TOWARDS A BETTER TECHNOLOGY POLICY FOR COAL-BASED POWER IN INDIA

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Abstract
As India stands poised on the edge of significant growth in coal power, it is critical not only to consider and implement technologies that meet the near-term needs of the country but to also set the coal-based power sector on a path that would allow it to better respond to future challenges. A well-thought-out and robust technology policy based on empirical data and analysis can greatly facilitate and further energy technology innovation processes in India. This requires a strategic analysis of emerging technologies in relation to the needs, challenges, and constraints particular to India. This paper aims to contribute to such a planning process by assessing coal-power technology options in the Indian context, and by providing preliminary policy conclusions.

Keywords: technology policy, coal-based power, technology assessment.

1. Introduction
The expansion and modernization of India's energy sector is crucial for increasing India's industrial growth, providing greater opportunities for employment, including in rural areas, and helping meet basic human needs. Energy technologies play a central role in the expansion and enhancement of the energy sector. The scale and complexity of energy technologies necessitates a role for the government in their development. Development of energy technologies typically requires large investments and long time scales, which the private-sector may not necessarily invest in without government intervention, regulation, and incentives. Furthermore, the long-lifetimes (~50 years) of high-investment energy technologies, such as coal power plants, have significant economic and environmental ramifications for the life of these technologies, which add further impetus for government polices in the development and deployment of suitable technologies.

1.1 Coal-based Electricity Sector
While India has made enormous strides in electricity growth, power availability India falls far short of global benchmarks – in 2002, per-capita consumption was 420 kWh, in contrast to the non-OECD average of 1100 kWh and the OECD average of 8000 kWh (IEA, 2004), and the country has been routinely experience energy shortages of 6-12% and shortages of peak demand between 11-20% over the last decade. Lack of power availability is widely seen as a bottleneck to industrial development as the country aims to rapidly increase its pace of economic growth (World Bank, 1999). Long term projections indicate that an installed capacity of nearly 800 GW by 2030 is required to maintain an average annual GDP growth of 8% (Planning Commission, 2006). Furthermore, as a clean energy carrier, electricity use for lighting and small-scale industrial activities is an important element of increasing economic and social development for the poor. The Government of India intends to install 100 GW of new capacity in the 10th and 11th plan periods (2002-2012), with an investment of nearly Rs. 8 trillion ($160 billion), to meet its goal of providing "reliable, affordable and quality power supply for all users by 2012" (Ministry of Power, 2001).

Coal-based power plants have dominated the power generation sector since the 1970s. As of March 2004, coal plants constituted 57% of installed capacity of utilities, while generating about 72% of utility-supplied electricity in the country (CEA, 2005). This domination of coal in the power sector is likely to continue in the future: about 50 GW of new coal-based capacity is planned for the 11th Plan,[1] and longer term scenarios explored by the

[1] http://cea.nic.in/thermal/Shelf_of_Thermal_Power_Projects_11th%20Plan.pdf.

Planning Commission suggest that coal will continue to dominate the power sector consumption at least for the next three decades (Planning Commission, 2006).

Currently, the country's thermal power stations are almost exclusively based on sub-critical pulverized coal (PC) technology. While this technology offers certain advantages – a well-established manufacturing base, low costs, and relative ease of maintenance, it is also increasingly apparent that relying on this technology is increasingly at odds with many of the challenges facing the Indian power sector at present, and the issues that are likely to become important in the future. At the same time, there are now a number of different existing and emerging technological options that potentially can help the coal power sector meet its goal of rapid capacity addition in a manner consistent with its other challenges. The availability of different (and evolving) technology options and the need to assess their suitability in the context of existing and anticipated future challenges, highlight the need for a systematic and careful technology decision-making process to develop suitable technology policies in this sector. This situation is very different from the past when only subcritical PC was the only one technology option that dominated the global technology landscape and the focus in the Indian coal power sector was mainly on adaptation and multiplication of the technology rather than choosing between widely disparate options.

Much of the current policy focus in relation to the Indian power sector is on the nature and impact of on-going electricity restructuring and reforms in the country. While these are important topics, there has been less attention paid to technology policy for the future of the coal sector, although the recent Integrated Energy Policy report (Planning Commission, 2006) does call for technology missions in various coal-utilization technologies. Currently, technology investment decisions in the Indian power sector are primarily driven by the need to increase generating capacity, which has had the result of deploying the least risky and cheapest technology (subcritical pulverized coal). The historical shortages of power, partly due to increasing demand as a result of population and economic growth and partly due to lack of sufficient capacity additions, have given a strong urgency to increasing capacity without necessarily placing this growth in the context of longer-term strategy, especially regarding the kinds of technological choices that the country must make for the future and the elements of a technology innovation program to support this approach.

