ghosh (2005), IPCC (2005), and references therein; websites such as http://www.iea-coal.org.uk/site/ieaccc/home and http://europa.eu.int/comm/energy_transport/atlas/htmlu/heat_and_power.html.

[55] The critical point of steam-water, where water and steam are indistinguishable, is at a temperature of 374.15oC and pressure of 218 atmospheres (221 bar or 225.6 kg/cm2).

[56] The term "pulverized coal technology" includes all related technologies for coal preparation, boiler, turbine-generator, related accessories, and control systems.

[57] The Industrial Policy Resolution (1948) called for'prime-mover','electrical engineering', and'heavy machinery' industries to become subject of Central government regulation and control, and the Industrial Policy Resolution (1956) went even further by stating that the heavy electrical machinery and generation and distribution of electricity were to be the exclusive responsibility of the State (GoI, 1948b, 1956).

BHEL has had significant technology collaborations with European, U.S., and U.S.S.R. companies, both in order to accelerate the pace of manufacturing and to meet the constraints imposed on the holding company by financial institutions (Govil, 1998). The first indigenously manufactured 60 MW pulverized coal unit was installed at Ennore in 1970. Shortly thereafter, BHEL began to manufacture larger-sized units. These included: the first indigenous non-reheat 100 MW unit at Badarpur in 1973; the first 110 MW reheat unit at Kothagundem in 1974; the first 200 MW unit at Obra in 1977; and the first 500 MW at Trombay in 1984. In the following decades, BHEL completely dominated the power plant supply. Between 1970 and 1980, more than 60% of India's new plants were manufactured by BHEL; between 1981 and 1991, almost all of the power plants were BHEL-made (Chikkatur and Sagar, 2007).

The current "standard" for coal-power technologies in India is the BHEL 500 MW subcritical PC unit. These units are based on assisted circulation boilers with main steam pressure of 170 kg/cm^2 (CEA, 2003). The boiler-feed-pumps are turbo-driven (unlike the 200/210 MW units), which reduces the designed turbine heat rate to 1940 kcal/kWh (CEA, 2003). Currently, more than 25 of these units are in operation with an average designed gross efficiency of 38% (high heating value (HHV))[58] and net operating efficiency of 33% (see Table 5). However, many utilities are now entering the global markets for power plants through their tender process, which has the potential for bringing in new technologies to India. For example, two supercritical power plants currently in construction in India are based on Russian and Korean technologies—obtained through a global tendering process. Nonetheless, BHEL is expected to continue its dominance in the Indian coal power sector.

EFFICIENCY OF EXISTING PLANTS

Improving efficiency is an important aspect of energy policy, especially given the aging stock of India's power plants (see Table 3). Higher efficiency contributes to greater energy security, reduced environmental impacts, and lower costs for electricity. [59]

Although the efficiency of coal-based power plants in India has improved in recent years, there is still plenty of room for further improvement (see Table 5). The average net efficiency of the entire fleet of coal power plants in the country is around 29%. The older units (less than 200 MW) have the worst efficiencies. However, in spite of poor efficiencies and low PLF, these power plants continue to operate because they supply electricity at low costs.[60] The best power plants—500 MW subcritical units—operate with a net efficiency of about 33%. In comparison, the average net efficiency for the 50 most efficient U.S. coal-based power plants is 36%, with the fleet average being 32%.[61]

[58] Efficiency is calculated using the high heating value (HHV) for coal. The higher heating value of a fuel is defined as the lower heating value (LHV) plus the latent heat of evaporation of water contained in the products of combustion. The energy used to evaporate water (latent heat of evaporation) is unusable for power generation; hence, the use of LHV for coal is more appropriate. Nonetheless, the HHV is more commonly used in India and in the United States.

[59] Efficiency improvement in transmission and distribution is also an important aspect that is not discussed in this paper.

[60] Most of the loans for these old power plants have been paid off, and therefore their fixed costs are very low. As a result, the cost of generation is mainly determined by the variable energy cost.

[61] http://www.powermag.com/plants_top.asp.

Table 5: Efficiency of existing power plants

Unit Size (MW)	Total units operating*	Units considered for data*	Avg. Gross eff. (Actual)	Avg. Gross efficiency (Design)	Percent Variation**	Avg. Net efficiency (Actual)	CERC norms	PLF
500	18	18	35.7%	38.1%	6.9%	33.3%	35.1%	81.9%
200/210/250 (KWU)^	154	48	35.0%	37.7%	7.6%	32.0%	34.4%	86.6%
200/210 (LMZ)^		37	34.6%	36.2%	4.7%	31.7%	34.4%	78.0%
100 to 200	84	32	27.6%	34.9%	26.6%	24.2%	—	66.5%
Less than 100	87	32	25.8%	31.2%	21.1%	22.8%	—	57.7%

Source: Chikkatur, 2005. Calculations based on CEA data (CEA, 2005c).
Average efficiency is calculated based on operation data for the period April 2000 to December 2003, as collected by the CEA.
* Units operating on Lignite and those installed after 2000 are not included here.
** Percent Variation is defined as (Design eff—Actual eff.)/Actual eff.
^ Design efficiency varies with technology—KWU units are based on Siemens technology, and LMZ units on Russian technology.

The poor efficiency of India's power plants is usually blamed on a variety of technical and institutional factors such as poor quality of coal, bad grid conditions, low PLF, degradation due to age, lack of proper operation and maintenance at power plants, ineffective regulations, and lack of incentives for efficiency improvements (Khanna and Zilberman, 1999; Shukla *et al.*, 2004; CEA, 2005c). Many of the SEB-owned plants have higher auxiliary consumption and specific coal consumption, in comparison with central and privately-owned plants—primarily because of poor management practices, lack of funds for maintenance, higher shut-down rates and poor response to load variations. Therefore, changes in management practices and institutional structures might improve efficiency (Khanna and Zilberman, 1999).[62] The quality of coal supplied to power plants has decreased significantly since the 1970s, and the ash content has increased to 40–45%. The use of low-quality coal increases auxiliary consumption, operation and maintenance costs and time, and reduces overall efficiency. The CEA (2005c) has noted that lack of emphasis on efficiency during operations and maintenance of the power plants is one of main reasons for poor performance. In fact, most power plants do not accurately measure efficiencies routinely or carry out energy audits to assess their efficiency levels (Chikkatur and Sagar, 2007).

