The prospects for HELE power plant uptake in India

Ian Barnes

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Author: Ian Barnes

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IEA Clean Coal Centre
14 Northfields
London SW18 1DD
United Kingdom

Telephone: +44(0)20 8877 6280

www.iea-coal.org

Preface

This report has been produced by IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

IEA Clean Coal Centre is an organisation set up under the auspices of the International Energy Agency (IEA) which was itself founded in 1974 by member countries of the Organisation for Economic Co-operation and Development (OECD). The purpose of the IEA is to explore means by which countries interested in minimising their dependence on imported oil can co-operate. In the field of Research, Development and Demonstration over fifty individual projects have been established in partnership between member countries of the IEA.

IEA Clean Coal Centre began in 1975 and has contracting parties and sponsors from: Australia, China, the European Commission, Germany, India, Italy, Japan, Poland, Russia, South Africa, Thailand, the UAE, the UK and the USA. The Service provides information and assessments on all aspects of coal from supply and transport, through markets and end-use technologies, to environmental issues and waste utilisation.

Abstract

A recent study by the IEA Clean Coal Centre examined the role of HELE coal-fired power plant in helping to meet the goal of reduced carbon dioxide emissions by setting out an overview of the prospects for the role of HELE technologies in a number of major coal-user countries. Ten countries were studied: Australia, China, Germany, India, Japan, Poland, Russia, South Africa, South Korea and the USA.

The study concluded that there are likely to be significant gains to be had from adopting a HELE pathway and a deeper analysis of the Indian situation was warranted. This report presents the results of that analysis.

India's coal fleet is relatively young, predominantly subcritical but with a large tranche of future capacity planned or under construction. However, the future capacity that is planned is largely supercritical, rather than the current state-of-the-art ultrasupercritical technology that has been extensively proven in other countries. Indian projections and current policy seem to indicate that this trend will continue in the near future. This would seem to be a missed opportunity for India to ensure that she has the most efficient and modern plant to drive her economic growth; lower efficiency plant built in preference to the best HELE alternatives now would be 'locked in' to the generating sector for the lifetime of that plant, which could be as long as forty years.

The choice of subcritical, and now supercritical plant, over more advanced options is attributed to a cautious and conservative approach, gathering 'home grown' experience on plant performance and maintenance in the light of challenges posed by India's high ash coal resource. While this was undoubtedly a reasonable approach where power generation technologies were developed and built using regional skills and facilities, in the modern globalised power market significant experience exists in dealing with a wide range of coal types and manufacturers are prepared to design and offer high performance plant to burn even the most difficult coals, with full commercial guarantees. Fortunately, recent developments show that the Indian market is becoming more receptive to ultrasupercritical as the technology of first choice, and the recent initiative on AUSC development is promising, but there is still much to be done to avoid the Indian coal fleet becoming locked into mainly supercritical plant.

Acronyms and abbreviations

APC	auxiliary power consumption
AUSC	advanced ultrasupercritical
BEE	Bureau of Energy Efficiency
CCS	carbon capture and storage
CEA	Central Electricity Authority
CEM	continuous emissions monitoring
CERC	Central Electricity Regulatory Commission
CPCB	Central Pollution Control Board
CSE	Centre for Science and Environment
DBFOT	Design, Build, Finance, Operate, and Transfer (model)
DISCOM	Distribution Company (India)
GHG	greenhouse gases
GW	gigawatt
HELE	high efficiency, low emission (plant)
HHV	higher heating value
ICB	International Competitive Bidding
IEA	International Energy Agency
IEA CCC	IEA Clean Coal Centre
IGCC	integrated gasification combined cycle
IRR	internal rate of return
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
LE	life extension
MJ	megajoule
MNRE	Ministry of New and Renewable Energy
MOC	Ministry of Coal
MOP	Ministry of Power
MTOE	million tonnes of oil equivalent
MWe	megawatts electrical
NCEF	National Clean Energy Fund
NEEPCO	North Eastern Electric Power Corporation
NITI	National Institution for Transforming India
NMEEE	National Mission on Enhanced Energy Efficiency
NOx	oxides of nitrogen
NTPC	National Thermal Power Corporation Ltd
PFC	Power Finance Corporation
PLF	plant load factor
PM	particulate matter
PSU	public sector undertakings
R&M	renovation and modernisation
SEB	State Electricity Board
SPV	special purpose vehicle
STPP	Super Thermal Power Project
TSS	total suspended solids
TWh	terawatt hours
UDAY	Ujwal Discom Assurance Yojana
UMPP	ultra mega power projects
USC	ultrasupercritical
WCA	World Coal Association

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1 Introduction

Coal remains an important source of energy for the world, particularly for power generation. During the last 15 years the demand for coal has grown rapidly, and although this growth has slowed recently, various projections for future growth in energy demand suggest that the trend will continue, dominated by coal use in the large and rapidly growing economies of China and India. At the same time, continuing pressure to cut carbon dioxide (CO_2) emissions to mitigate the effects of climate change, specifically to limit the average rise in global temperature to below 2°C, will require the halving (from current levels) of carbon dioxide emissions by 2050. To contribute to this goal, emissions from coal-fired power generation will need to be reduced by around 90% over this period; cuts this deep will require carbon capture and storage (CCS).

In the International Energy Agency (IEA) 450 ppm carbon dioxide climate change scenario, around 3400 large-scale CCS plant must be operating globally by 2050 to abate the required amount of carbon dioxide emissions. At the same time, the growing need for energy, and its economic production and supply to the end-user, must remain central considerations in power plant construction and operation.

In 2012 the IEA published a report 'Technology Roadmap – High-Efficiency, Low-Emissions Coal-Fired Power Generation' (IEA, 2012) which concluded that in general terms, larger, more efficient and hence younger coal plants are the most suitable for economic CCS retrofit. However, this would currently only be possible on around 29% of the existing total installed global coal-fired power station fleet. They reported that, on average, the efficiency of existing world coal-fired capacity is comparatively low, at about 33%, although the recent establishment of large tranches of modern plant, particularly in China, is raising this figure (Minchener, 2014). The existence of a large number of low efficiency plant means that relatively large amounts of coal must be used to produce each unit of electricity. As coal consumption rises, so do the levels of carbon dioxide and other pollutants. Consequently, it has been recognised that the installation of coal-fired plant operating at the highest efficiencies is the most appropriate option for CCS retrofit in order to gain the greatest reduction in carbon dioxide emissions per unit of electricity generated. Such plants are described by the acronym HELE which stands for high efficiency, low emission (plant). HELE plant are a significant step forward to reducing carbon dioxide emissions. Figure 1 illustrates the impact of employing progressively more effective HELE technologies on carbon dioxide abatement (IEA, 2012).

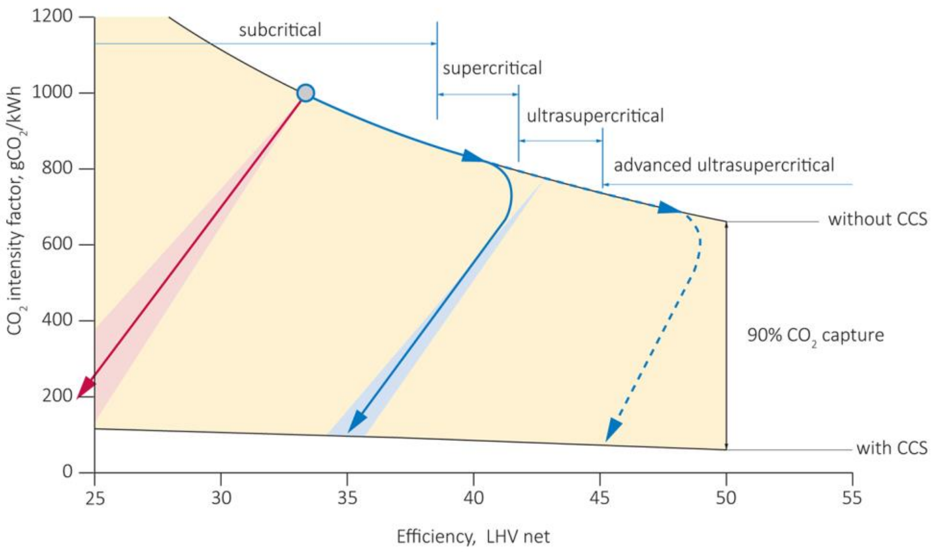

Figure 1 Reducing carbon dioxide emissions from pulverised coal-fired power generation (IEA, 2012)

HELE plant upgrades are considered to be a 'no regret' option for coal plant owners and operators. A current state-of-the-art coal-fired plant operating with a high efficiency ultrasupercritical steam cycle will be more efficient, more reliable, and developments in materials technology would suggest a longer life expectancy than its older subcritical counterparts. Most significantly, it would emit almost 20% less carbon dioxide compared to a subcritical unit operating under similar duty. Also, emissions of SO_2, NOx and particulates are reduced as the more efficient plant requires less coal for the same electrical output. In the near future, the developments in advanced ultrasupercritical (AUSC) steam cycles promise to continue this trend and a plant operating at 48% efficiency (HHV) would emit up to 28% less carbon dioxide compared to a subcritical plant, and up to 10% less than a corresponding ultrasupercritical plant. Once established, HELE plants become the units of choice for CCS retrofit, further adding to the carbon dioxide savings achieved through higher generating efficiencies. Figure 2 illustrates the principle of this approach (IEA, 2011).

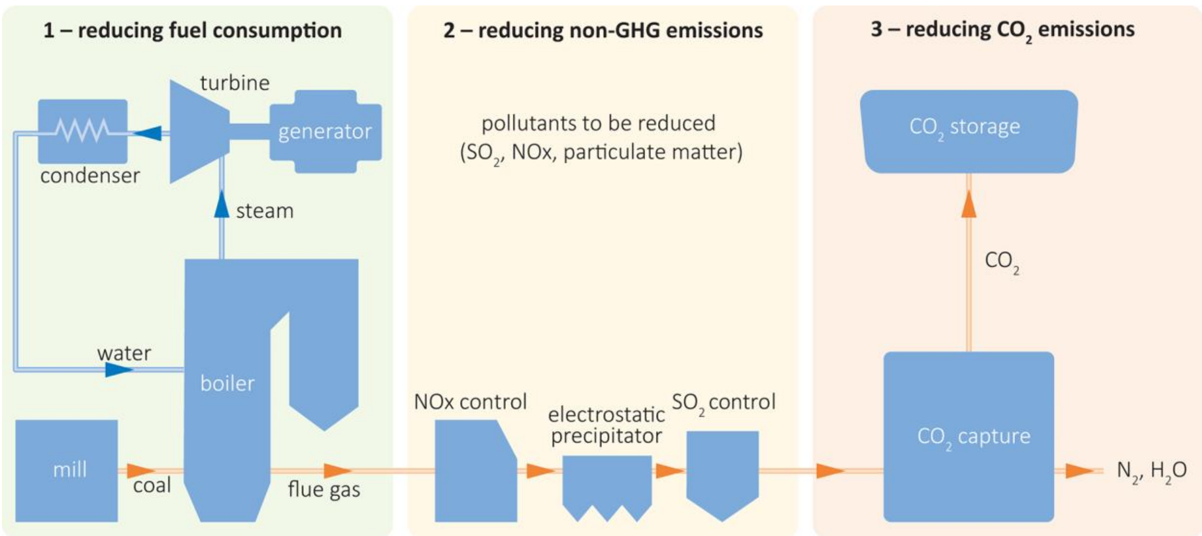

Figure 2 IEA conceptual HELE roadmap (IEA, 2011)

A recent study by the IEA Clean Coal Centre examined the role of HELE coal-fired power plant in helping to meet the goal of reduced carbon dioxide emissions by setting out an overview of the prospects for the role of HELE technologies in a number of major coal using countries (Barnes, 2014). Ten countries were studied: Australia, China, Germany, India, Japan, Poland, Russia, South Africa, South Korea and the USA. The target countries have differing coal-plant fleet ages and efficiencies, and different local conditions and policies which impact on the scope for HELE implementation.

The profile of the coal fleet for each country was calculated to meet future electricity demand under three scenarios: continuing with the existing fleet, and retiring and replacing older plant on the basis of a 50-year and 25-year plant life respectively. The potential impact of HELE upgrades on emissions of carbon dioxide and costs of implementation were determined and quantified. The results were considered in terms of potential carbon dioxide savings, and the prospects for adopting a HELE upgrade pathway in the context of each country's current energy policy outlined. For the Indian scenario, the following conclusions were drawn:

India's future energy needs are typical of a rapidly developing country. A rapid growth in coal-based energy demand extends to 2040 and shows no sign of levelling off. Under the base case scenario, demand cannot be met using existing capacity and new ultrasupercritical plant are required. Emissions of carbon dioxide rise in line with the projected demand from 764 Mt/y to 1444 Mt/y under this scenario (an 89% increase).

Under the 50-year scenario, new ultrasupercritical units are required but again complement rather than replace the relatively youthful existing stock. Emissions of carbon dioxide continue to rise under the 50-year scenario but are mitigated by the widespread adoption of the higher efficiency plants ranging from 764 Mt/y in 2015 to 1349 Mt/y in 2040 (a 76% increase).

Finally, when AUSC is introduced into the plant mix in 2025, emissions first level out and then decline, despite the increasing demand trend; 764 Mt/y in 2015 to 1063 Mt/y in 2040 (a 39% increase).

India is on track to have the fastest growing coal fleet from 2020 onwards with coal-sourced electricity demand projected to more than double by 2040. The current coal fleet is mostly subcritical, but a large number of supercritical units have been built recently, and more are planned with the majority being supercritical under the 12th Five-Year Plan, and observers suggest that the 13th Five-Year Plan (2017-22) will stipulate that all new coal-fired plants constructed must be at least supercritical. However, the projections in this study show that there are further gains to be achieved from moving to ultrasupercritical plants for replacement even under the modest 50-year plant life scenario, and if AUSC is adopted, carbon dioxide emissions first level out and then decline, despite the increasing demand trend. A largely AUSC coal fleet would generate 1091 Mt carbon dioxide in 2040 against a base case of 1444 Mt; a 24% reduction. If the most effective carbon dioxide abatement pathway is followed (25-year plant retirement, AUSC upgrades after 2025, CCS installation) emissions could fall to 159 Mt carbon dioxide in 2040. Much Indian power generation coal is high in ash and there may be barriers to the adoption of ultrasupercritical technologies.

Finally, the study concluded that there are likely to be significant gains to be had from adopting a HELE pathway and a deeper analysis of the Indian situation was warranted. This report presents the results of that analysis.