It is with the intention of attending to this lacuna that we summarize the main challenges and constraints facing the power sector and present accordingly an assessment of emerging technologies as a first step to the development of better technology policies in this sector. Some policy implications of this assessment are discussed in the end.[2]

2. Challenges and Constraints in the Coal-Power Sector

The challenges and constraints for technology development and deployment in the coal-power sector and their implications for future technologies are summarized in Tables 1 and 2.

Table 1: Challenges and their Implications for Technology Policy

Challenges		
	Description	*Implications for Technology Policy*
Need for rapid growth	• Meeting socio-economic goals requires a rapid increase in electricity capacity and consumption.[3] • A large fraction of the new growth in electricity is expected to be based on coal.	Technologies must be commercially mature to be rapidly deployed in the short-to-medium term.
Enhancing energy security	• Coal is the only significant domestic resource. Hence, there is need for increasing the use of this resource to increase energy security, while also ensuring that power generation relies on	Technologies must be able to use domestic coal and/or allow fuel flexibility, so that other fuels, such as petcoke, biomass,

[2] A full consideration of all elements of the technology innovation process (i.e., research, development, demonstration, and deployment (RD^3)) is necessary for a successful and holistic technology policy. While setting R&D priorities and future directions for the energy sector is important, and often receives most of the attention, issues such as the effectiveness of R&D programs and coupling of these programs to demonstration and deployment efforts must also receive adequate consideration. In addition, energy innovation policies must take into account the specificities of the national context (i.e., relevant economic, social, and environmental issues).

[3] In addition to increase in capacity, it is important that efficiency in transmission and distribution of electricity is improved by minimizing transmission loss and commercial theft.

Challenges		
	Description	*Implications for Technology Policy*
	multiple fuels, sourced from diverse locations.	etc., can be utilized.
Protection of local environment	• Coal-power plants strongly impact the local environment by causing pollution of air, water and land resources. Reducing these impacts over time is an important priority for the government.	Technologies with high-efficiency, combined with better pollution clean-up technologies, are needed.
Carbon mitigation	• Coal combustion accounts for about 40% of total CO_2 emissions of the country. Given that more than 70% of the coal consumed in country is used for power generation, reduction of CO_2 emissions will significantly impact coal power plants. • However, the nature and timing of emission targets are unclear and will likely not be determined in the short-term.	Although there is no current need for capturing CO_2 from power plants, high-efficiency technologies that might allow for low-cost carbon capture are most relevant.

Table 2: Constraints and their Implications for Technology Policy

Constraints		
	Description	*Implications for Technology Policy*
Coal availability and quality	• There is currently significant uncertainty about the exact quantity of coal reserves in the country. While there may be 250 BT of coal resources, coal reserves may only be 45-70 BT. • Coal demand is expected to outstrip domestic supply – leading to increased imports. • The quality of domestic coal is poor with high ash content and low calorific values.	Technology choices might be constrained by the quality of domestic coal. Furthermore, the extent of available coal reserves will also impact technology choices in the long-term, with high-efficiency being preferred.
Finance resource limitations	• Financial resources are limited, particularly in the State sector. Although equity shortfalls are of primary concern in the short-term, enormous outlay of capital is required for accelerated growth in the power sector. • Low cost of generation and supply is important for increasing electricity access for the poor.	Cost is a key criterion for technology selection, and technologies with high-efficiency and low capital costs are favored. Technology costs are interlinked with maturity and indigenous capacity.
Limited technical capacity (R&D, manufacturing, and O&M)	• There has not been enough investment in developing coal power technologies in India, and most of the existing efforts have been limited to BHEL. • There is significant manufacturing and O&M capacity within BHEL, NTPC and other manufacturers and utilities. • Capacity for innovation in the country is limited, with little R&D coordination between academia, government and industry.	Technology choices need to be consonant with indigenous capacity. Limited investment might affect indigenous technology development.
Institutional issues	• Historical power shortages have created a panic-mode of operations, wherein there is more emphasis on mitigating short-term problems, rather developing a long-term strategy. This has led to a narrow focus on generation and risk-averse attitudes towards new technologies. • Lack of significant domestic policy research capacity has hampered systematic technology planning.	Focus on rapid capacity additions has emphasized technology replication rather than innovation. Limited competition, dominance of government-owned enterprises, and lack of long-term technology planning limit the development and deployment of new technologies.

3. Coal-Power Technology Options and Analysis

As mentioned earlier, there is a multiplicity of existing and emerging technology choices for coal power. While combustion continues to remain the dominant pathway, a number of advanced coal technologies have been developed to meet the worldwide challenge of making power generation cleaner, more efficient, and more able to utilize coals of varying qualities, characteristics that are also relevant in the Indian context. Pulverized coal technologies have improved, resulting in increased efficiency and reduced local pollution. New combustion pathways using circulating fluidized-beds have been introduced to utilize lower quality coals including biomass, waste coal and washery middlings. Combustion with pure oxygen (oxyfuel combustion) instead of air is also being considered for ease of carbon capture. Efforts are also underway to commercialize coal-gasification-based systems. Entrained-flow gasifiers have been used commercially for converting coal into a high-energy-content gas that can be converted to methanol and hydrogen, which in turn can be used for making chemicals and Fischer-Tropsch (F-T) liquids such as synthetic diesel.