It has been estimated that the efficiency of existing Indian power plants can be improved by at least 1 to 2 percentage points (Deo Sharma, 2004). The large gap between the actual and design efficiencies (see Table 5) also indicates that there is ample scope for efficiency improvements. Increasing efficiency by one percentage point in a power plant can reduce coal use, and corresponding air pollution and CO_2 emissions, by 3% (Deo Sharma, 2004). The efficiency of a power plant is also the most sensitive parameter in determining its cost of generation. Hence, the combination of the potential for significant gains in efficiency and the wide range of benefits that would result from any such improvements provide a powerful impetus for efficiency improvements in existing power plants and for deploying high-efficiency plants in the future (Chikkatur, 2005; Chikkatur *et al.*, 2007).

[62] For example, since the introduction of power sector reforms, there is some increase in power plant efficiencies, but this can be mainly attributed to changes in fuel mix (i.e., increased installation of more efficient natural gas plants) rather than increases in the power plant efficiencies (Shukla *et al.*, 2004; Perkins, 2005).

Thus far, the Indian government has focused mainly on improving generation and life-extension of older power plants. Since 1985, nearly 400 units (totaling more than 40 GW of capacity) have been serviced through the Renovation and Modernization (R&M) program (CEA, 2004a). By providing technical and financial support to the cash-strapped power plants, these programs have helped power plants maximize their generation by increasing the plant load factor. The Life Extension program has extended the life of older power plants by 15 to 20 years (CEA, 2004a).

However, these government programs are not specifically aimed at improving efficiency; hence, programs specifically focused on improving efficiency in existing power plants are necessary (Chikkatur, 2005). One step in the right direction is the Centre for Power Efficiency & Environmental Protection (CenPEEP), a NTPC-USAID collaboration, which acts as a resource center for acquiring, demonstrating, and disseminating technologies and practices for reducing greenhouse gas emissions from power plants. Efforts such as CenPEEP must be strengthened and expanded. Furthermore, it is important to consider phasing out the older, less-efficient, smaller-sized units (see Table 5), despite their relatively low generation costs.

Finally, regulators can take a much more active role in pushing for efficiency improvements. For example, they can provide for tariff-based incentives based on the efficiency performance of power plants (Chikkatur *et al.*, 2007). Current electricity regulations in India continue to be based on cost-plus mechanisms,[63] despite regulators' hope that competitive bidding for tariffs will be available in the future.[64] Current tariffs based on normative benchmarks for performance are hobbled by information asymmetry, wherein some utilities have withheld relevant information from regulators. One way to get around this is to promote performance-based incentives for improving efficiency that are tied to benchmarks determined by actual performance (Chikkatur *et al.*, 2007).

ENVIRONMENTAL CONCERNS

Coal-based power plants significantly impact the local environment. Direct impacts resulting from construction and ongoing operations include:[65]

- flue gas emissions—particulates, sulfur oxides (SO_x), nitrous oxides (NO_x), and other hazardous chemicals;
- pollution of local streams, rivers and groundwater from effluent discharges and percolation of hazardous materials from the stored flyash;
- degradation of land used for storing flyash; and
- noise pollution during operation.

[63] Under the current approach of cost-plus tariffs, regulators approve the fixed and variable costs of utilities based on a range of benchmarks determined by the regulators and the profits of the utility (i.e., rate of return on investment and other incentives) are included in the tariff calculation—hence the term "cost-plus."

[64] While competitive pricing might reduce costs and improve efficiency of power plants, it is not feasible in the Indian context yet because relevant institutions and market mechanisms are not developed enough.

[65] For details, see Chikkatur and Sagar, (2007) and references therein.

Indirect impacts of these plants result mainly from coal mining and include: degradation and destruction of land, water, forests and habitats; and displacement, resettlement and rehabilitation of people affected by mining operations.

The primary responsibility for creating and enforcing environmental regulations lies with the state and central pollution control boards, which are under the state and central ministries of environment and forests, respectively. For large thermal power plants, the central Ministry of Environment and Forests (MoEF) has to give an environmental clearance, based on an environmental impact assessment (EIA) for the project, before it can be approved for construction.[66] Although the EIA and subsequent public hearing process is expected to take input from local communities, analysts have pointed out that the EIA process has been subverted in many cases.[67]

Enforcement of environmental regulations is a serious challenge, especially since power supply is constantly in demand. Although there are provisions in the law that allow for shutting down power plants if they do not meet environmental standards, shut-downs do not happen because India "can hardly afford to close any unit in the power starved situation" (CEA, 2004b, 2005a). The Central Pollution Control Board (CPCB) has noted that many thermal power plants default on meeting pollution standards; about one-third of the thermal power plants in the country have failed to meet the expected standards for effluents and emissions (Chikkatur and Sagar, 2007).

With the projected increase in installed capacity, a key challenge for the government is to enforce and tighten its existing regulations and to add new regulations as deemed appropriate to protect local environment and ecologies. The MoEF and CPCB have initiated a process with industries for developing a Charter on the Corporate Responsibility for Environmental Protection (CREP)[68] to install cleaner technologies. It is expected that the CREP process will lead to better norms and tighter enforcement of regulations.