2 Growth in India and the need for power

In reviewing the prospects for economic growth and the concomitant need for power, the IEA observed that India is in the early stages of a major transformation, bringing new opportunities to its 1.3 billion people (IEA, 2015). Energy use in the country has almost doubled since 2000, and a combination of economic growth and social policies has lifted millions out of extreme poverty. That said, average energy consumption per capita is only around one-third of the global average and some 240 million people have no access to electricity. Three-quarters of Indian energy demand is met by fossil fuels, a share that has been rising as households gradually move away from the traditional use of solid biomass for cooking. Coal provides the majority of Indian electricity, accounting for over 70% of generation, and is also the most plentiful domestic fossil fuel resource.

Various projections of India's future energy needs predict that it will grow more than any other country in the period to 2040, as the economy increases five-fold (Puri, 2016; Luthra, 2014). At the same time the population is predicted to grow to 1.7 billion, overtaking China to become the world's most populous country. Energy consumption is predicted to more than double by 2040, accounting for 25% of the rise in global energy use, with a consequent growth in the use of coal and oil.

Total electricity demand is predicted to increase by 4.9% per year, reaching almost 3300 TWh in 2040 (Figure 3). The installed capacity increases from approximately 300 GW to nearly 1100 GW by 2040. Nearly half of the net increase in predicted coal-fired generation capacity worldwide is set to take place in India, where coal remains crucial to the electricity generation system.

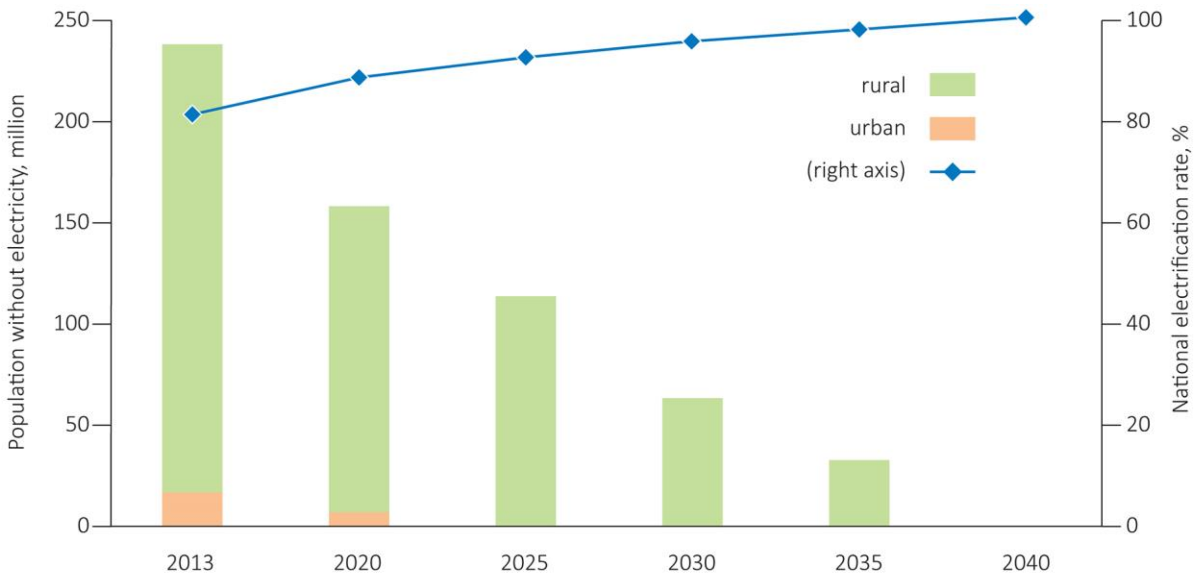

Figure 3 Population without access to electricity and electrification rate in India in the IEA New Policies Scenario (IEA, 2015)

An increasing population with rising aspirations will drive a strong demand for infrastructure and consumer goods. An extra 315 million people are anticipated to move to India's towns and cities by 2040, and this trend to urbanisation drives many of the changes in energy use, accelerating the switch to modern fuels and the rise in appliance and vehicle ownership, and pushing up demand for steel, cement and other energy-intensive materials. The Indian government is committed to providing '24 x 7 Power for All' by 2040. Also, government backed campaigns such as 'Make in India' (New Indian Express, 2014) will further drive massive industrial growth requiring a large rise in the energy needed to fuel development (Figure 4). Growth on this scale brings new environmental strains, including the risk of worsening air quality unless mitigating and remedial measures are put in place.

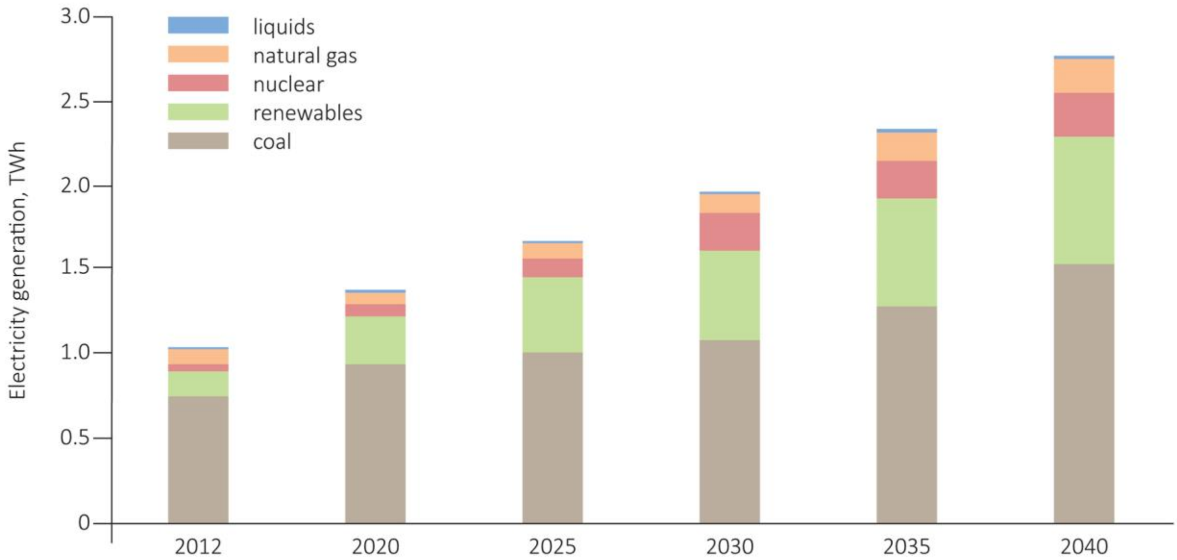

Figure 4 Electricity generation by fuel source TWh (IEA, 2015)

Recent government initiatives have set out ambitious plans to increase the share of renewables in the generating sector, particularly wind and solar power. Ambitious targets of 160 GW of renewables by 2022, of which 100 GW is solar have been set although their achievement means surmounting issues related to land acquisition, remuneration, network expansion and financing. In some states, renewable projects are being developed without due consideration to important issues such as grid interconnection and may through a 'dash for renewables', risk becoming stranded assets (Tomar, 2016).

A vibrant power sector is vital for India to achieve her aspirations for her people but the extremely poor financial health of the distribution sector has created continuing uncertainty for investors and generators with a corresponding under-investment in infrastructure and low quality service in many regions.

2.1 Structure of the Indian power sector

Figure 5 India – regions and major cities

India's energy sector has a complex structure in which five government ministries co-operate and co-ordinate to meet the country's need for power (Figure 6) (IEA, 2015). Furthermore, the central government interacts with the regional state governments to enact policy initiatives, and this complexity can make market operation and reforms difficult to achieve. Observers have opined that this situation contributed to a weakness in energy policy and provision, including inadequate energy delivery infrastructure and control and co-ordination issues (Misra, 2014).

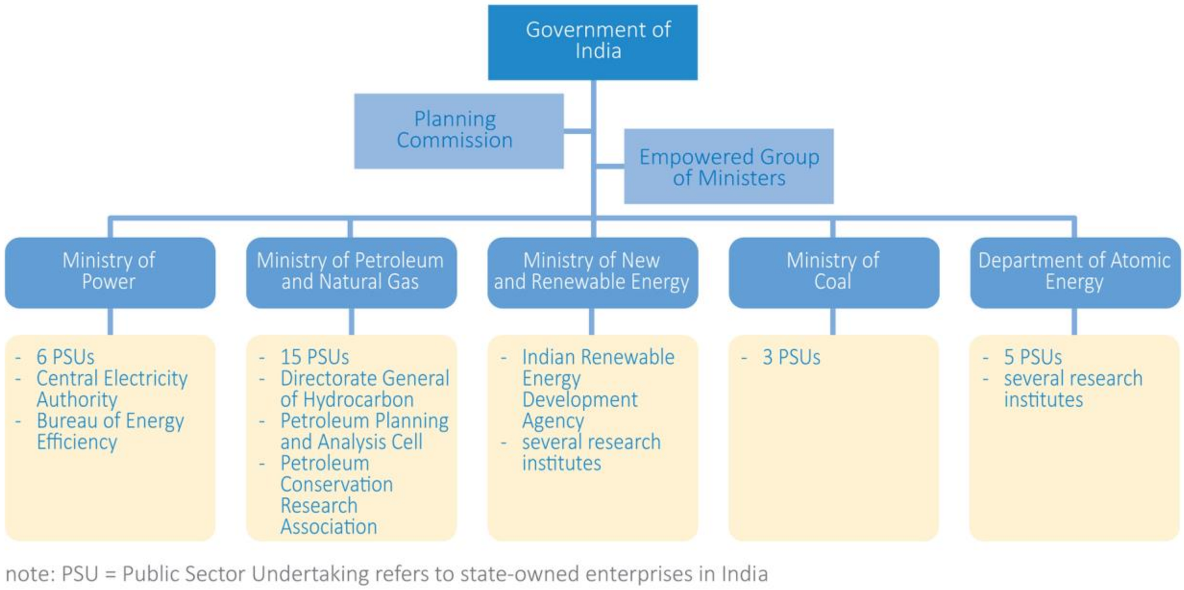

Figure 6 Institutional structure of energy administration in India (IEA, 2015)

The ministries are overseen by the National Institution for Transforming India (NITI), which replaced the former Planning Commission in 2015. The Planning Commission operated a top-down system of control whereas the new NITI is established with responsibilities covering a wide range of key policy elements, and as a provider of strategic and technical advice to the central and state governments and is intended to have a more consultative, coordinating role, especially where issues cross central-state boundaries (Prime Minister's Office India, 2015).

The three major ministries responsible for India's electrical power generation; Coal, Power and New and Renewable Energy, were created from the former single energy ministry over twenty years ago. Recent changes by the Modi government in 2014 in an effort to improve co-ordination now have the three ministries reporting to a single minister, Piyush Goyal (Singh 2015).

The Ministry of Coal (MOC) has primary responsibility for developing policies and strategies for coal production and future developments and has an interest in three public sector undertakings (PSU) involved in coal production. The Ministry of Power (MOP) is responsible for planning, implementing and monitoring in the power sector. The MOP oversees six PSU and two statutory authorities. The Ministry of New and Renewable Energy (MNRE) leads on policy development and the promotion of new and renewable energy.

The electricity generation and distribution sector is equally complex with a series of interacting publicly- and privately-owned stakeholders (Figure 7).

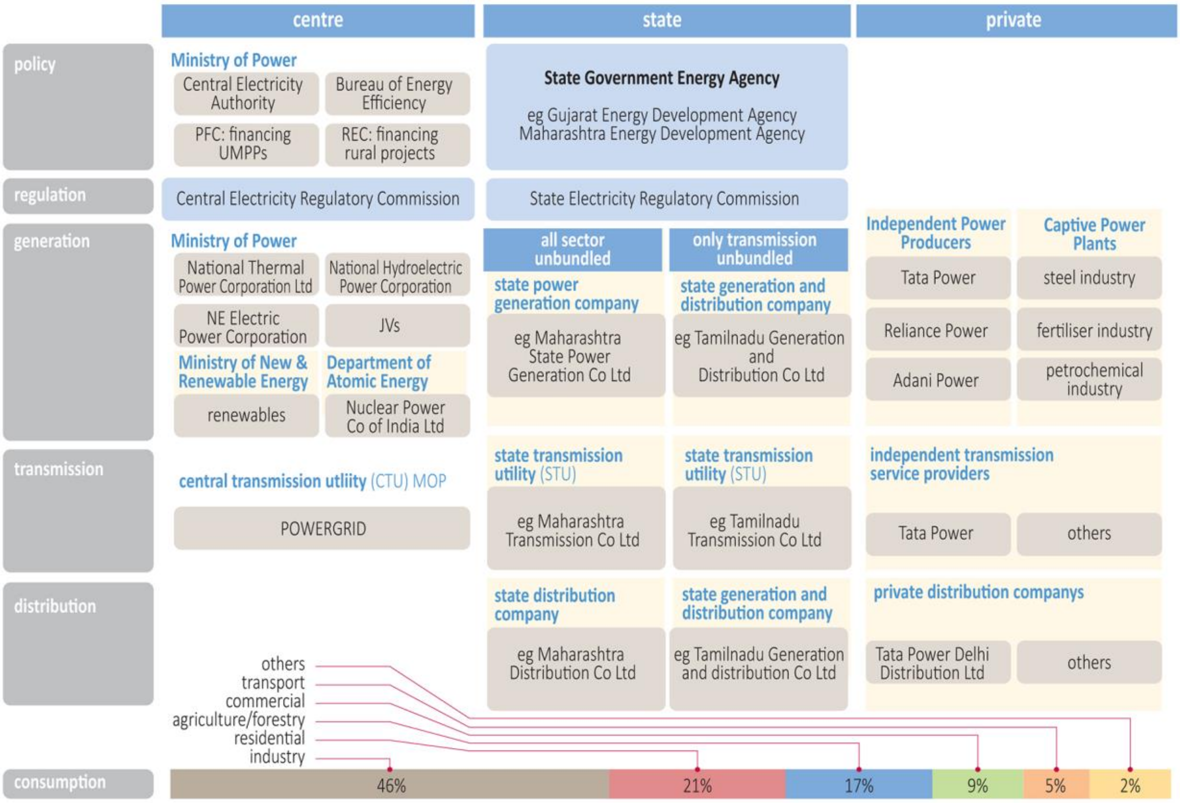

Figure 7 Key players in the power sector (IEA, 2012)

The central government plays a key role in electricity planning, and the formulation, implementation and monitoring of policy in the sector through the MOP. It also provides an oversight and co-ordination role for two statutory bodies, Central Electricity Authority (CEA) and the Bureau of Energy Efficiency (BEE), and six state-owned utilities. These agencies cover thermal and hydropower generation, transmission, distribution and financing. The state governments are also important to the Indian electricity sector as state-owned utilities control a large share of the transmission and distribution network (Sontakke, 2014). In practice, most of the work in the electricity sector is undertaken by the states, with some engagement and support from the central government (IEA 2014).