Based on a detailed assessment of technologies (Chikkatur and Sagar, 2006), we believe that a number of advanced technologies are (may be) particularly relevant in the Indian context – these technologies and their performance/cost characteristics are shown in Table 3.

Table 3: Comparison of Technical and Performance Characteristics of Relevant Technologies[4]

Technology	**Subcritical PC**	**Supercritical PC (SC-PC)**	**Advanced / Ultra supercritical PC (USC-PC)**	**Circulating FBC (CFBC)**	**Oxyfuel PC/CFBC**	**IGCC -- Entrained-flow**	**IGCC -- Fluidized-bed**
Use in India:	Almost all Indian TPS	Sipat-I TPS (in construction); Barh TPS (order placed)		Surat Lignite TPS, Akrimota Lignite TPS		Might be useful for using refinery residues.	R&D, pilot scale plant. Plans for demonstration plant.
Worldwide:	Standard technology worldwide	Europe (Denmark, Netherland, Germany); Japan, U.S., China, Canada	Netherlands, Denmark, Japan	U.S., Europe, Japan, China, Canada	Development and planned pilot plants in Europe, Australia, Canada. Useful for mainly for CCS.	Demonstration / commercial plants in U.S., Europe, Japan, China	A 6 MW unit in Europe, 100 MW demo plant in U.S., biomass IGCC in Brazil. Widespread use for chemicals production and poly generation
Level of Maturity	Commercial	Commercial	Commercial / Demonstration	Commercial	R&D / Pilot scale	Gasifier – commercial; IGCC – commercially proven.	Gasifier – commercial; IGCC – demonstration
Output flexibility	Electricity; steam and heat are also possible	Electricity; steam and heat are also possible	Electricity; steam and heat are also possible	Electricity; steam and heat are also possible	Electricity; steam and heat are also possible	Electricity, syn-gas, chemicals, FT liquids, H_2, steam, heat	Electricity, syn-gas, chemicals, FT liquids, H_2, steam, heat
Fuel flexibility	Can be flexible, with loss in efficiency	Can be flexible, with loss in efficiency	Can be flexible, with loss in efficiency	Highly flexible. Use of high ash coals supported.	Same as PC and CFBC.	Very flexible, but limited to low ash-content and ash fusion temp. coals.	Very flexible, but limited to high ash fusion temp. coals. Limited use of oils.
Net Efficiency (net HHV) India:	31 – 34%; 33%	35%		30%; 33%			40%
Worldwide:	36-39% (w/o FGD) 37-38% (w/ FGD)	39 – 41%	40 – 44%	34 – 40%	34% (USC-PC) 25% (CFB-subcritical)	35 – 40%	44-48%
Capital Cost (TPC; $/kW) India:	610 (w/o FGD) 750 (w/ FGD)			770			1290
Worldwide:	930-1090 (w/o FGD) 1080 – 1280 (w/FGD)	1090-1290	960-1300	1070-1340	1410 2370-2410 (w/ CCS)	1200-1610	1250-1270

While the technologies chosen above reflect our biases, and the list is by no means inclusive of all possible technologies, we believe that this is a good starting point. Over time, other technologies (such as pressurized pulverized coal, chemical looping, circulating moving-bed, fuel cell-based power generation, etc.) might gain in their applicability, and they would need to be considered at that time.

The performance and cost characteristics of technologies can vary significantly based on technical and economic assumptions. Generally, technology analyses use a range of data from international sources, and it is not clear

[4] Detailed technical information about these technologies and references for the shown data are available elsewhere. See Chikkatur and Sagar (2006) and references therein.

how comparable these analyses are and how translatable they are to the Indian context. Therefore, engineering-based analyses with technical and economic factors/assumptions representative of the Indian context are critical. Such engineering-based comparative assessments for India are generally lacking, except for a recent Nexant (2003) study.

Even in the absence of such engineering-based analysis, one could take further the kind of analysis shown here (in Table 3) by, for example, assessing the relative performance of technologies for the Indian context based on indicators that correspond to the challenges and constraints of the Indian coal power sector (shown in Table 1 and 2). This also allows for a quantitative comparison of these options and eventually the development of a technology roadmap as an aid to decision-making and policy analysis. While the details of such an analysis are presented elsewhere (Chikkatur and Sagar, 2006), Figure 1 shows some of the results.