Emission of Criteria Air Pollutants

Stricter control of criteria air pollutants (particulates, SO_x and NO_x) from coal-power plants is essential. Emission of particulates from power plants is of serious concern in India because of the high ash content of Indian coals. Most of the particulate emissions come from flue gas, although fugitive dust from coal-handling plants and dried-up ash ponds also are significant sources of particulate pollution. Particulate emissions are better regulated than other pollutants, in part because of the use of electrostatic precipitators (ESPs) in all plants. However, the high resistivity of ash in Indian coals reduces ESP collection efficiency, making it important to modify ESPs to improve performance. The high ash content also leads to problems in ash disposal, as power plants require large tracts of land for storing and land-filling ash. Currently, MoEF is actively pursuing a 100% utilization of power plant ash in industrial and agricultural processes.

Stack emissions of sulfur oxide and nitrogen oxide emissions are not regulated, and only ambient air concentrations are monitored and regulated for these pollutants. Typical Indian coal has lower sulfur content than U.S. or Chinese coals (see Table 2). Coal supplied to Indian power plants has sulfur content ranging from 0.1

[66] See: Environment Impact Assessment Notification S.O.60(E); http://envfor.nic.in/legis/eia/so-60(e).html.

[67] For example, see: Sunita Dubey, "EIA: Foundations of Failure" (2006), http://www.indiatogether.org/2006/mar/env-eiafail.htm and Sunita Dubey, "Weakening the enviro-clearance process" (2004), http://www.indiatogether.org/2004/aug/env-eiaweakn.htm.

[68] See: http://cpcb.nic.in//Charter/charter.htm.

to 0.8%, with a consumption-weighted average of 0.59% (Reddy and Venkataraman, 2002).[69] In comparison, the average sulfur content of coals consumed by U.S. power plants is about 1.1% (EIA, 2000).[70] Hence, only one Indian power plant[71] has SO_x emission control technologies, and the focus of regulation is more on dispersal and dilution of SO_x than on reducing emissions. It has been estimated that about 7 tons of SO_2 was emitted for every GWh generated by Indian power plants during 1990–1995 (Garg *et al.*, 2001b).

Similar to SO_x, emissions of NO_x from coal-based plants are not regulated in India, although there is a limit in the ambient air quality. About 30% of NO_x emissions in India derive from power generation, and there is a close relationship between coal and oil consumption with regional NO_x emission levels (Garg *et al.*, 2001b).

The CPCB's CREP process was expected to produce emission standards for SO_2 and NO_x from coal power plants, but the current status of the CREP standards remains unclear.[72]

GHG Emissions

Control of CO_2 emissions to mitigate climate change impacts is becoming an important challenge for the power sector. India's CO_2 emissions from fossil fuels have been increasing at a compounded annual growth rate of 5% from 1990 to 2004 (Marland *et al.*, 2007), in comparison to ~5.4% for China, ~1.6% of US, and ~1.8% globally. More recently (from 2000 to 2004), India's emission growth rate has decreased to 3.8%, while the United States' is down to 0.3%; however, the rates for China and worldwide emissions have increased dramatically to 10.7% and 3.2%, respectively (Marland *et al.*, 2007). Despite being the fourth largest emitter of CO_2 emissions worldwide, India's total emissions in 2004 were still about 4.5 and 3.7 times smaller than U.S. and China emissions, respectively. Furthermore, India's carbon emissions on a per-capita basis in 2004 were almost one-sixteenth the comparable figure for United States and one-third the figure of China.

According to India's National Communication to the UNFCCC, coal contributed about 62% of India's total CO_2 emissions of 817 Tg in 1994; 43% of emissions were from energy transformation (electricity generation and petroleum refining) (MoEF, 2004). Solid fuels account for about 70% of India's annual CO_2 emissions from fossil fuel use (see Figure 8). Given that coal is primarily used for power generation, most of the fossil-fuel-based GHG emissions from India are from coal-based power plants. The emission factor for coal in India (95.8 tCO_2/TJ on NCV basis) is assumed to be lower than the IPCC default for sub-bituminous coal (96.1 tCO_2/TJ); in 2005–06, the average specific emission factor for all Indian coal-based plants was 1.1 tCO_2/kWh (CEA, 2007a).

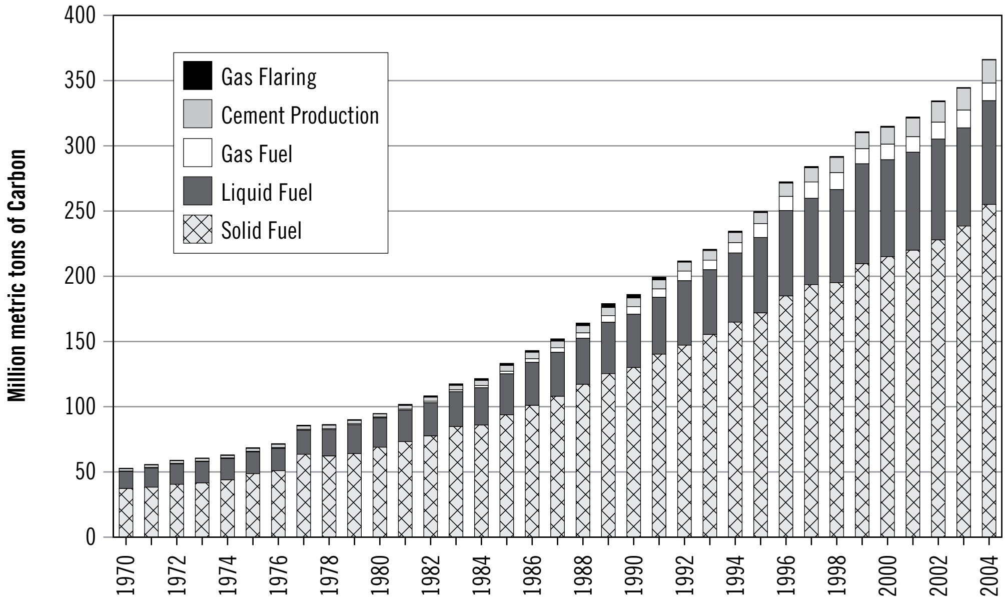
[69] Garg *et al.* (2001b) have claimed a weighted average of 0.51% for sulfur in Indian coals.