The majority of power generation in India is undertaken by government-owned utilities that are responsible for approximately 70% of the country's total generation. Private power producers currently account for about 30% of total generation but are slowly increasing their market share.

The largest government owned utility is the NTPC Ltd (formerly the National Thermal Power Corporation) and it is also the largest power company in India. NTPC has a portfolio of thermal, hydro, nuclear and renewable plants with a combined capacity of 38 GW. The majority (~90%) of its installed capacity is coal-fired. Although the NTPC is largely government-owned it has Maharatna status, which is granted to a company meeting specific criteria (Figure 8). Maharatna status gives an organisation greater autonomy from the central government in decision making and these companies can incur unlimited capital expenditure; enter into joint-ventures or strategic alliances; restructure the organisation including opening offices abroad; and raise debt from capital markets (NTPC, 2015).

Eligibility Criteria for Grant of Maharatna, Navratna and Miniratna Status to CPSEs

The eligibility criteria laid down by the Government for grant of Maharatna, Navratna and Miniratna status to Central Public Sector Enterprises (CPSEs) are following:

Criteria for grant of Maharatna status:

The CPSEs fulfilling the following criteria are eligible to be considered for grant of Maharatna status:

i. Having Navratna status.
ii. Listed on Indian stock exchange with minimum prescribed public shareholding under SEBI regulations.
iii. Average annual turnover of more than Rs 25,000 crore, during the last 3 years.
iv. Average annual net worth of more than Rs 15,000 crore, during the last 3 years.
v. Average annual net profit after tax of more than Rs 5,000 crore, during the last 3 years.
vi. Should have significant global presence/international operations.

Criteria for grant of Navranta status:

The Miniratna Category-I and Schedule 'A' CPSEs, which have obtained 'excellent' or 'very good' rating under the Memorandum of Understanding system in three of the last five years, and have composite score of 60 or above in the six selected performance parameters, namely,

i. Net profit to net worth.
ii. Manpower cost to total cost of production/services.
iii. Profit before depreciation, interest and taxes to capital employed.
iv. Profit before interest and taxes to turnover.
v. Earning per share.
vi. Inter-sectoral performance.

Criteria for grant of Miniratna status:

The CPSEs which have made profits in the last three years continuously and have positive net worth are eligible to be considered for grant of Miniratna status.

Figure 8 Eligibility Criteria for Grant of Maharatna, Navratna and Miniratna Status to CPSEs (Press Information Bureau Government of India Ministry of Heavy Industries & Public Enterprises, 2014)

The North Eastern Electric Power Corporation (NEEPCO) was established to develop electricity capacity in the north east of India. NEEPCO has 11.3 GW of installed capacity and accounts for almost half of the installed capacity in the region (NEEPCO 2015).

Of the private sector power producers, Adani Power is the largest in India. It has an installed capacity of approximately 10.5 GW and owns India's largest power plant, Mundra, in Gujurat. Mundra power station has nine generator units with a combined capacity of around 4.6 GW (Adani Power 2015).

Tata Power is India's largest integrated power company. Notably, Tata Power was responsible for developing India's first 4 GW ultra mega power projects (UMPP) in Gujurat based on supercritical technology. Tata Power has a total installed capacity of approximately 9 GW comprising thermal, hydro, solar and wind technologies (Tata Power 2015).

Electricity tariffs charged by central government controlled utilities and independent power producers that deliver power to more than one state are regulated by the Central Electricity Regulatory Commission

(CERC). CERC also issues licences for companies transmitting electricity across states and acts as an arbitrator in disputes between companies. State Electricity Regulatory Commissions are responsible for setting tariffs for state-owned utilities (IEA 2012).

2.2 The current status of India's coal-fired power sector

2.2.1 Efficiency, availability and environmental performance

India's overall electricity generation efficiency remains relatively low compared to other countries. A fifth of operational power units are more than 25-years old and another 40% are more than 15-years old, but less than 25-years old (CEA, 2009). Nearly all of India's coal-fired power plants are subcritical, with an average efficiency of about 33%, compared to, for example 39% for subcritical plants in the USA (IEA, 2011a). India's first supercritical power plant (a 660 MW unit by NTPC) was not put into operation until 2011. The 12th Five-Year Plan currently framing policy foresees about 40% of new coal power plants using supercritical technology (Mathur, 2011) and it was mandatory for UMPP to adopt supercritical technology to improve fuel efficiency. In addition to low efficiencies, Indian plants tends to have a low plant load factor (PLF), which is a measure of the utilisation rate of operational plants and otherwise referred to as availability in other countries. Historically, the nationwide thermal PLF improved slowly from below 70% in the 1990s to approximately 78% in 2007 and 2008. However, it has decreased in recent years to around 73% in 2010-12 (MOP, 2011a; CEA, 2012b). The PLF of state-generating companies is much lower at 68% compared to 82% for publicly-owned central government-generating companies. The PLF of private power plants has fallen owing to power demand growth dropping, resulting in excess capacity, from over 90% in 2007-09 to 67% in 2011-12. The low PLF is reported as being partly caused by the unexpected and unscheduled maintenance of ageing plants, and the delayed operational stabilisation of new plants. However, the main cause of loss of plant availability is the shortage of coal and gas supply and the poor quality of coal supplied (IEA, 2011a). The ongoing low PLF undermines the financial performance of generating companies and reduces the volume of generated electricity.

A recent in-depth study of the performance of Indian coal-based thermal power plants underlined these observations. The two-year long research study was undertaken by the Centre for Science and Environment (CSE) under CSE's Green Rating Project (GRP), and was the first of its kind aimed at auditing the industrial power sector on its environmental performance and compliance. CSE analysed and rated 47 coal-based thermal power plants from across the country on a variety of environmental and energy parameters. About half of all the plants operating in 2011-12 were selected for the rating. The three top power plants were awarded for their overall environmental performance, while two others received awards for their efficient use of resources such as energy and water (The Hindu, 2015). The key findings of the exercise were as follows:

- The sector's overall score was a low 23% with 40% of the plants in the study receiving less than a 20% score. A plant adopting all the best practices would have scored 80%. The average efficiency of the plants studied was 32.8%, one of the lowest among major coal-based power producing countries. Average carbon dioxide emissions were 1.08 kg/kWh.

- The top performing plants were West Bengal-based CESC-Budge Budge (Sipat), followed by JSEWL-Toranagallu (Karnataka), Tata-Trombay (Maharashtra) and JSW-Ratnagiri (Maharashtra). They scored between 45–50% in the marking scheme. In addition, Tata-Mundra (Gujarat) received an award for having the highest energy efficiency, while Gujarat Industries Power Company Ltd (GIPCL), Surat, won an award for lowest water use.
- India's thermal power plants are estimated to withdraw around 22 billion cubic metres of water, which is over half of India's domestic water need. Even the plants with cooling towers use an average of 4 m^3/MWh.
- 55% of the units were violating air pollution standards which are already poorly enforced – particulate matter (PM) emissions are at 150–350 mg/m^3.
- Fly ash disposal remains a major problem. Presently, only about 50–60% of the 170 million tonnes of fly ash generated by the sector is utilised; the remaining ash is dumped into poorly designed and maintained ash ponds. Currently, about a billion tonnes of these ashes lie in these ponds and leakages pollute land, air and water. By 2021-22, the sector is projected to produce 300 million tonnes of fly ash every year.
- Ash slurry, which contains toxic heavy metals, was found in nearby rivers and reservoirs of twenty plants (*see* Figure 9). Tests undertaken by CSE laboratories found that nearly 40% of the plants did not meet the basic total suspended solid (TSS) norms for effluents discharged. 60% of plants had not installed effluent and sewage treatment plants.
- Thirty-six of the 47 plants were unable to meet the MoEF's mandated target of utilising 90% of the solid waste (ash) generated – average use was only 54%).
- The performance of NTPC Ltd, the largest coal-power producing company in India, was reported as performing below par. However, NTPC did not disclose its plant data, and so ratings were based on a primary survey and publicly available information. The six plants of NTPC that were rated received scores of between16% and 28%. The poorest performing plant was Delhi's Badarpur facility.

Figure 9 Power station ash discharge into the Katel river (photography courtesy of DownToEarth, 2015)

2.2.2 Closing older inefficient plant

In May 2016, S D Dubey, Chairman of the Central Electricity Authority, the planning wing of the power ministry announced plans to shut ageing coal-fired power plants with a combined capacity of 37 GW in an effort to cut emissions and reduce the use of fuel and water (Bloomberg 2016). The selected plants are more than 25-years old and are considered inefficient and uneconomic. It is intended to replace them with supercritical units, but no timescale was given for the transition. This development is in line with several initiatives by Prime Minister Modi in an attempt to balance energy security with the need to protect the environment.

A majority of the old capacity earmarked for closure, 22 GW, is controlled by provincial governments, while 13 GW is owned by government companies, such as NTPC Ltd. About 2 GW of capacity belongs to non-state producers but no plant owners were named (CEA, 2015).

The Central Electricity Authority has been charged with holding talks with plant owners and electricity buyers to prepare a roadmap for phasing out the old capacity. However, closure of such plant is likely to encounter resistance on a regional basis. Electricity pricing is a particularly sensitive and politically charged issue in India. The old and fully-written down plant can produce power at a relatively low cost, compared to a modern replacement. This takes no account of the environmental impact of such plant of course. It has been suggested that some form of 'efficiency tax' might be enacted to encourage operators to replace and upgrade their old capacity (Razdan, 2016).

2.2.3 Power distribution issues

Average transmission and distribution losses exceed 25% of total power generation. These losses are almost 2.5 times the world average. The transmission and distribution losses are due to a variety of reasons such as a substantial amount of electrical energy being sold at low voltage, sparsely distributed loads over large rural areas, inadequate investment in distribution systems, improper billing practices and theft (Figure 10). The power generator companies sell power to State Electricity Boards (SEB) or a distribution company (India) – DISCOM. SEB were facing financial ruin and are sustaining losses of Rs 700 billion annually and therefore did not have enough resources to purchase power from the generators. Hence a situation has risen wherein there is an excess of power but no one can afford to buy it. The government recently introduced a scheme called 'Ujwal Discom Assurance Yojana' (UDAY) to rescue SEBs. Under the scheme, 75% of the loans on the SEB books will be transferred over to the books of their respective state governments. Transferring such huge loans will provide some relief to the SEBs in terms of finance costs, however, the SEBs situation will improve substantially only if there are regular price increases. The price of electricity is very politically charged in India and most political parties intending to gain votes from large interest groups, such as farmers, may offer them free power. The fear of losing such votes therefore makes the state government reluctant to increase the power tariffs.

Figure 10 Electricity theft through unauthorised connections (photograph courtesy of Pradesh18, 2015)

2.2.4 Land use issues

Economic development in India invariably runs into land-use conflicts, given the enormous population of the country and the wealth disparity between the bulk of the population and the new emerging middle class. Local communities, who are promised improved social amenities and local employment opportunities in return for compulsory land acquisition, often resist based on a history of broken promises. Coal deposits in India are often found under tracts of national forests, waterways and remote but populated areas. Land issues also impact on other power generation technologies, especially those requiring a large footprint for a new development such as solar farms. Sometimes the solutions to these problems are harsh: Prime Minister Modi used executive orders in December 2014 to impose compulsory land acquisition orders for project developments.

These issues with the associated project delays and community resistance are financial risks that need to be factored into a new power project's viability. A failure to do so materially increases the risk of stranded assets for new power projects, particularly in the fossil fuel sector.

2.3 Indian 'ultra mega' coal-fired power plants

The UMPP was an ambitious initiative of the Indian government to meet increasing power needs. It was launched in 2005-06 by the Ministry of Power to facilitate the development of a series of large power plant projects, each having a capacity of approximately 4 GW (Government of India Ministry of Power, 2015). These were intended to be situated at coal pitheads and coastal locations and were aimed at delivering power at competitive cost to consumers through economies of scale. The Indian government oversaw the development of UMPP under a tariff-based competitive bidding route using supercritical technology on a build, own and operate (BOO) basis. The Central Electricity Authority (CEA) was the technical partner and the Power Finance Corporation (PFC) the nodal agency.

To encourage investment, address perceived risks and get a good response to competitive bidding, the PFC incorporates special purpose vehicles (SPV) for each UMPP to undertake the bidding process on behalf of the power procuring (beneficiary) states. The purpose of the SPV is to carry out the bid process management and obtain various clearances/consents for the projects so that these may be transferred to the successful bidder along with the SPV, who is selected through the tariff-based International Competitive Bidding (ICB) in accordance with the 'Guidelines for determination of tariff by bidding process for procurement of power by distribution licensees', issued by the Ministry of Power.

Initially 16 UMPP, each with a capacity of about 4 GW, were identified in various parts of the country. Four were awarded to developers: Sasan in Madhya Pradesh (Reliance Power), Mundra in Gujarat (Tata Power), Krishnapatnam in Andhra Pradesh (Reliance Power) and Tilaiya in Jharkhand (Reliance Power) (Table 1 and Figure 11 to Figure 14).

Table 1 Initial UMPP awards

Name of UMPP	Type	Date of transfer	Levelised tariff (Rs. per kWh)	Successful developer
Mundra, Gujarat	Coastal	23.04.2007	2.264	Tata Power Ltd
Sasan, Madhya Pradesh	Pithead	07.08.2007	1.196	Reliance Power Ltd
Krishnapatnam, Andhra Pradesh	Coastal	29.01.2008	2.333	Reliance Power Ltd
Tilaiya, Jharkhand	Pithead	7.8.2009	1.77	Reliance Power Ltd

However, only two – Sasan and Mundra are in operation. Reliance Power withdrew from the Tilaiya UMPP, citing inordinate delays. Krishnapatnam was also deferred. The government invited bids for two further UMPP at Bedabahal in Odisha and Cheyyur in Tamil Nadu in 2015 but their bids were cancelled due to poor response from the power sector stakeholders.

Figure 11 Tata Power UMPP at Mundra, Gujarat under construction (Tata Power 2015)

The UMPP have experienced a number of problems such as issues associated with land acquisition. For the UMPP the acquisition of land was undertaken by the government. Land acquisition is a difficult issue in India and particularly so in areas controlled by Naxalite factions (The Hindu, 2013). The Tilaiyya power plant, Jharkhand, is in such an area and has faced inordinate delays. As a bid to circumvent delays in land acquisition for planned new UMPP, the energy ministry proposed converting plants older than 25 years, which were originally built on large areas of land and were thought suitable for locating new UMPP plants.