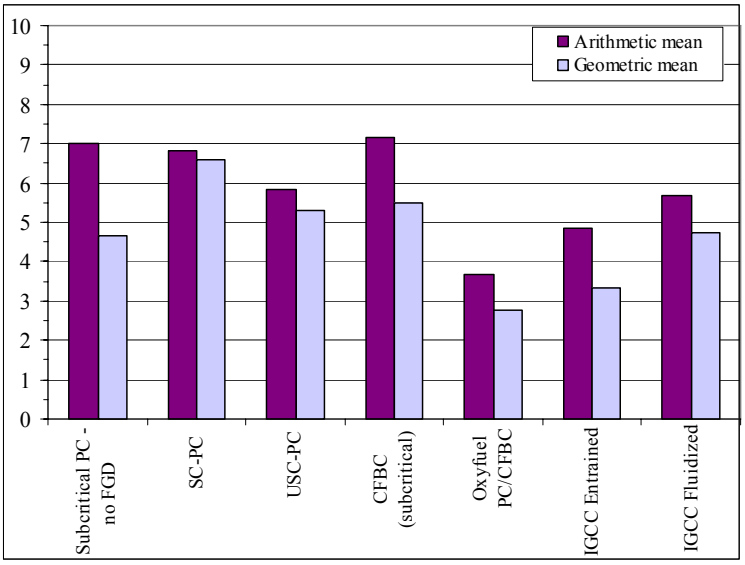

Figure 1: An assessment of coal power technologies based on performance of specified attributes that correspond to challenge and constraints. The overall score for each technology corresponds to the mean of the scores representing relative performance on each attribute, where 10 represents the best performance and 1 the worst performance. Attributes covered: ability to use domestic coal; maturity of technology; relevant technological capabilities in country; capital cost; efficiency; and environmental impact. Note that the arithmetic mean provides information about the overall average of the ratings on the various attributes, whereas the geometric mean is sensitive to spread of the ratings (being derived from their product).

The overall scoring of the technologies indicate that supercritical PC and CFBC rank as the best overall technology options in the present circumstances: supercritical PC because of its efficiency, maturity, and relatively low cost and CFBC because of its fuel flexibility and reduction in SO_x and NO_x emissions. Although subcritical PC has a better score in the arithmetic mean, it fares poorly for the geometric mean (because of its poor performance on efficiency and environmental attributes) – indicating that it is not the best overall technology. IGCC technologies, as well as the more advanced technologies such as oxyfuel combustion, are currently not the best options because of their low maturity and relatively high costs, although they rate high on efficiency and environmental attributes. Finally, we note that our above analysis is only a first step towards better technology assessments for India that incorporates key challenges and constraints in the Indian coal power sector.

4. Some Policy Implications

We present below some of the key elements of a technology policy for future of the coal-power sector, based on the analysis discussed above:

- Given that the global technology landscape is changing rapidly and the evolving nature of some key challenges and constraints, it is important to not make rigid technology choices, but rather to keep technology options open (e.g., continue to explore both gasification and advanced combustion pathways)

- In the meantime, it is important to improve efficiency of existing subcritical PC power plants, while tightening/enforcing pollution control.
- In terms of deployment in the short-to-medium time-frame, only higher efficiency combustion technologies (supercritical PC and CFBC) should be considered.
- An on-going monitoring & feasibility assessment program must be established to evaluate appropriateness of emerging future technologies for the country.
- Specific elements of selected technologies must be advanced through a strategic RD^3 program to better position the country for deployment of technologies, as the feasibility of options becomes clearer. At the same time, a program of domestic policy research is needed to couple and coordinate technical efforts with suitable implementation pathways.
- Given the inevitability of carbon constraints, it is important to invest in a focused effort to explore carbon storage opportunities, with detailed reservoir studies and storage feasibility. This approach allows the country to be prepared without committing to particular technology pathways, especially since the timing and nature of India's greenhouse gas commitments are unclear.

5. Conclusion

A well-thought-out and robust technology policy based on empirical data and analysis can greatly facilitate and further the energy technology development and deployment processes in India. In the case of the coal-power sector, our preliminary analysis indicates India should not make rigid technology choices at this point, given the evolving nature of challenges and technologies. Instead, it should focus on deploying high-efficiency combustion technologies in the short-term, while engaging in a strategic RD^3 program to advance and keep open key technology options. At the same time, new and emerging technologies worldwide must be monitored and assessed continuously. The analysis presented here is a first step, and can be thought of as a foundation for a more comprehensive assessment process that is needed to build consensus among decision makers and stakeholders on a robust technology policy and a suitable domestic innovation strategy for the future of the country's coal-power sector.

Acknowledgement

Financial support for this work was provided through the Kennedy School of Government's Energy Technology Innovation Project from the David & Lucile Packard Foundation, the William and Flora Hewlett Foundation, and the Winslow Foundation.

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