[70] In 1997, the average sulfur content in coal received by U.S. electric utilities was 1.09 pounds/million BTU, and the average BTU content of coal was 10,266 BTU per pound of coal (EIA, 2000).

[71] The Trombay Thermal Power Station near Mumbai has an FGD.

[72] In September 2005, a committee formed to address this issue recommended to get more reliable data on NO_x emissions before suggesting draft standards. See: http://cpcb.nic.in/oldwebsite/Charter/status.htm

Figure 8: Indian carbon emissions from fossil fuel use (1970–2004)



Source: Marland *et al.*, 2007.[73]

Options to reduce CO_2 emissions from coal-based power plants include: a) increasing efficiency of energy conversion by increasing the efficiency of existing power plants and switching to new, higher-efficiency technologies, b) using less carbon-intensive fuels or mixtures of fuels (such as coal-biomass mixtures); and c) capturing and storing CO_2 from power plants.

Ash Storage, Use, and Water Pollution

As discussed earlier in this paper, the quality of Indian coal is worsening, with coals containing higher ash content being burned in power plants. Given the high ash content in Indian coals, at least one acre of land is needed for one MW of installed capacity (CEA, 2004b)[74]; hence, there are many large power plants with more than 1000 acres of land dedicated simply for ash storage. Currently, nearly 90 MT of ash are produced annually, and there are at least 15,000 hectares of land with about 750 MT of ash in active ash ponds (Chikkatur and Sagar, 2007). Lack of uniform engineering design for ash ponds also has resulted in inefficient land-use at some power plants (NEERI, 2003). The use of such large areas for ash storage leads to air and water pollution and creates adverse effects for local communities, as land near power plants cannot be used for agricultural production, cattle grazing, etc. (NEERI, 2003). Moreover, there is some concern about heavy metal leaching from ash ponds, especially as many ash ponds are not lined for protection (Sushil and Batra, 2006). On the other hand, fly ash also is being considered for use in agriculture, as an ameliorant for improving crop productivity and for stabilizing degraded soils (Jala and Goya, 2006).

[73] Other calculations of India's CO_2 emissions by Garg *et al.* (2001a) and (2004) are about 15–20% less than the emissions calculated by Marland *et al.* (2007).

[74] Power plants in Maharastra require between 1.3–2.8 acres/MW. In comparison, U.K. plants typically require about 0.4 acres/MW (Dalal, 1999).

Indeed, more studies are needed to assess the human health and safety aspects of putting Indian fly ash to productive use; some studies are already underway[75] and interest in the use of fly ash is growing. For example, the Ministry of Environment and Forests in 1999 (amended in 2003) mandated a 100% utilization of fly ash in a phased manner by 2013–14 by stipulating that brick, cement, and other manufacturers for the construction industry within 100 kilometers from a power plant are required to use fly ash in their manufacturing process.[76] The Ministry has further demanded that fly ash from power plants be given free through 2010 (MoEF, 1999; CEA, 2005b). It is expected that future power plants will plan on 100% utilization of generated fly ash even prior to their commissioning. Given these mandates, fly-ash utilization increased tenfold from 1992–93 to 2003–04, and about 30% of the generated ash is utilized today.

ADVANCED TECHNOLOGIES

Advanced technologies are necessary for increasing efficiency, reducing environmental pollution and lowering carbon emissions from the Indian power sector. As discussed earlier, India's coal-power generation is primarily based on the subcritical PC technology—mainly because of the need to rapidly install generation capacity in the country using domestic resources while building up indigenous manufacturing (Chikkatur and Sagar, 2007). Meanwhile, coal utilization technologies for power generation at the worldwide level have been improving, driven mainly by the need for higher efficiency, better local environmental performance, and growing interest in capturing CO_2 from power plants.

Although subcritical PC has been (and continues to be) the standard technology worldwide, there is now a range of advanced, more efficient, and cleaner technologies for producing electricity using coal. PC is becoming more efficient with the use of supercritical and ultra-supercritical steam parameters (which require advanced materials). Better post-combustion pollution clean-up technologies also are being deployed to improve the environmental performance of PC technologies.[77] Combustion with pure oxygen (oxy-fuel combustion) is under development for facilitating capture of CO_2. Fluidized-bed combustion (FBC) technology has been developed for burning lower-quality coals and for high-sulfur and high-moisture-content coals.[78] In addition to combustion, coal gasification followed by combined cycle operation (Integrated Gasification and Combined Cycle (IGCC)) is expected to be deployed commercially with the goal of achieving increased efficiency and easier capture of CO_2. These various technologies are at different stages in their development worldwide; all of them have different performance characteristics and technical barriers to overcome. However, it is quite likely that some or all of these technologies will have significant market shares worldwide over the course of the next 20 to 30 years.

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[75] See, for example, research activities by Technology Information, Forecasting and Assessment Council (TIFAC). See: http://www.tifac.org.in/do/fly/fly.htm.

[76] http://www.envfor.nic.in/legis/hsm/so763(e).pdf

[77] Some of these technologies include bag-filters and advanced ESPs for particulate control, flue-gas desulfurizers (for reducing SO_x), selective catalytic reducers and low NO_x burners (for reducing NO_x), and other multi-pollutant control technologies.

[78] Unlike pulverized coal combustion, fluidized-bed combustion (FBC) boilers use larger particles of coal (sized at 3 mm) that are suspended in the boiler by upward-flowing jets of air (hence the term 'fluidized-bed'). The key advantage for using CFBC boilers is their relative insensitivity to coal properties—these boilers can burn high-ash, high-moisture-content, and low-calorific-value coal (including lignite), and therefore they are well suited for using the poor-quality Indian coals (see Chikkatur and Sagar (2007) for more details).