However, investigations by the state governments found that creeping urbanisation had largely eroded the amount of available land, and surveys by the Central Electricity Authority (CEA) concluded there are no longer enough land or water resources to support the new plants. As a result, the CEA recommended that the plants should not proceed.

Serious administrative delays have given rise to accumulating financial overheads. As the infrastructure projects are financed via debt, any delay will reduce the viability of projects due to an increasing interest burden. Further, since UMPP were awarded via competitive bidding, any delay will lower the internal rates of return (IRR) jeopardising the financial viability of the project. Coal supplies to the proposed plants have also proved to be a big issue. Coal for the plants was supposed to be imported or sourced from local captive mines. Out of the two operational UMPP, Tata Power's Mundra UMPP is using imported coal while Sasan is using local coal. The Indian coal has a low calorific value, and a high ash content, with a high silica content, which increases the capital expenditure of such plants, as they need to invest in larger units and additional equipment. The developers need to sell the electricity generated to the State Electricity Boards (SEB), which are in dire financial circumstances and allegedly have a poor record of payment (Government of India, 2015b). Finally, it was claimed that there was an absence of clarity on coal price and power-purchase agreements. UMPP work on a design, build, finance, operate, and transfer (DBFOT) model. The power producers claim that this model does not address all the risks associated with the projects because all losses go to the power generator, before the project is transferred. Due to the lack of enthusiasm among the private players, the government decided to formulate a new standard bid document, which would address the issues related to coal price pass-through and power-purchase agreements.

Most recently, the Ministry of Power has concluded that slowing demand growth means that India doesn't require any additional power plants in the short term beyond those already under construction, or renewable projects which the government has committed to. In the light of this and the issues described above, the Indian government has acknowledged that the UMPP programme was failing to fulfil its promise, with state governments showing no interest in four massive 4 GW power plant projects in Chhattisgarh, Karnataka, Maharashtra and Odisha. As a result, it has officially scrapped the special purpose companies created to develop the projects and no more UMPP are likely to be built. The failure of the UMPP initiative must be viewed as a setback to HELE advancement in India.

2.4 Recently commissioned plant

Despite the setback experienced in the UMPP, a number of smaller plants have been commissioned recently featuring supercritical steam cycles. Some selected examples follow.

Lalitpur Super Thermal Power Project

Bharat Heavy Electricals Limited (BHEL) recently commissioned three supercritical units of 660 MW each at the 1980 MW coal-based Lalitpur Super Thermal Power Project (STPP) in Uttar Pradesh. All three units have been synchronised by BHEL four months ahead of schedule through enhanced focus on project execution using innovative erection techniques and meticulous project management, according to a BHEL release. The 3 x 660 MW Lalitpur STPP was developed by Lalitpur Power Generation Company Limited, promoted by the Bajaj Hindusthan group, in Lalitpur in Uttar Pradesh. The main plant package contract of this 1980 MW power plant is executed by BHEL and is based on supercritical technology.

The key equipment for the project has been manufactured by BHEL at its Haridwar, Tiruchi, Hyderabad, and Bengaluru units, while the construction of the plant has been undertaken by the company's Power Sector – Northern Region.

Figure 12 Lalitpur Super Thermal Power Project (STPP) in Uttar Pradesh (Lalitpur Power Generation Company 2016)

Mundra Thermal Power Station, Gujarat

The 4620 MW Mundra Thermal Power Station located in the Kutch district of Gujarat is currently the second biggest operating thermal power plant in India. It is a coal-fired power plant owned and operated by Adani Power. The power plant consists of nine generating units (four subcritical 330 MW units and five supercritical 660 MW units). The first 330 MW unit was commissioned in May 2009 and the last 660 MW unit of the plant commissioned in March 2012. The coal used for the power plant is mainly imported from Indonesia. The plant's water source is sea water from the Gulf of Kutch. The boilers and generators for the first four units were supplied by Babcock & Wilcox and Beijing Beizhong respectively. SEPCO III, China was the engineering, procurement, and construction contractor for the last five 660 MW units, which feature supercritical technology. The boilers were supplied by Harbin Boiler and the turbine and generators were supplied by Dongfang Machinery.

Figure 13 Mundra thermal power station, Gujarat (Adani Group 2016)

Sipat thermal power plant, Chhattisgarh

The 2980 MW Sipat super thermal power plant located at Sipat in the Bilaspur district of Chhattisgarh, ranks as the fifth largest thermal power station in India. It is a coal-based power plant owned and operated by NTPC. The power plant built in two stages is installed with six generating units (three 660 MW supercritical units and three 500 MW units). The first unit of the plant commenced commercial operation in August 2008, while the last unit was commissioned in June 2012. The power plant, built at an estimated cost of more than $2 billion, was renamed as Rajiv Gandhi Super Thermal Power Station in September 2013. Coal for the Sipat plant is sourced from Dipika mines of South Eastern Coalfields Limited (SECL). The plant uses water from the Right Bank Canal (RBC) originating from the Hasdeo Barrage.

Figure 14 Sipat thermal power plant, Chhattisgarh (NTPC 2016)

2.5 Summary

The predicted growth in India's population and associated economic activity is likely to double energy demand by 2040. Despite an ambitious drive to establish a significant capacity in renewables capacity, coal is likely to remain crucial to meeting the country's future electricity needs.

India's energy sector has a complex structure in which five government ministries co-operate and co-ordinate to meet the country's need for power. Furthermore, the central government interacts with the regional state governments to enact policy initiatives, and this complexity can make market operation and reforms difficult to achieve.

India's overall electricity generation efficiency remains relatively low compared to other countries. There is a large tranche of older capacity in the power fleet and a significant number of units based on subcritical technology. Recent initiatives to improve the situation include a scheme for closing old, inefficient plant and the development of very large power stations (UMMP). Both schemes have met with resistance and have been bedevilled by the complexities associated with India's complex institutions and the political interactions between national and regional governments. The lack of finance from the regional electricity boards also hampers the development of new plants.

3 Policy and legislative drivers

3.1 Energy policy

The key policy document for the future direction of the Indian economy is the Five-Year Plan. The 12th Five-Year Plan, which covers the period 2012-17, sets out targets for the energy sector based on 'low carbon strategies for inclusive growth' and includes ambitious targets for increasing the share of renewables in the generation mix. Twelve focus areas were identified for action in the plan (Table 2).

Table 2 Twelve focus areas for the 12th Five-Year Plan 2012-17
1. Advanced Coal Technologies
2. National Wind Energy Mission
3. National Solar Mission
4. Technology Improvement in Iron and Steel Industry
5. Technology Improvement in Cement Industry
6. Energy Efficiency Programmes in the Industry
7. Vehicle Fuel Efficiency Programme
8. Improving the Efficiency of Freight Transport
9. Better Urban Public and Non-motorised Transport
10. Lighting, Labeling and Super-efficient Equipment Programme
11. Faster Adoption of Green Building Codes
12. Improving the Stock of Forest and Tree Cover

The plan acknowledges that India will continue to rely heavily on coal to meet its increasing power demand and that this brings additional environmental and natural resource challenges, as the power sector is the highest contributor (at 38%) to India's greenhouse gas emissions. There are several initiatives presented in the plan that aim to mitigate the impact of large coal use; these are outlined below.

The plan requires that 50% of the Twelfth Plan target must be achieved through supercritical units. This is also the case for any additional coal-based capacity in the forthcoming Development Agenda that supersedes the Thirteenth Plan. The plan notes that supercritical technology is now mature and is only marginally more expensive than subcritical power plants. It also acknowledges that determined efforts are needed to achieve these results, and that reform of coal linkages incorporating mining and transportation will be necessary to incentivise adoption of supercritical technology.

The plan also mandates the need to invest in research and development of advanced ultrasupercritical (AUSC) units through government sponsored research. The first AUSC plant, which is a collaboration between BHEL, NTPC and IGCAR, was expected to be operational in 2017. However, this has now been pushed back to 2021 (Project Monitor, 2014). The project is expected to result in a demonstration unit at NTPC's Dadri complex in Uttar Pradesh and is planned to be undertaken in two phases, of which phase-I is the Research & Development (R&D) phase and is expected to cost Rs 1554 crore, equivalent to approximately US$231 million. Of this, Rs 1100 crore has been requested from the government.

The plan also notes that coal gasification provides opportunities for higher efficiency. However, studies on the gasification of high ash Indian coal suggest that any efficiency gain over subcritical units is only marginal. Underground coal gasification is also included as a potential technology for the utilisation of deep coal deposits, that cannot be mined using conventional means, or because they are located in environmentally fragile regions. It also allows the possibility of in situ carbon capture. Given India's coal shortage, the plan stipulates that there should be greater research on this technology, including establishing pilot projects. Coal bed methane extraction is similarly earmarked for greater research and development effort.

India has ambitious targets for renewable energy growth. As part of its Union Budget 2015-2016, India aims to install 60 GW of wind power capacity and 100 GW of solar power capacity by 2022, which is more than six times the current installed capacities of approximately 22 GW and 3 GW, respectively.

The 13th Five-Year Plan that was in the process of formulation when Prime Minister Modi came to power has been superseded by a larger and more focused 15-year National Development Agenda that will include internal security and defence as well. The new blueprint will be implemented after the last of the Five-Year Plans, the 12th (2012-17) ends next year. Economic Times (India) reported that the Prime Minister had given his go-ahead to the proposed plan as an initiative that seeks to combine long-term planning, regular reviews and stringent monitoring into one coherent scheme.

The previous Five-Year Plan system has drawn criticism in the past from various quarters due to the absence of long-term focus, present in other nations' development models. The NITI has been asked to formulate the long-term 15-year development blueprint of the country keeping in view the millennium development goals and needs of India. As per the proposed blueprint, there will be a shorter seven-year action plan within the larger framework and a review within three years for any course correction. For the first time, internal security and defence have been included in the plan process so that the long-term planning element can be brought into these areas, for better preparation. These subjects were traditionally not part of the plan process.

The NITI has also been charged with creating a 'dashboard' for constant monitoring, evaluation and reviewing and also set outcome targets for all major infrastructure schemes and social sector work. A plan for the current financial year is under evaluation within the Prime Minister's office.

The specifics of the National Development Agenda with regard to energy have yet to be made public, but there is likely to be continuing focus on 'electricity for all' and expansion of the renewable energy sector. As mentioned previously, it is also likely that supercritical technology will be mandated for new thermal plants, but importantly not ultrasupercritical at the time of writing (June 2016).

The interactions between the various ministries and the NITI has thrown up an interesting example of dispute resolution associated with the construction of new coal-fired capacity – Bhadradri Thermal Power

Project. In August 2015 the government of Telangana had requested that the Ministry of Power approve 4 x 270 MW coal-based thermal power units based on subcritical technology. The Ministry of Power responded that it had adopted the policy of denying permission to plants with subcritical technology constructed during the 13th Five-Year Plan. The state of Telangana argued that they were entitled to clearance for the project because they would complete it within the period of the 12th Five-Year Plan. While NITI supported the state's position, the Ministry of Power responded that it had already been denying permission to all subcritical plants. The impasse was, however, resolved when the representation from the Ministry of Environment, Forests and Climate Change stated that even if the Ministry of Power granted permission on the grounds that the project would be completed before the 13th Plan, environmental clearance could not be given. The official advised the State to adopt supercritical technology to ensure that the necessary environmental clearance would be granted. The matter was thus resolved (Jain, 2015).

A recent mandatory regulation, the Perform, Achieve & Trade (PAT) Scheme under National Mission on Enhanced Energy Efficiency (NMEEE), requires that all thermal power plants in India reduce their operating heat rates by specified percentages by March 2015 from a 2010 baseline (Shakti Sustainable Energy Foundation, 2015). The required improvements can be in the form of simple heat rate improvement, Auxiliary Power Consumption (APC) reduction identified through energy audits, and cost-intensive Renovation & Modernisation (R&M) and Life Extension (LE) approaches. All thermal power plants with an annual energy consumption of more than 30,000 Mtoe are covered under this scheme. This includes 84 coal-based power plants which were required to meet the notified targets by March 2015. The minimum threshold of 30,000 Mtoe of annual energy consumption is equivalent to a 20 MW power plant and thus ensures coverage of all power plants commissioned before 2007 under the scheme. Energy reduction targets are given to each plant on the basis of its deviation of Operating Net Heat Rate (ONHR) from Design Net Heat Rate (DNHR).

3.2 Environmental policy

India's rapid growth and increasing urban population is bringing with it problems of pollution; an issue that is familiar in other emerging economies. Pollution from the power and transport sectors are major threats to health and the Indian government is now taking steps to address the growing issue of air quality. Sloss (2015) recently reviewed the status of emissions legislation in India. Currently, there are no emission limits for coal-fired plant for the primary pollutants SO_2 and NOx and only relatively light controls for particulates where limits between 150–350 mg/m^3 apply depending on the size and age of the plant. To deal with local pollution from SO_2 emissions, power plants are required to have a minimum stack height. Mohan (2015) recently estimated the emissions from Indian coal plant and concluded that coal-fired power plants accounted for 60% of particulate emissions, 45–50% of SO_2 emissions and 30% of NOx emissions. With the projected increase in coal-fired capacity, emissions of these species will continue unless measures are taken to reduce and control them; HELE plants have an important part to play here.

New emissions limits have recently been proposed, roughly in line with those operating in the EU and China (Table 3).

Table 3 Proposed emission standards for Indian coal-fired power plants (MOEF, 2015)

Coal-fired plants	Pollutant	Plant size	Standard, mg/m^3
Units installed before 31/12/2003[1]	Particulates	All	100
	SO_2	<500 MW	600
		>500 MW	200
	NOx	All	600
	Mercury	<500 MW	–
		>500 MW	0.03
Units installed after 2003 and before 31/12/2006[1]	Particulates	All	50
	SO_2	>500 MW	200
	NOx	All	300
	Mercury		0.03
Units installed after January 2017†	Particulates	All	30
	SO_2	All	100
	NOx	All	100
	Mercury	All	0.03

[1] Units to meet the limits within 2 years from the date of notification
† Includes all units, which have been accorded environmental clearance and are under construction

These limits are reported as coming into force in 2017 but until a comprehensive measuring and monitoring capability has been established and proven, measurement and enforcement is likely to present a problem for the authorities. At a recent workshop on energy efficiency organised by the US Department of State, these new Indian emission limit values were discussed and it was stated that the final decision on the acceptance and subsequent enforcement of the limits lies with the Ministry, including the timeframe for implementation (IEA Clean Coal Centre, 2015). There was general agreement that the limits would be likely to come into force but that it was not possible to say when this would happen or how stringently the standards would be applied. It was agreed that installation of control technologies for SO_2 and NOx in India would be expensive and possibly a challenge in some areas with limited water availability. Also, the installation of emissions control technologies incurs an efficiency penalty owing to the auxiliary power requirements of the control plant. Where limestone is used for SO_2 control it would create a new waste stream of gypsum, although this could be dealt with by creating a new market for wall-board type materials.