Power-Generation Technologies

Not all advanced power-generation technologies are feasible for utilizing Indian domestic coal. Over the past 30 years, the subcritical PC technology has been well-adapted for use with Indian coals. However, given its low efficiency, subcritical PC fails to meet many of India's future challenges. Hence, the more efficient and commercial supercritical PC technology is most relevant for India, especially in the short term. According to a recent Nexant (2003) study, supercritical PC technologies, including flue gas desulfurizers (FGD), would be at least 5% more efficient (35.1%) than current 500 MW subcritical units (33.3%), and the use of washed coal would increase the efficiency by another 1%. In terms of capital cost, supercritical PC would cost only about 7% more than subcritical PC;[79] however, the addition of FGD would increase the total plant cost significantly (Nexant, 2003). An important caveat about the use of supercritical PC technologies in India: coal washing to reduce ash content might become an issue for supercritical boilers in India, as erosion of boiler tubes would likely increase with increased temperature and pressure. Therefore, the prospects for ultra-supercritical PC technologies might be limited by the high ash content of Indian coals. The CEA (2003) has suggested the use of supercritical steam parameters of 246 kg/cm^2 of pressure and temperatures between 568°C and 593°C, with the unit size in the range 800–1000 MW.

There are currently two supercritical PC plants under construction at Sipat and Barh, and they are expected to be operational by 2009. Although BHEL has obtained licenses and technology-transfer linkages for manufacturing supercritical PC boilers and turbines, it has not yet secured any orders. The NTPC-owned Sipat and Barh plants are based on Korean and Russian technology, respectively. Currently, only about 17% (8 MW) of the new planned coal-based capacity for the 11th Plan (48 GW) is based on supercritical PC technology[80](CEA, 2007b). Furthermore, nearly all of the supercritical technology is expected to be installed in the central sector, and there is minimal interest in the state and private sectors for this technology. However, the government has proposed a new scheme, "Ultra-mega power plants," in which at least seven supercritical plants of 4000 MW each are planned under international bidding. It is expected that these plants would come online beyond 2012, in the 12th Plan (CEA, 2007b).

In contrast to advanced PC technologies, BHEL has developed and manufactured several circulating fluidized-bed combustion (CFBC) boilers at the utility scale. BHEL's CFBC boilers (2x125 MW) were used in the Surat Lignite Power Plant, commissioned in 2000. Given the high ash content of Indian coals, one might have expected greater use of CFBC technology in India; however, CFBC is mainly being considered for use with lignite, middlings from coal washeries, and other waste coal.

Gasification of coal was considered in India as early as the 1970s, but Indian coals, in general, are not amenable to the "standard" gasification process. The slagging, entrained-flow gasifier is the most well-developed gasifier for power generation today.[81] It requires a finely powdered feedstock with low ash content that can be injected into the gasifier at high pressures, so that the coal can be gasified quickly in the one-pass-through system. Ash is removed as a molten slag, which requires the feedstock coal to have low ash-fusion temperatures. Hence, this type of gasifier generally is not compatible with most Indian coals, which have both high

[79] Currently, typical total plant cost of a 500 MW coal-based power plant in India is between $0.7–0.9 million/MW, with an additional 20% cost increase for financial charges and interest during construction—leading to an estimated cost of about $0.5 billion for a 500 MW power plant (Chikkatur and Sagar, 2007).

[80] See: http://cea.nic.in/thermal/Shelf_of_Thermal_Power_Projects_11th%20Plan.pdf; accessed March 23rd, 2007.

[81] Entrained-flow gasifiers are currently offered by General Electric, Conoco-Phillips, and Shell for IGCC application.

ash content and high ash-fusion temperature (Chikkatur and Sagar, 2007).[82] The entrained-flow gasifier can, however, be used with tertiary Indian coals, which have lower ash content and lower ash-fusion temperature, although they suffer from high sulfur content.

Standard Indian coals can be gasified using fluidized-bed and moving-bed gasifiers, in which coal, ash and adsorbents (for sulfur absorption) are suspended with upward moving streams of steam and air/oxygen. The elutriated particles are captured by a cyclone collector and recycled back to the bed. There is greater circulation of solids in a fluidized-bed gasifier, allowing for more of the carbon to be combusted; hence, the fluidized bed allows for greater fuel flexibility including the use of high-ash coals, biomass and waste (DTI, 1998). Although several small-scale demonstration plants were built in Europe and the U.S., there is significantly low investment in this technology worldwide, as it is not relevant for most coals. However, it is quite amenable for use with Indian coals, and there has been some R&D on developing a fluidized-bed gasification process in India, primarily led by the Council for Scientific and Industrial Research, the Indian Institute of Chemical Technology, and BHEL (Chikkatur and Sagar, 2007). In the late 1990s, BHEL developed a pilot IGCC plant using fluidized-bed gasifiers, and BHEL is expected to participate in any further demonstration of IGCC technology in India. Currently, BHEL and NPTC are collaborating on a 100 MW IGCC demonstration plant based on Indian coals. According to BHEL analysis, it is expected that the 100 MW demonstration plant using its gasification technology could have efficiencies of between 33–40%, with a total plant cost of about $125 million.[83]

Compared to combustion-based technologies, IGCC offers several advantages, including increased efficiency from the combined cycle, decreased resource consumption, improved environmental performance, lower cost of pollution-control technologies,[84] and greater ease of carbon capture. There are also several disadvantages. Chief among these is a high degree of complexity—IGCC is more like a chemical plant than a power plant. Other disadvantages include higher capital costs, potentially lower reliability and availability, and lower technology maturity (and therefore greater perception of technology risk).

Emissions of pollutants from an IGCC plant are considerably lower than those from combustion-based PC plants. IGCC essentially has no particulate emissions, since almost all of the particulates have to be removed before the syngas enters the gas turbine; and, unlike in a PC plant, gas cleaning is part of the IGCC process, rather than being considered an "add-on". Compared to a supercritical PC plant, an IGCC plant based on U-GAS fluidized bed gasifiers would have 30 times lower particulate emissions, 7 times lower NO_x emissions, 20% lower SO_x emissions, and 2.5 times lower water discharge. The IGCC plant also would be expected to consume at least 1.5 times less water per MWh than standard PC plants, which can be a significant advantage as demand for water rises in India (Nexant, 2003).

Pollution-Control Technologies

Technologies for limiting local air pollutants are not yet widespread in India. Typically, flue-gas cleanup technologies are considered to be part of coal-utilization technologies. However, in the Indian context, it is important to discuss emission cleanup technologies separately because only one pollution reduction technology—the electrostatic precipitator (ESP)—is used routinely in Indian plants.

[82] However, it might be possible to inject fluxing agents to reduce the high ash-fusion temperature of Indian coals (PowerClean, 2004).

[83] See: http://www.ciigbc.org/documents/Thermal%20.pdf

[84] The cost of cleanup technologies is lower in an IGCC because of the smaller volume of syngas to be cleaned, in contrast to cleaning up of flue gases from PC plants.

Table 6: List of available pollution-control technologies

Cleanup Technology	Category	Emission cleaned	Applicable technologies
Coal washing/beneficiation	**Pre-combustion**	**fly ash sulfur mercury carbon-dioxide**	**PC, IGCC**
Electrostatic precipitator (ESP)	Post-combustion	fly ash	PC, FBC, IGCC
Baghouse filter	Post-combustion	fly ash	PC, FBC
Cyclone	Post-combustion	fly ash	FBC, IGCC
Sulfur removal plant	Pre-combustion	sulfur	IGCC
Limestone	In-combustion	sulfur	FBC
Flue gas desulfurization (FGD)	Post-combustion	sulfur	PC
Low-NO_x burners	In-combustion	nitrogen oxides	PC
Selective Catalytic Reducers	Post-combustion	nitrogen oxides	PC
CO_2 shift reactor	Pre-combustion	carbon-dioxide	IGCC
Amine scrubbing	Post-combustion	carbon-dioxide	PC, IGCC, FBC

Source: Chikkatur and Sagar (2007).

Generally, emission-reducing technologies can be categorized into pre-combustion, in-combustion and post-combustion technologies (see Table 6). Coal washing and beneficiation can be considered as pre-combustion cleanup technologies since they increase plant efficiency, reducing the overall amount of emissions. Gas-cleaning technologies in an IGCC plant to remove particulates and sulfur from the syngas are considered pre-combustion cleanup technologies, as the cleanup occurs prior to combustion. Low-NO_x burners in PC boilers and gas turbines, and the use of limestone for sulfur removal in fluidized-bed combustion, can be considered as in-combustion technologies. End-of-pipe technologies for PC plants—such as ESPs, flue-gas desulphurizers (FGDs), and selective catalytic reducers—are considered to be post-combustion technologies (Chikkatur and Sagar, 2007).

The high ash content and high resistivity of Indian coals requires modification of ESPs: it is essential to increase the size of the precipitator collection area, design effective electrical control of ESP, and ensure frequent removal of ash from the hoppers (Gyllenspetz *et al*. (1998)). Given these inherent difficulties, an important challenge for power plants is to continue to reduce their particulate emissions. Properties of the flue gas might need to be altered to reduce resistivity and improve collection by the ESP. NTPC has been doing some research, with support from USAID, on conditioning the flue gas with moisture to increase ESP performance and injecting sodium in the boiler to reduce flue gas resistivity and particulate loading (NTPC, 1999; U.S. DOE, 1999).

Although there is no regulation on SO_2 emission rates, the MoEF does stipulate that space for FGD installation be set aside in power plants with 500 MW (and greater) units and for power stations with total installed capacity of 1500–2000 MW. This space will help facilitate retrofitting of FGDs, if stringent norms are specified at a later stage. In sensitive areas,[85] the installation of FGD is insisted upon even for stations with smaller capacity (CEA, 2004b). Currently, only one power plant in India—the 500 MW Trombay power station owned by Tata Power Corporation—has installed a seawater-based FGD; another FGD is scheduled for installation at the Dahanu power station owned by Reliance Energy Limited. The use of coal washing to reduce sulfur in coal has limited use in India, as the sulfur in Indian coal is mostly in organic form and is chemically bound to the coal matrix; hence, it cannot be removed by physical cleaning methods (Lookman and Rubin, 1998).

In terms of NO_x control, there are NO_x controls for many new boilers in India, and the country has developed its own selective catalytic reducer technology using injection titania catalysts; a pilot-scale technology demonstration was performed at NTPC's Badarpur thermal power plant in 1988–89 (CPCB, 2000). However, deployment of this technology has been held back by lack of statutory standards for NO_x emissions.

Carbon Capture

Carbon capture in Indian power plants will require low pollutant levels in flue gas and high power plant efficiency. Capturing carbon emissions from power plants results in lower power output, loss in efficiency, and higher generation costs. As shown in Table 6, installing technologies for capturing CO_2 can be considered yet another pollution-reducing activity. However, CO_2 is not considered a pollutant in the Indian policy context, and the decision to capture CO_2 from power plants is inexorably linked to larger political decisions surrounding global climate change mitigation.[86]

There are three major carbon capture systems for power plants: post-combustion (PC, FBC); oxy-fuel combustion (PC, FBC); and pre-combustion (IGCC). In post-combustion capture, clean flue gas at atmospheric pressure with CO_2 concentrations less than 15% is passed through an amine-scrubbing process that selectively separates much of the carbon dioxide, which is then compressed and transported away for storage (IPCC, 2005). In oxy-fuel combustion capture, the flue gas, which is mainly CO_2 and H_2O after particulate and sulfur cleaning, can be cooled and dried to have CO_2 concentrations between 80 to 98%. This gas can then be compressed, dried, and either sent directly for storage or further purified before storage (IPCC, 2005). In a pre-combustion system, the produced syngas will be sent to a CO_2 shift reactor, where the carbon monoxide will be converted to CO_2 and hydrogen (H_2) using a water gas shift reaction.[87] The resulting CO_2/H_2 mixture, with CO_2 concentrations in the range of 15–60% (dry basis), can then be separated using physical or chemical solvents (IPCC, 2005). Prior to the water shift reactor, other impurities, such as particulates and hydrogen sulfide, need to be removed from the syngas.