As is the case in the USA, India has a federal system for environmental regulation with central as well as state standards. States can set standards and limits which are more stringent than those set at the national level. In India, action taken at the state level is often more important than that taken at the national level since implementation and monitoring of compliance is largely dealt with at the state level. State Pollution Control Boards could be targeted with state-specific limits, particularly in large coal-burning states like Tamil Nadu and Maharashtra.

Pande (2015) has highlighted the difficulties in implementing an effective emission controls policy. There is a significant lack of resources within the relevant Government Agencies where 200–300 technical staff are required to monitor something like 50,000 plants. This limits inspections to once, or twice a year at most. There are temptations for plant operators to bypass pollution control systems to gain in efficiency and availability and although the Indian system treats violations of pollution standards as criminal offences, prosecuting offenders can be very time consuming and expensive. Continuous emissions monitoring (CEM) equipment is now required in all plants for particulate monitoring but regulatory requirements and capacity building/training for its use are not yet in place. Pande (2015) goes so far as to suggest that "convincing plants to turn on their pollution control equipment may be one of the quickest and cheapest ways to reduce pollution across India". A new programme to encourage the use of continuous monitoring equipment across targeted regions in India, run by the Harvard Kennedy School, hopes to show that enhanced information sharing within India will improve pollution abatement (Pande, 2015).

3.3 Summary

The specifics of the National Development Agenda that is thought likely to supersede the 13th Five-Year Plan, with regard to energy have yet to be made public, but there is likely to be continuing focus on 'electricity for all' and an expansion of the renewable energy sector. It is also likely that supercritical technology will be mandated for new thermal plants, but importantly not ultrasupercritical at the time of writing. Determined efforts are needed to achieve these results, and that reform of coal linkages incorporating mining and transportation will be necessary to incentivise the adoption of supercritical technology. The plan also mandates the need to invest in research and development of advanced ultrasupercritical units through government sponsored research.

India's rapid growth and increasing urban population is bringing with it problems of pollution; an issue that has affected other emerging economies. Pollution from the power and transport sectors are major threats to health and the Indian government is now taking steps to address the growing issue of air quality. New emissions limits have recently been proposed, roughly in line with those operating in the EU and China. These limits are reported as coming into force in 2017 but until a comprehensive measuring and monitoring capability has been established and proven, measurement and enforcement is likely to present a problem for the authorities.

4 What might be achieved with HELE technologies?

The HELE technologies applicable to PC-firing plant centre on improvements to the steam cycle allowing for higher steam temperatures and pressures and a consequent improvement in steam cycle efficiency. Historically, the majority of PC-fired plant was based on subcritical steam cycle technology, but with improvements in boiler tube materials, supercritical and ultrasupercritical steam cycles are now considered to be state-of-the-art. The definition of supercritical and ultrasupercritical boiler pressure and temperature conditions differs from one country to another, particularly the usage of the term ultrasupercritical, but the ranges cited by Nalbandian (2008) and shown in Table 4 are used frequently. A switch from subcritical to current ultrasupercritical steam conditions would raise efficiency by around four to six % points with a corresponding decrease in carbon dioxide emissions.

Table 4 Approximate pressure and temperature ranges for subcritical, supercritical and ultrasupercritical pulverised coal power plant (Nalbandian, 2008)

Pulverised coal power plant	Main steam pressure, MPa	Main steam temperature, °C	Reheat steam temperature, °C	Efficiency, %, net, HHV basis (inland, bituminous coal)
Subcritical	<22.1	Up to 565	Up to 565	33–39
Supercritical	22.1–25	540–580	540–580	38–42
Ultrasupercritical	>25	>580	>580	>42

By way of illustrating the theoretical potential of HELE technologies, Figure 15 summarises the impact of different steam cycle conditions on an 800 MWe power station boiler burning hard coal and operating at a capacity factor of 80%. The unit will generate 6 TWh electricity annually and emit the following quantities of carbon dioxide, depending on its steam cycle conditions and corresponding efficiency.

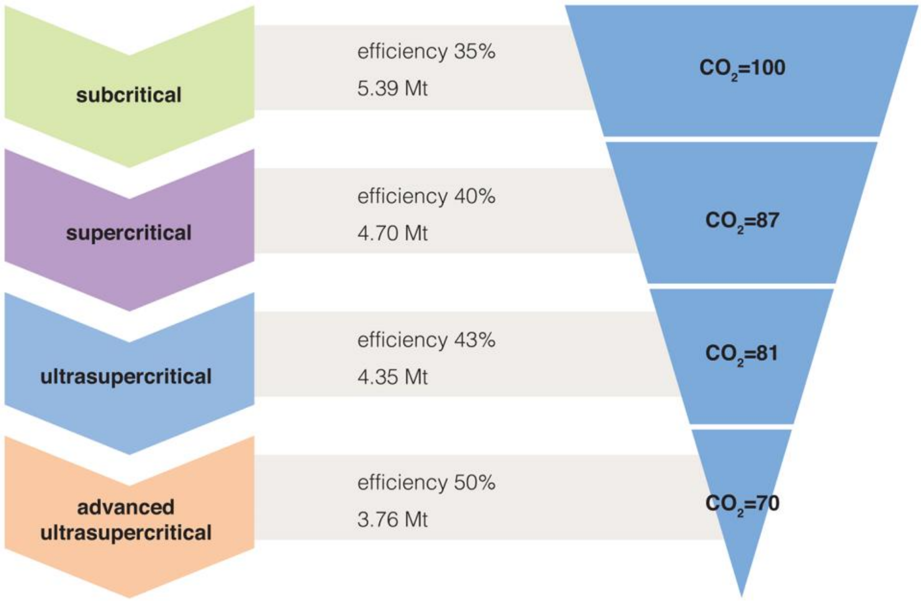

Figure 15 The impact of HELE technologies on emissions of carbon dioxide (Barnes, 2014)

The profile of the current and planned Indian coal-fired power generation fleet in Figure 16 below shows clearly the overwhelming predominance of subcritical capacity with the first supercritical units not appearing until 2010. Even units reported as planned or under construction are mostly supercritical with only a small contribution from ultrasupercritical capacity. Once these plants are built and in operation, they will be 'locked in' to the generation mix for as long as forty years. The absence of more ultrasupercritical plant may therefore be considered as an opportunity missed.

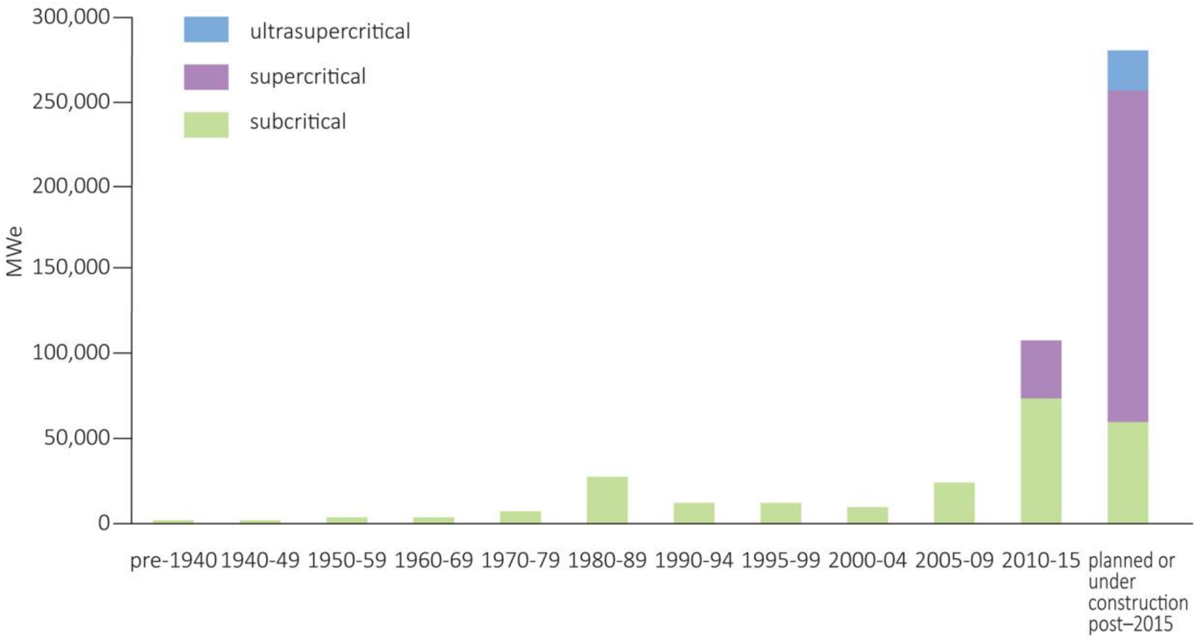

Figure 16 Indian coal-fired power plant by age and steam cycle conditions (MWe)

In the analysis outlined earlier (Barnes, 2014), the Indian situation was modelled using a progressive approach based on a 25-year plant retirement cycle which reflects evolving practice in emerging economies such as China to upgrade and replace plant (Minchener, 2014). The coal fleet profile was reviewed in 2020, 2030 and 2040, and plant older than twenty-five years is retired and replaced with ultrasupercritical units in the 2020 review. For the 2030 and 2040 reviews, replacement plant is based on AUSC units, assumed to be commercially available after 2025. The corresponding unabated carbon dioxide emissions from the revised coal fleet were calculated and then emissions assuming 90% capture CCS retrofit post-2020. Over the review period 2015–40 the projected coal-based electricity demand is plotted (blue line); the calculated carbon dioxide emissions from the coal fleet at each review point are plotted (red line), together with the composition of the fleet by steam cycle conditions (subcritical – green, supercritical – purple, ultrasupercritical – light blue and AUSC (25-year plant retirement scenario only) – orange. A third trend line – dashed red, sets out the emissions of carbon dioxide that would follow from the fitment of CCS according to certain assumptions set out in the referenced study (Figure 17). It should be noted that the additional capacity required by the plant derate that accompanies the operation of CCS is not included, or shown in this graphic; neither is the additional carbon dioxide that would be associated with that capacity. The dotted red line for CCS-carbon dioxide should therefore be regarded as a trend line.

While the analysis may be seen as a 'best case' assuming a shorter plant replacement cycle and the aggressive implementation of the best available HELE technologies it demonstrates what might be achieved for the Indian situation.

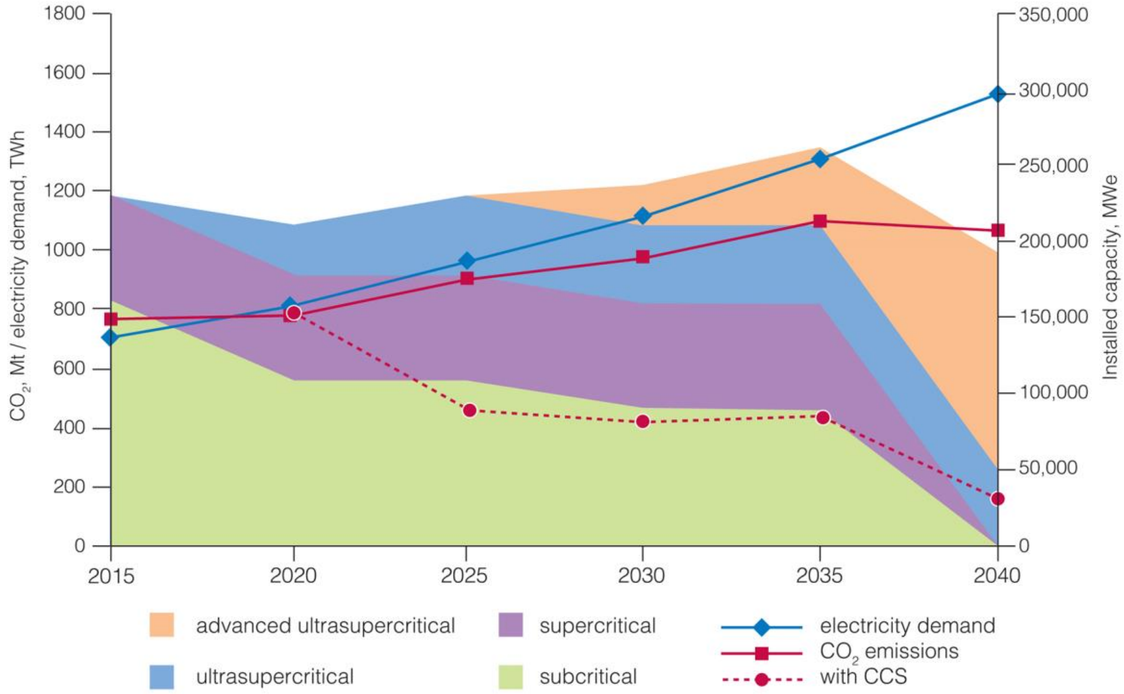

Figure 17 Development of the Indian coal-fired power fleet based on a 25-year retirement scenario and with aggressive implementation of HELE technology (Barnes, 2014)

4.1 Future coal-fired power generation perspectives

In this section possible development scenarios for the Indian coal-fired power sector are presented and discussed.

4.1.1 India energy security scenarios 2047

In August 2015, NITI explored a range of potential future energy scenarios for India, for diverse energy demand and supply sectors leading up to 2047. It considered India's possible energy scenarios across energy supply sectors such as solar, wind, biofuels, oil, gas, coal and nuclear, and energy demand sectors such as transport, industry, agriculture, cooking and lighting appliances. The model allows users to make energy choices interactively, and explore a range of outcomes for the country from carbon dioxide emissions and import dependence to land use. NITI has published the results of a modelling exercise examining the Indian power sector's development up to 2047. The specific results for the coal-fired component are summarised below.

Developments in coal-based power were modelled for four different trajectories designated Level 1 to Level 4. The following paragraphs describe the future scenarios and the results of the model. The installed capacity and electricity generated according to these scenarios is given in Figure 18 and Figure 19 below.

Level 1

Coal-based power generation is discouraged due to increasing fuel prices, import dependence, pressure to reduce carbon emissions, reducing prices of renewable energy and others. Installed capacity grows slowly to a high of 271 GW in 2032, corresponding to the least coal scenario of the Integrated Energy Policy (Planning Commission, 2006, p. 46), and will reduce thereafter to 253 GW by 2047. The load factor of power plants remains at approximately 73% up to 2032 and increases to 74% in 2047. As a result, total electricity generated in 2047 from coal-fired power plants would be 1453 TWh.