The key issues with carbon capture in power plants are the increased auxiliary consumption, coal use, and cost of generation with capture. Post-combustion capture in new PC plants can lead to an increase of 24–40% in auxiliary energy consumption, with a 14–25% increase in pre-combustion in new IGCC plants (IPCC, 2005). It is generally believed that pre-combustion capture with IGCC is cheaper than post-combustion capture with PC technologies. Hence, there has been a considerable focus on commercially deploying IGCC

[85] Sensitive areas include large urban areas, reserved and protected forest land, coastal regulation zones, nature reserves, parks and special protection areas as specified by MoEF (NEERI, 2003).

[86] The political context for climate change mitigation in India is discussed in more depth in Chikkatur and Sagar, *Policy Options for Carbon Mitigation in the Indian Coal-Power Sector,* prepared for the Pew Center on Global Climate Change.

[87] $CO + H_2O \rightarrow CO_2 + H_2$

for this reason. However, for low-rank coals (high-moisture, sub-bituminous coals), the economics of post-combustion capture in PC plants is similar to, or cheaper than, the economics of carbon capture in IGCC plants (Holt, 2006).

Furthermore, it is important to recognize that retrofitting carbon capture equipment to existing plants will significantly alter plant design, efficiency and economics (for both PC and IGCC plants). As a consequence, only high-efficiency plants can be considered for carbon capture retrofitting. Difficulties of retrofitting are further exacerbated in India because of relatively lower emission standards for flue-gas emissions. In the amine-scrubbing process, excess SO_x and NO_x will permanently bind itself to the amine, reducing its absorptive property for CO_2 and increasing the risk of solid formations in the amine solution. The process also results in excess consumption of chemicals to regenerate the solvent, while at the same time producing high waste streams (IPCC, 2005). Hence, it is important to clean these impurities from the flue gas to very low levels before attempting carbon capture.

The power and efficiency penalty for installing CO_2 capture equipment on existing plants is also quite high; for example, an estimated 65 MW (30%) will be lost in a 210 MW unit, with a 30% hit in efficiency, if the unit is equipped with a monoethanolamine (MEA)-based post-combustion capture technology (Sonde, 2005). Carbon capture will also increase the cost of power generation in India. It is estimated that an amine-based capture technology would increase the total operating cost of a 210 MW power plant by Rs. 1500–1700/tCO_2 (Sonde, 2005), which will add an additional Rs. 1.7–1.9/kWh—almost doubling the cost of power (see Table 4). Such high costs and loss in net power and efficiency implies that it is crucial to install high-efficiency power plants as a precursor to any possible retrofitting for carbon capture.

Geological Storage

An assessment of geological storage capacity in India will require further study and exploration. Potential storage sites in India might exist in the Gangetic, Brahmaputra and Indus river plains, and along the immediate offshore regions in the Arabian Sea and Bay of Bengal (IPCC, 2005). A preliminary estimate of storage capacity by Dooley and Friedmann (2004) indicated that about 385 GtCO_2 might be stored in Indian sedimentary basins—a significant amount relative to the current total emissions of about 1.2 GtCO_2. Much of the storage (96%) is in on-land and off-shore saline reservoirs, and only 14 GtCO_2 (4%) of storage is expected to be in oil, gas, and coal-bearing regions (Dooley and Friedmann, 2004). A more recent estimate indicates that about 360 GT of potential storage exists in on-shore and off-shore deep saline reservoirs, 7 GT in depleted oil and gas fields, and 5 GT in unmineable coal seams (Singh *et al.*, 2006).[88]

Geological exploration and assessments are necessary not only for CO_2 storage, but also for identifying new hydrocarbon and coal resources. Indian sedimentary basins, in general, are not yet geologically well explored; only about 18% of the 3.14 million square km is moderately to well explored, with 30% completely unexplored and more than 50% of the basins being either poorly explored or under preliminary exploration (DGH, 2004).[89] Much of the current exploration is mainly for hydrocarbon and coal resources. However, basins suitable for CO_2 storage may not always be hydrocarbon-rich. For example, the Gangetic basin, located south

[88] There is also a potential storage capacity of 200 GT in basalt formations, although storage in these formations is still at the research level (Singh *et al.*, 2006).

[89] India has 26 sedimentary basins with 1.78 million sq. km within the 200 m isobath (1.39 million sq. km, onshore; 0.39 million sq. km, offshore), and the rest in deep water (DGH, 2004). Exploration of these basins is governed by licensing polices established by the government.

of the Himalayan range, is relatively unexplored because it does not have much potential for hydrocarbon resources. However, this basin is particularly suitable for CO_2 storage in underground saline reservoirs, and much of the estimated on-land storage capacity estimated by Dooley and Friedmann (2004) is in this basin. Hence, detailed geological work needs to be done for assessing CO_2 storage sites, including estimating storage capacity and determining specific sealing mechanisms.

While there is significant potential for storage in saline reservoirs, current data from hydrocarbon exploration can be used to assess the feasibility of using the well-mapped oil and gas reservoirs for CO_2-based enhanced oil recovery (EOR). India's total hydrocarbon resource is estimated to be about 28 billion tons of oil and oil-equivalent of gas (DGH, 2004). Most of the actual oil production is currently from on-shore basins, although off-shore basins have been explored recently for oil and natural gas.[90] Also, in 2000, an estimated 25% of the oil and gas wells in India were dry and many more are on the verge of being dry (Garg *et al.*, 2004). Hence, CO_2-based EOR might serve to extract more oil out of these wells and be an important first step for demonstration of CO_2 storage in India, although the storage capacity in saline reservoirs is significantly higher than the capacity in oil and gas fields.