In this scenario, new technology development/deployment will be slow. The addition of subcritical capacity will stop after 2022, ultrasupercritical technology will be introduced in 2027 and IGCC is introduced in 2037. The share of IGCC in the coal-fired capacity addition during 2042-47 would be 30%, and its share of the total capacity in 2047 would be 18.6 GW at Level 2 capacity addition, amounting to approximately 6%, while 64% of the capacity would be supercritical plant. The total demand for Indian grade coal in 2047 in this scenario is 1390 million tonnes.

Level 2

Level 2 projections are in line with Planning Commission's projections for next decade with a reduced growth rate thereafter. Installed capacity will grow rapidly to 297 GW in 2027, and then grow slowly to 333 GW in 2047 due to increasing coal prices, increasing import dependence and increasing pressures to reduce emissions. Average load factor is assumed to improve to 75% for the next two decades and to 76% by 2047. Total electricity generated from coal-fired plants in 2047 would be 1963.4 TWh.

New technology development/deployment will be slightly faster here than in the first scenario. The addition of subcritical plant will stop after 2017 as per current Government plans (Ministry of Power, 2012). Ultrasupercritical technology will be adopted after 2017 and IGCC after 2027. IGCC will contribute 50% of the capacity addition in 2047). The share of IGCC in the coal-fired capacity in 2047 would be 10%, and supercritical technology would have a share of 55%. Total demand for Indian grade coal in 2047 in this scenario is 1083 million tonnes.

Level 3

Level 3 assumes a coal-fired capacity addition slightly lower than that assumed for the 8% GDP growth scenario in the interim report of the Expert Group on Low Carbon Strategies for Inclusive Growth (Planning Commission, 2011, pp 41,42). The growth rate of capacity addition is assumed to reduce subsequently. In this scenario, installed capacity will grow to 381 GW by 2032, and then slow down to reach 459 GW by 2047. Current average load factor will improve to 77% for the next two decades and to 78% in 2047, resulting in total generation of 2798.5 TWh in 2047.

New technology development/deployment would be strongly encouraged in this scenario and hence its adoption would be faster. The addition of subcritical capacity would stop after 2017, ultrasupercritical technology would be adopted in 2022 and IGCC in 2027. IGCC's share of the capacity addition in 2047 would be 65%. In 2047, the share of IGCC in the coal-fired capacity would have increased to 20% and supercritical technology would have reduced to 43%. Total demand for Indian grade coal in 2047 in this scenario is 1057 million tonnes.

Level 4

Level 4 assumes a coal-fired capacity addition slightly lower than that assumed for the 9% GDP growth scenario in the interim report of the Expert Group on Low Carbon Strategies for Inclusive Growth (Planning Commission, 2011, pp 41,42). The growth rate of capacity addition is assumed to reduce subsequently. Installed capacity will grow to 591 GW in the next 35 years, that is, by 2047, due to improved domestic coal supply, softening of imported coal prices and availability of more carbon space to countries like India. Current average load factor will improve to 79% for the next two decades and to 80% in 2047, resulting in electricity generation of 3704.7 TWh in 2047.

In this scenario, new technology development/deployment will be aggressively promoted and adopted. There would be no more subcritical capacity installed after 2017. From 2022, 20% of new capacity addition would be ultrasupercritical technology and 20% of new capacity addition from 2027 would be IGCC. Of the capacity addition ending in 2047, 80% would be IGCC, resulting in a share in the total installed capacity in 2047 of 26%. Total demand for Indian grade coal in 2047 in this scenario is 1036 million tonnes.

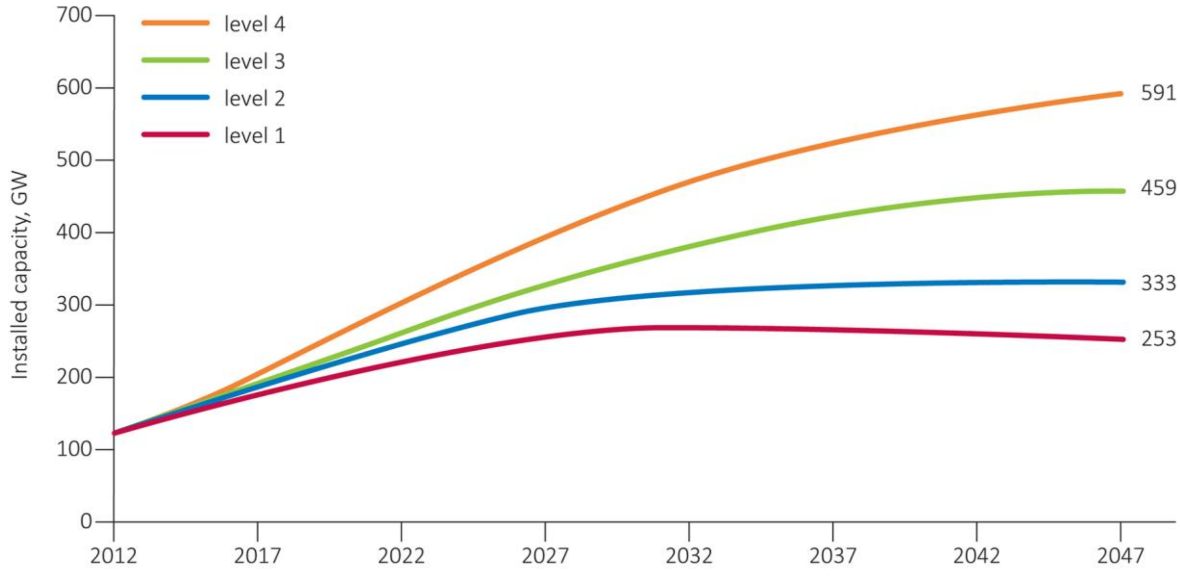

Figure 18 Installed capacity to 2047 predicted under four scenarios

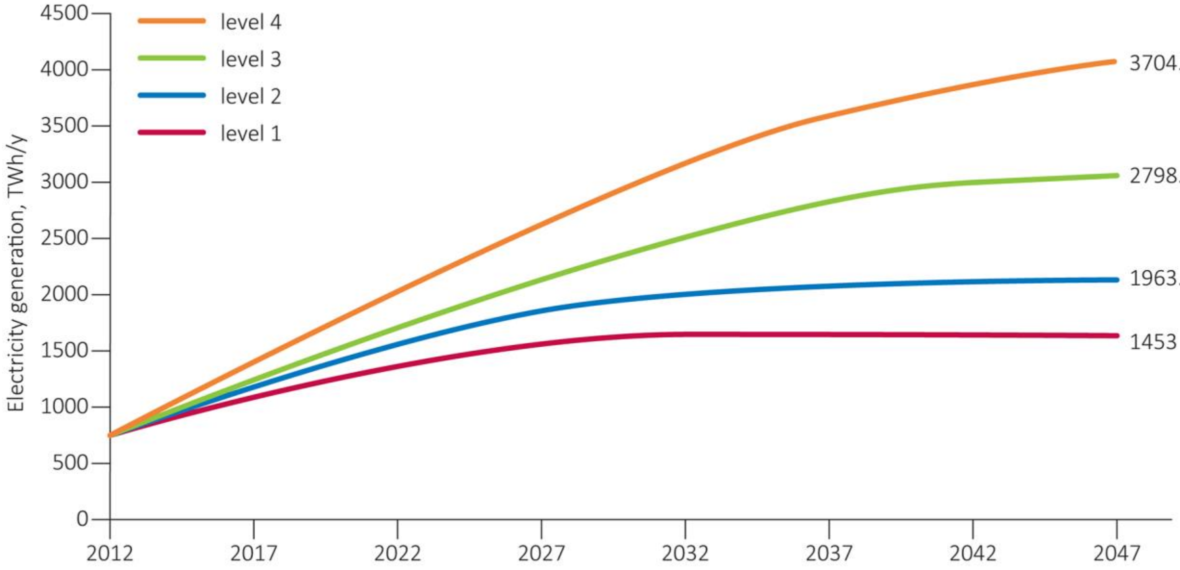

Figure 19 Electricity generated to 2047 predicted under four scenarios

The share of different technologies in total coal-based installed capacity for these four scenarios in 2032 and 2047 year are shown in Figure 20 and Figure 21. The subcritical technology based capacity that still exists in 2047 arises from existing capacity, which does not retire fully until 2047.

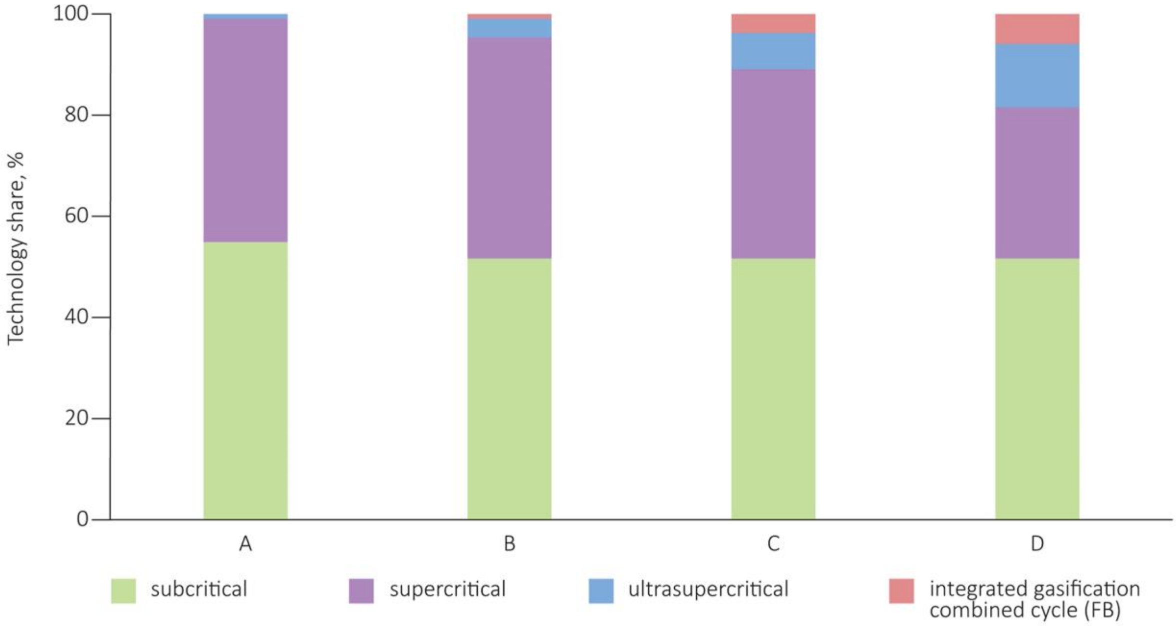

Figure 20 Shares of different coal-based power generation technologies in 2032

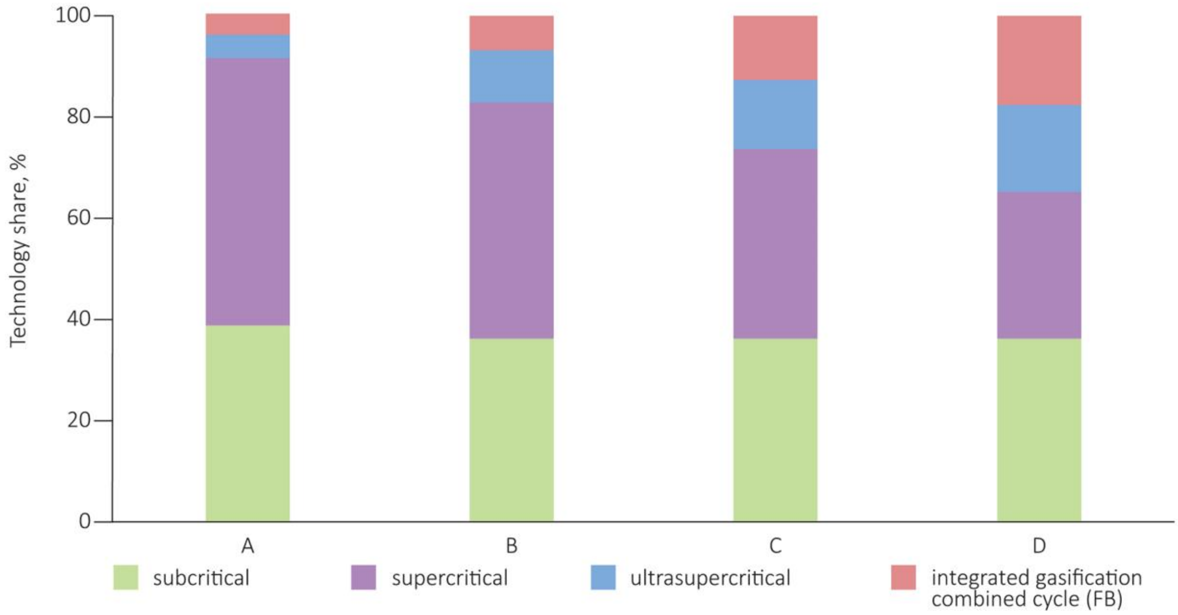

Figure 21 Shares of different coal-based power generation technologies in 2047

A set of assumptions was used in the exercise, specifically;

- Capacities modelled include utility and captive (tied to an industrial process) power plants fired by coal or lignite, although a lower load factor is assumed for the captive plant.
- Captive power plants are of smaller unit size and generally use less efficient technologies. Utility plants are assumed to be based on newer technologies such as supercritical technology.
- The coal-based power capacities have also been cross-checked with projected coal production scenarios to ensure that imports of coal for power production do not become unrealistic.
- The average life of a power plant is 40 years.
- Gross calorific value of Indian coal for power generation = 14.8 MJ/kg.
- Gross calorific value of imported coal = 23.0 MJ/kg.

The specific coal consumption for different technologies for high ash Indian coal are defined as follows:

Table 5 Specific coal consumption for different technologies utilising high ash Indian coal

Technology	Specific coal consumption (kg/gross kWh)
Subcritical (current India)	0.74
Supercritical	0.61
Ultrasupercritical	0.53
Integrated gasification combined cycle (IGCC)	0.50

Although the forecasts set out above are broadly in line with those of other organisations in respect of electricity demand and the role of coal in securing future supplies, the technology mix is questionable. A relatively minor role is envisaged for ultrasupercritical plant in the future coal fleet, with most added capacity being subcritical. Also, the 2047 scenario includes a significant role for IGCC-based plant. Industry observers opine that IGCC has presently failed to live up to its promise as a future coal-based option and so its significant inclusion in the future Indian coal fleet may be over optimistic.

4.1.2 World Coal Association analysis

Recognising India's growing role in the international coal market, the World Coal Association (WCA) has recently commissioned an external analysis to consider future demand, carbon dioxide abatement costs and levelised electricity cost for India (World Coal Association, 2015). Taking as its starting point, the projections of the IEA New Policies Scenario, the study notes that electricity demand in India is forecast to grow at over 4% per year. Under the New Policies Scenario, this translates to an installed coal capacity of almost 500 GW by 2040 (more than three times the 2012 installed capacity). The dominance of coal in India's energy mix can be attributed to two key factors: affordability and access. Although the competitiveness of renewables and gas-fired technology is likely to improve over time, coal is expected to remain the most affordable option through to 2035, driven by low domestic coal prices and limited gas availability. Since 2010, approximately 87 GW of new coal capacity has been added to the grid, of which 61 GW has been subcritical. By 2018, an additional 88 GW of new coal capacity is forecast to come on-line, with 32 GW of this subcritical. In addition, India currently has a further 292 GW of coal capacity in the planning stages. The IEA estimates that India will require around $1.2 trillion investment in power generation through 2040. Taking a 'broad brush' view to the impact of the future coal-fired generation fleet, the study sets out the impact on carbon dioxide emissions of the coal fleet based on the current development pipeline, a wholesale shift to supercritical technology and a completely ultrasupercritical fleet. The projected outcomes, along with the implications for carbon dioxide abatement in terms of subcritical plant closure, new wind turbines, and cars removed from the road are given in Figure 22.

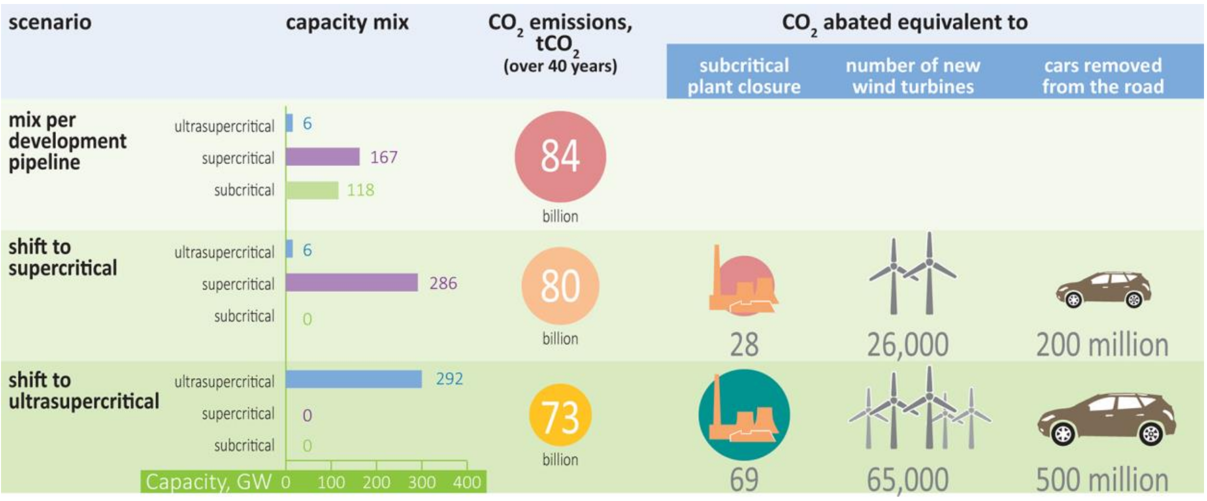

Figure 22 The potential environmental benefits of deploying cleaner coal technology in India (World Coal Association, 2015)

In the India Energy Security Scenarios 2047, it can be clearly seen that the preference is for supercritical technology with only a minor contribution from ultrasupercritical plant and no mention of the prospects for AUSC, despite India having an AUSC research and development programme. Savings in emissions of carbon dioxide are therefore relatively modest. Also, there is a relatively large contribution from IGCC plant over that projected for ultrasupercritical plant.

The WCA study sets out what might be achieved with ultrasupercritical plant (but again, no AUSC capacity is envisaged) and acknowledges that this prospect is some distance from the current development trend line which is focused on supercritical plant at best.

Both studies further highlight the risk that by basing new plant on supercritical steam cycles, India will find itself with a young, but relatively inefficient coal fleet to meet future energy demands.

4.2 Coal supplies and quality

4.2.1 Production

In recognition of the need to fuel India's future coal-fired fleet, Prime Minister Modi announced plans to double Indian coal production to 1.5 billion tonnes by 2020 (Marandi and Sharma, 2015). However, this target has recently been revised down to 900 Mt/y (Rowland, 2015). The Coal Ministry plans to auction 204 coal blocks that have the potential to produce 800 million to 900 million tonnes of coal and generate revenue of about 7 trillion rupees (US$121 billion). Indian coal reserves are mostly located close to the surface and are recovered by opencast (surface) mining. That said, some reserves are located below population centres or in inaccessible forests where surface mining approval is also difficult to obtain so it is likely that these will be accessed via underground mining. Coal occurring at depths greater than 300 metres is usually economically extractable only with underground mining techniques. In a recent analysis by the IEA on Indian coal, their projections indicated that future production is likely to be dominated by surface mining, which has been the main source of growth in supply over the last decade, although the projected share of underground mining rises steadily from the mid-2020s to reach 12% by 2040 (Figure 23).

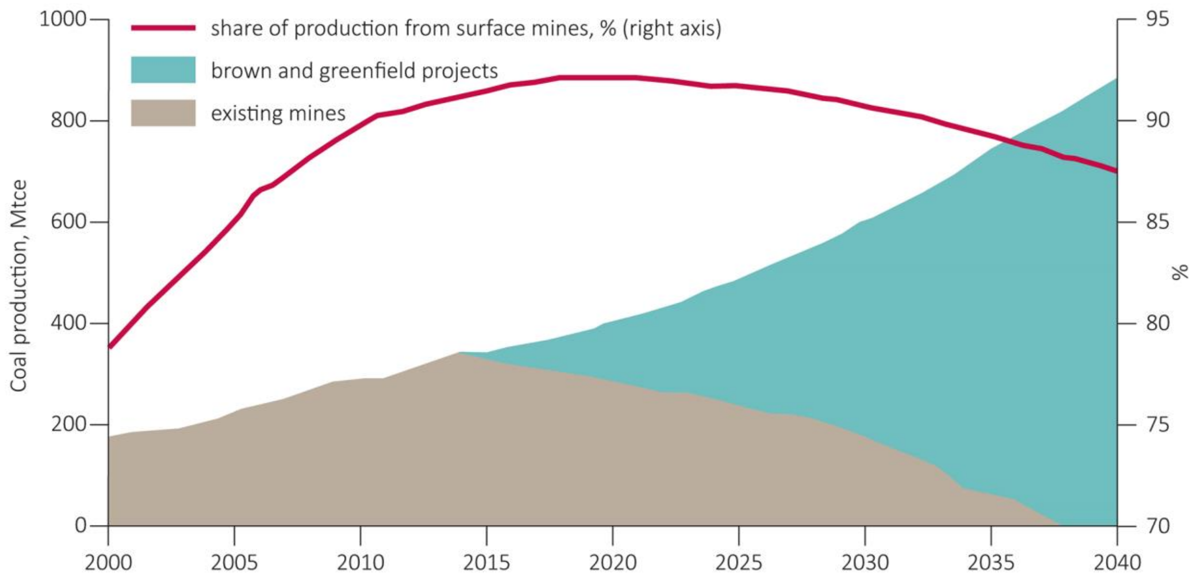

Figure 23 Coal production by type of mine and share of surface mines in India in the IEA New Policies Scenario (IEA, 2015)

The shift towards underground mining is increasingly necessary to sustain production growth. Even where the depth of the reserves may theoretically allow for surface mining, in many cases underground mining may be preferred as it avoids disturbance of the land and settlements over the deposits, accelerating mine approval. The New Policies Scenario assumes that efficient and highly mechanised underground technology (as found for instance in China, Australia or the USA is gradually adopted by the coal industry in India over the Outlook period; the speed at which new technologies are adopted in practice will be related to the extent to which the sector is opened to competition. However, supply chain problems have left many plants stranded without a steady coal feed (Carrington, 2014). Prasad and Prasad (2015) suggest that delays on environmental clearances for new coal mines are the reason for the gaps between supply and demand. The state-owned Coal India provides 80% of the coal but has faced significant production delays – 60 of the country's 103 coal-fired power plants had less than a week's supply of coal on hand in 2013-14. It is therefore not surprising that many Indian companies are investing in overseas coal mines (Shearer and others, 2015). Indian ports reportedly saw a 24% increase in coal imports between April and July 2015 (Rowland, 2015). There is also the issue of the transport and supply chain – lack of road, rail and ship interconnectivity causes significant delivery issues and investment in new equipment, both in the mining and transport sector, is lacking (Prasad and Prasad, 2015).

4.2.2 Quality

Indian hard coal is mostly bituminous, with relatively low moisture but high ash content. Three-quarters of current coal production has an ash content of 30% or greater, with some of the highest ash coals approaching 50%. In comparison, coal traded on the international market rarely exceeds 15% ash content. The majority of the ash in Indian coal is so-called inherent ash, that is small particles of mineral matter that are embedded in the combustible part of the coal. Contrary to free ash – mineral impurities that are related to the extraction process – inherent ash cannot easily be removed from the coal. The high-ash content reduces the calorific value of the coal. Most of the coal currently produced in India falls in a range of 14.6 MJ/kg to 20.9 MJ/kg. This is markedly lower than the average heat content of coals typically found in other large producing countries, such as China, the USA or Russia.

Indian coal-fired power plants consume around 0.7 kg coal/kWh whereas plants firing low-ash coals consume only 0.45 kg coal/kWh (lower average thermal efficiency is the other main reason) (Bhushan and others, 2015; Barnes, 2014). The whole of the coal chain is therefore involved – from the production, movement and handling of coal, much of which is incombustible, to the disposal of excess ash. However, data suggest that coal washing to remove ash is only economical for plants which are bringing in coal from over 400 km away. The CPCB (Central Pollution Control Board) has set a cap of 34% on ash in coals which must travel over 1000 km.

4.2.3 Transportation

Indian Railways move around 52% of the coal that is mined in the country, a share that's expected to rise significantly with the government's ambitious plans to increase coal production. However, Indian Railways has suffered from considerable under-investment in the past and coal supply logistics are often complex and uneconomic with coal sometimes being transported long distances where a local market could equally well be served (Figure 24). Also, the railways are facing severe capacity constraints and freight transportation costs by rail are much higher than in most countries as freight tariffs in India have been kept high to subsidise passenger traffic. The delays in coal delivery are a frequent cause of power blackouts as crucial deliveries are delayed. India's plans for an expanded power sector depend critically on rail links between ports, mines and their customers. In 2015 a White Paper was published setting out a programme of investment and restructuring to improve the situation involving important stakeholders such as the Coal Ministry.

Figure 24 Clearing coal from railway tracks

Early indications are favourable and in late 2015, the Coal Ministry agreed with the Railway Ministry a programme of investment in additional railway rakes – a rake is a group of coupled freight wagons, excluding the locomotive, that typically move together. Coal India agreed to fund the procurement of the new rakes which will be used for transportation of coal from mines to ports or plants. In the first phase the railways will procure approximately 3000 high capacity rakes to serve the South East Central coal sector and the East Coast circuit. These rakes will be introduced into existing circuits to transport coal from the MCL Talcher and IB area and South Eastern Coalfields Ltd to the ports of Paradip and Dharma, Vishakhapatnam area and the utility plants located in the Nagpur and Raipur regions.

The availability of rakes from the Indian railways for transportation of coal has improved in recent years. While the average rake availability was 180 in 2015, it has improved to 205 rakes in 2016 according to a senior coal ministry official (Srinivasan, 2015).

4.2.4 Coal issues for HELE plant

As noted above, indigenous Indian coal is high in ash, and consequently low in energy content, as-fired. Furthermore, although the ash content can be reduced by washing, there is a limit to what can be achieved given the intimate association of the mineral matter with the carbonaceous coal structure. Utilising high ash coal for power generation presents a number of issues, including the need to size the plant appropriately to process a greater quantity of material than would be the case for a low ash coal. This leads to a significant quantity of post-combustion ash that must be managed and, ideally, utilised. Inside the boiler a high ash loading can be associated with boiler tube erosion. If the ash contains low melting components, slagging and fouling deposits form in the boiler gas pathway. These issues are often cited as reasons why the majority of Indian plants operate with a subcritical steam cycle and new plant operating on supercritical and some ultrasupercritical has only been recently introduced. Industry observers report that the transition to ultrasupercritical plant may not take place in the Indian power generation sector until 2025; at this point other countries may be commissioning AUSC plant (Trueby, 2016).

These 'Indian coal-specific issues' may have been legitimate in the past, but in today's fully-globalised power equipment market there is a wide range of experience in utilising any type of coal, including high ash variants. Indeed, commercial companies such as Doosan Babcock are offering ultrasupercritical plant fuelled by high ash coals to the Indian market and have recently won a contract to supply such technology in the form of a 660 MW unit based at Harduaganj (Welford 2016). They also have three other projects at the proposal stage. Harduaganj and two other projects use indigenous Indian coals with ash contents typically in the range 35–45%, corresponding steam conditions are marginally below 600°C which is above the benchmark of 580°C reported by Nalbandian (2008). The fourth project (Jawarharpur) has steam conditions in excess of 600°C, although this is not firing exclusively Indian coal (Table 6).

Table 6 Recent power projects in India (Doosan Babcock)

	Harduagan (660 MW x 1)	Panid (660 MW x 1)	Obra (660 MW x 2)	Jawaharpur (660 MW x 2)
Steam conditions	280kg/cm^2, 596/596 °C	280kg/cm^2, 596/596 °C	280kg/cm^2, 596/596 °C	280kg/cm^2, 603/603 °C
Boiler maximum continuous rating	2065 t/h	2065 t/h	2105 t/h	Add 1% make-up to feedwater
Main fuel	Indian coal	Indian coal	Indian coal	Indian coal/imported coal
Gross energy content (MK/kg)	15.5	15.5	15.5	15.5
Initial deformation temperature (°C)	1200	1200	1200	1200
Moisture content (%)	10.5	10.5	10.5	10.5

BHEL, which builds the majority of India's coal-fired power plants, has not yet developed or licensed ultrasupercritical technology as it previously did for supercritical technology (Alstom for boilers and Siemens for steam turbines).