In addition to saline reservoirs, there might be some potential for storing CO_2 in basalt basins of the Deccan Trap. Although such storage is largely untested and there is substantial scientific debate surrounding storage in basalts and other storage media,[91] this might be an important storage option for CO_2 emissions from central India.[92] Singh and collaborators (2006) have estimated a potential storage capacity of 200 GT in basalt formations. Sedimentary basins underneath the basalt might also be potential storage sites for CO_2, since the basalt can act as a cap-rock and provide minerals for carbonization of CO_2.

Furthermore, it is estimated that only about 43% of India's current CO_2 emissions from stationary sources might have potential CO_2 storage sites within a 300 km buffer zone (IPCC, 2005).[93] Other studies have indicated that only some of the top 20 large point sources in India are within 200 km of potential storage sites, although all of them are within 500 km of potential sites (Garg *et al.*, 2004). Given that India might have problems locating good CO_2 storage sites near its current stationary sources, it is essential that proper assessments of storage capacity be undertaken immediately—particularly in on-land and off-shore saline reservoirs—and future power plant sitings should take possible CO_2 storage locations into account.

[90] About 1 million sq. km is currently under exploration (primarily by ONGC), of which 78% is offshore exploration. However, only about 19,400 sq. km of this area is under mining and production (50% ONGC, 25% OIL); 63% of the current mining is in land-based basins (DGH, 2004).

[91] Personal communication, J. Friedmann (2006).

[92] As part of the Carbon Sequestration Leadership Forum, laboratories in India and the United States are already assessing storage possibilities in basalt, with support from NTPC (Sonde, 2005).

[93] This estimation is based on surface area assessment of sedimentary basins. However, surface area studies are fundamentally unreliable, as it does not take geology in account (Bradshaw, 2005; IPCC, 2005).

Conclusion

Coal plays a crucial role in India's future development, particularly in its power sector. Demand for coal in India is projected to increase dramatically in the short to medium term, although there are several key constraints that the Indian coal industry has to overcome. Advanced power generation technologies have a central role in helping to meet the various challenges in the country's coal-power sector. Although several new technologies have been explored in the Indian power sector, it is far from clear what the appropriate future technology choices might be, as all of the current and emerging technologies worldwide have their strengths and limitations. Therefore, it is critical for policy makers not only to consider and implement technologies that meet the near-term needs of the country, but also to set the coal-based power sector on a path that would allow it to better respond to future challenges, including the key challenge of reducing GHG emissions.

This paper reviews the Indian coal and coal-power sectors against the backdrop of the broader effort to reduce greenhouse gas emissions from a growing power sector throughout the world. It is part of a Pew Center on Global Climate Change Coal Initiative, a series of reports examining and identifying policy options for reducing coal-related GHG emissions. The Pew Center brings a cooperative approach and critical scientific, economic, technological, business and policy expertise to the global climate change debate at the state, federal and international levels.

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List of Acronyms

BHEL	Bharat Heavy Electricals Limited
CBM	coal bed methane
CEA	Central Electricity Authority
CenPEEP	Centre for Power Efficiency & Environmental Protection
CIL	Coal India Limited
CMPDIL	Central Mine Planning and Design Institute Limited
CO_2	Carbon Dioxide
CPCB	The Central Pollution Control Board
CREP	Charter on the Corporate Responsibility for Environmental Protection
CSIR	Council for Scientific and Industrial Research
DGH	Directorate General of Hydrocarbons
ECC	The Energy Coordination Committee
EIA	environmental impact assessment
EOR	enhanced oil recovery
ESPs	electrostatic precipitators
GHG	Greenhouse gas
GSI	Geological Survey of India
GW	Gigawatt (10^9 watts)
HHV	Higher heating value; (also known as the gross calorific value or gross energy). The HHV of a fuel is defined as the amount of heat released by a specified quantity (initially at 25 °C) once it is combusted and the products have returned to a temperature of 25 °C.
IGCC	integrated gasification combined cycle
KW	kilowatt
KWh	kilowatt-hour
KWU	Kraftwerk Union, steam turbine design now owned by Siemens
LMZ	Turbine produced by the Leningrad Metal works in Russia
LNG	Liquified natural gas
MEA	monoethanolamine
MEC	Mineral Exploration Corporation
MoEF	Ministry of Environment and Forests
MOSPI	Ministry of Statistics and Programme Implementation
MT	Million Tons or Megatons ($1x10^6$ metric tons)
MW	megawatts ($1x10^6$ watts)
NLC	Neyveli Lignite Corporation

NO_x,	Nitrogen Oxides
NTPC	National Thermal Power Corporation
OECD	Organization for Economic Cooperation and Development
ONGC	Oil and Natural Gas Corporation
PC	Steam-based subcritical pulverized coal
PLF	plant load factor
Rs.	Indian Rupee (national currency). 1 Rs. = US$ 0.02475 (March 10, 2008)
SCCL	Singareni Colliery Company Limited
SEBs	State Electricity Boards
SO_x	Sulfur Oxides
TWh	Terawatt hours
UCG	underground coal gasification
U-GAS	a fluidized-bed gasification technology
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

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This paper describes key elements of an administrative structure that could efficiently and effectively manage a program to accelerate deployment of carbon capture and storage at coal-fueled electric power plants. It is part of a Pew Center on Global Climate Change Coal Initiative, a series of reports examining and identifying policy options for reducing coal-related GHG emissions. The Pew Center brings a cooperative approach and critical scientific, economic, technological, business and policy expertise to the global climate change debate at the state, federal and international levels.

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