Looking ahead to the commercial availability of AUSC technology, Babcock & Wilcox have described the detailed design considerations for an 840 MW modified tower boiler incorporating an AUSC steam cycle (Weitzel and others, 2012). They noted that Indian coals that are widely used for new power projects are generally low in sulphur and therefore have a reduced likelihood of fireside corrosion problems. However, the ash content of Indian coals is very high, as is the silica/quartz content, making it very erosive. Thus, much lower gas velocities are required when passing through the convection tube banks, typically 50% less than a higher-grade USA coal. Special erosion protection provisions are also required on the pulverisers and boiler components. The size of the gas flow area increases about 50% and the amount of heating surface increases due to lower heat transfer rates. Compared to a boiler using US eastern bituminous coal, the furnace of a boiler using Indian coal is about 78% larger in volume and about 50% taller. The furnace width is about 38% more, impacting the length of the nickel alloy superheater/reheater outlet headers (Figure 25).

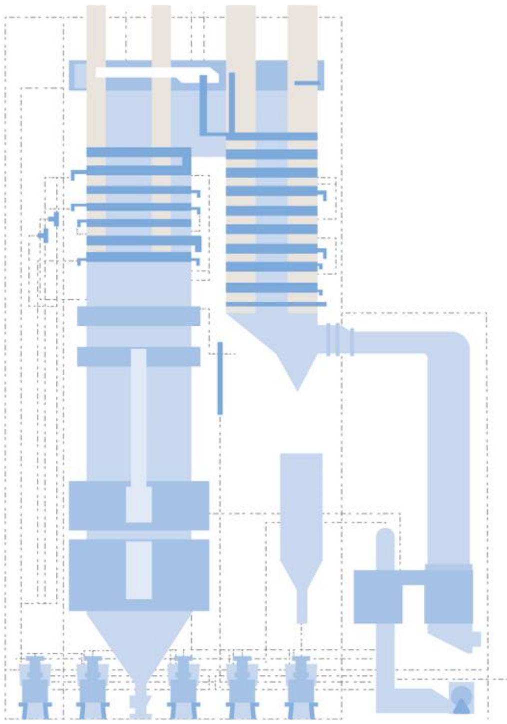

Figure 25 Conceptual design of an 840 MW modified tower based on AUSC technology.

Furnace wall average absorption rates are lower while the peak rates will be expected to be nearly the same. Staged firing for nitrogen oxides (NOx) reduction may be incorporated where regulations mandate it. Welford (2016) has noted that Indian high silica coal ash forms quickly on surfaces as loose agglomerations of tiny particles which present a highly effective insulating layer. This effect needs to be minimised through the removal of the material on a very regular and frequent basis without causing erosion problems. This can be achieved using a sootblowing system which operates more frequently but at lower pressures. He concludes that there does not seem to be an insurmountable barrier to the use of ultrasupercritical steam conditions with domestic Indian coals.

Industry workers have commented that the slow transition to ultrasupercritical, as compared to developments in other countries such as China may arise from a generally conservative approach to the technology, and a desire to gain 'home grown' expertise and experience with one type of system before moving on to the next (Gautam and Kumar, 2016). While this is understandable, there is a large body of experience in building and operating ultrasupercritical plant available both inside India through the UMPP, and externally through global players in the power market. This makes a reluctance to switch to exclusively ultrasupercritical plant harder to understand. Limits in domestic manufacturing capacity and a focus on sourcing plant based on Indian developed technology are also thought to be responsible for a bottleneck in supplying new ultrasupercritical plant (Trueby, 2016).

4.3 Technical services for HELE plant

Advanced steam cycle plant presents an issue with respect to its efficient operation and maintenance. For example, specialised welding skills are required for the installation and replacement of the tubing required for the more demanding steam cycles. The absence of such skilled workers can severely limit the introduction of more advanced plant, and may even force a downgrade to a less efficient steam cycle (Smouse, 2016). Industry observers have noted that there is a dearth of service providers in the Indian power sector (Krishnan, 2016). While the policy makers may be aware of these shortcomings, they have yet to put in place incentives to expand the network of service providers. Unlike the developed countries, the service industry in the Indian power sector has not kept pace with the growth of the power industry. The expertise lies mainly with the few Original Equipment Manufacturers (OEM) and non-OEM have neither the technologies nor resources. There is scope for capacity building in this area and it is necessary if the most modern HELE plant are to feature in India's future coal fleet.

4.4 The Indian AUSC development programme

A recent and promising development in improving the efficiency of India's coal fleet is the announcement of an accelerated programme for developing a power plant based on an AUSC steam cycle (Tech2, 2016). The Cabinet Committee on Economic Affairs, chaired by Prime Minister Narendra Modi, has approved a proposal for this development at an estimated cost of Rs 1554 crore (over US$230 million). The central government will provide one-time budgetary support, by the Department of Heavy Industry (DHI), of Rs 900 crore spread over three years, commencing from 2017-18, to power equipment major Bharat Heavy Electricals Ltd (BHEL) to implement the R&D project. There will be contributions of Rs 270 crore from BHEL, Rs 50 crore from power generating company NTPC Ltd, Rs 234 crore from IGCAR and Rs 100 crore from the Department of Science and Technology (DST). Under the plan, the Indira Gandhi Centre for Atomic Research (IGCAR) will develop the material for an 800 MW AUSC boiler that can operate at a pressure of 3.1 MPa and at a temperature of 710°C. The power equipment manufacturer BHEL will design and manufacture the boiler and other equipment while the power generator NTPC will be the end-user to produce power. IGCAR's director, Arun Kumar Bhaduri, said: "The research, development and design phases of the 800 MW advanced ultrasupercritical (AUSC) boiler for coal power plant will be ready by 2019-20. The timeline for the construction of an actual 800 MW power plant with AUSC boiler would depend on the regulatory approvals for the plant design and the funding of the plant construction." When asked about the 800 MW capacity instead of higher one such as 1000 MW, Bhaduri responded: "The capacity was decided taking into account factors like cost to power ratio and others." He suggested that once the first 800 MW AUSC boiler powered thermal power plant starts operations the capacity may be re-evaluated. He said that NTPC will decide on the location of the 800 MW AUSC boiler power plant and it will probably be located adjacent to one of NTPC's existing power plants.

4.5 Summary

The developments in steam cycle technology that have led to ultrasupercritical plant (the current state-of-the-art) and offer the prospect of advanced ultrasupercritical plant within a decade have been shown to give strong positive gains in terms of efficiency and a reduction in emissions, particularly of carbon dioxide. When India's coal-fired electricity generation sector is modelled against an aggressive policy of introducing the best plant at the earliest date, significant benefits may be achieved. However, current policy seems to concentrate on a gradual introduction of new capacity based on ultrasupercritical plants which, if followed, will leave India with a largely less efficient coal fleet for the foreseeable future.

This cautious approach has been associated with issues of coal quality and coal availability. A programme of restructuring and modernisation is tackling the latter bottleneck, but there is a persistent reluctance to embrace ultrasupercritical technology because of the high ash content of Indian coals. International experience suggests that there is no insurmountable problem with employing ultrasupercritical technology or even AUSC technology with Indian coals. The recently announced Indian AUSC development programme is promising and it is hoped that this will lead to the establishment of an AUSC option for new plant in the near future.

5 Funding HELE upgrades

India requires significant investment in new power capacity to meet the projected growth for electricity. Figure 26 illustrates the investment needs of the power sector for new capacity and associated transmission and distribution under three scenarios (IEA, 2015).

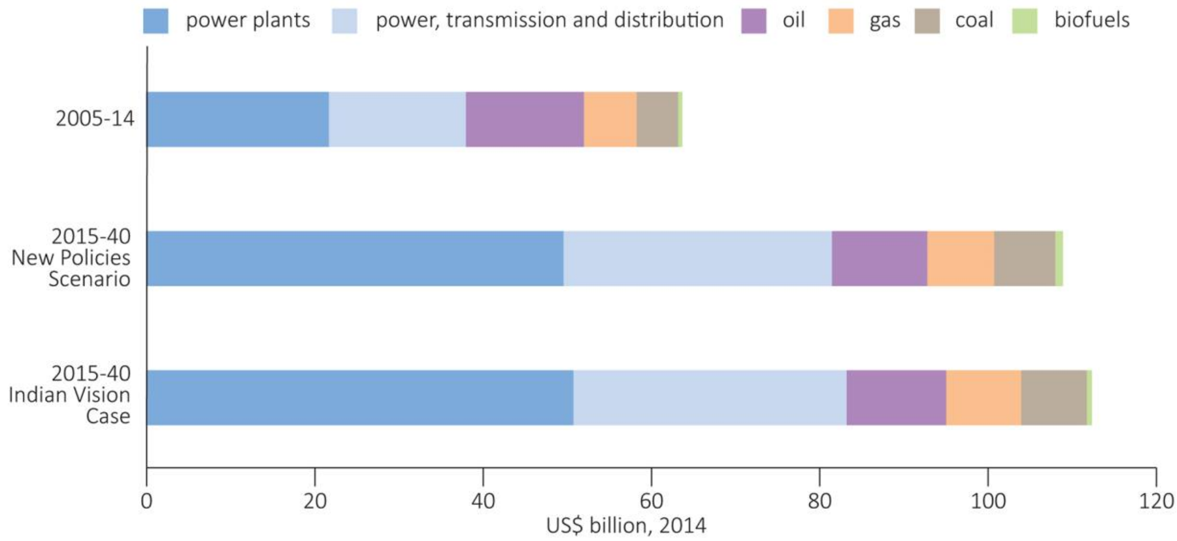

Figure 26 Average annual investment in energy supply in India in the New Policies Scenario and the Indian Vision Case (IEA, 2015)

Investment on the scale required will require a portfolio of investors in Indian energy. Government priorities in addition to energy will place great demands on the public purse and so a greater private participation in energy infrastructure projects is likely to be required. International investors, too, are likely to play a greater role. The investment climate is superficially attractive given India's size, its growth potential and a reforming administration keen to increase private and international participation. But doing business in India has long been regarded as challenging with complex administrative procedures and ambiguous boundary lines between national, state and local institutions.

The three main external sources of capital for financing the power sector would appear to be: public funds; domestic savings, channelled via the banking system or Indian capital markets; and international capital flows, including development finance. Until recently public financing and equity capital from the banking sector, together with some development finance and funding from Chinese equipment manufacturers, has met the capital needs of the Indian power sector. But the very substantial new capacity requirements taken together with a set of associated risks over political, regulatory, technological, and financial aspects affect the commercial viability of new projects and so additional sources of funding must be secured.

The Indian government has responded by developing new financial instruments such as India's Infrastructure Debt Funds. These are investment schemes designed to promote the flow of long-term debt into infrastructure projects. International financing, which may be a cheaper source of capital, requires a currency hedge to protect against the risk of devaluation and the Indian government has shown interest in providing such a government-sponsored currency hedging facility (Climate Policy Initiative, 2015).

At a time when multilateral funders such as the World Bank have stopped supporting nearly all coal-fuelled power projects, Japanese lending institutions and banks have been offering loans to construct high efficiency coal-fired plant. Energy minister, Piyush Goyal, has held meetings with Japanese institutions who are keen to finance the coal-based thermal power plants (Livemint, 2015). The state-owned generator, NTPC has already received 25.8 billion yen in loans from the Japan Bank for International Cooperation (JBIC) and the Japan International Cooperation Agency (JICA).

The Government of India set up a National Clean Energy Fund (NCEF) in 2010 by imposing a tax on coal at an effective rate of 50 rupees per tonne. The government expects to collect 10,000 Rupees crore under the Clean Energy Fund by 2015. The NCEF will support projects, programmes and policies that promote clean energy technologies. This fund can be used to establish a focused investment vehicle for companies investing in green technology, and environmentally supportive businesses such as renewable energy, green transport, and water and waste management among others. Mr Anil Razdan, the former Secretary for Power, has suggested that the coal levy (currently Rs 400 per tonne) that contributes to the renamed Clean Environment Cess (formerly known as the National Clean Energy Fund) could usefully be expanded to include clean coal technologies such as new HELE capacity (Razdan, 2016).

6 Concluding remarks

India is experiencing a period of rapid growth and urbanisation, and for the foreseeable future will experience substantially increased demands on its primary energy supply. Although the country is embracing energy technologies of all types, including an aggressive renewables drive, unless an unexpected transforming technology development occurs, coal will continue to play a fundamental role in meeting India's energy needs. India has significant reserves of coal, albeit of relatively low quality, and current initiatives show that it is conceivable that sufficient indigenous coal can be mined to meet predicted requirements, without the need for coal imports, other than for specialised purposes such as steel manufacture. Furthermore, progress is being made in improving the quality of that coal by investing in advanced mining techniques and implementing coal upgrading such as coal washing at local mines.

Transportation still remains an issue, with coal movements hampered by poor scheduling and logistics, but the fast-track construction of additional railway lines and reorganisation of relationships between the main stakeholders promises to improve this key sector.

There is a need for a substantial increase in coal-fired capacity. Thus, it is socially and economically imperative that such plant are of the highest efficiency and have inherently low emissions. This would enable power to be produced without endangering the health of the population and India would be able to comply with international commitments on transnational emissions such as carbon dioxide. This is, by definition, HELE plant.

India's coal fleet is relatively young, predominantly subcritical but with a large tranche of future capacity planned or under construction. However, the future capacity that is planned is largely supercritical, rather than the current state-of-the-art ultrasupercritical technology that has been extensively proven in other countries. Indian projections and current policy seem to indicate that this trend will continue in the near future. This would seem to be a missed opportunity for India to ensure that it has the most efficient and modern plant to drive its economic growth; lower efficiency plant built in preference to the best HELE alternatives now would be 'locked in' to the generating sector for the lifetime of that plant, which could be as long as forty years. That said, there are still prospects for improving the performance of lower efficiency plants through a carefully designed programme of analysis and improvement such as those that have been demonstrated elsewhere in the world.

The choice of subcritical, and now supercritical plant, over more advanced options is attributed to a cautious and conservative approach, gathering 'home grown' experience on plant performance and maintenance in the light of challenges posed by India's high ash coal resource. While this was undoubtedly a reasonable approach where power generation technologies were developed and built using regional skills and facilities, in the modern globalised power market significant experience exists in dealing with a wide range of coal types, and manufacturers are prepared to design and offer high performance plant to burn even the most difficult coals, with full commercial guarantees. Fortunately, recent developments show that the Indian market is becoming more receptive to ultrasupercritical as the technology of first choice, and the recent initiative on AUSC development is promising, but there is still much to be done to avoid the Indian coal fleet becoming locked into mainly supercritical plant.

Air quality in India is already a pressing issue and the planned increases in coal-fired capacity will only add to the problem unless strong measures are taken to ensure that new plant is fitted with the latest abatement technology, and through enforcing emission limits for existing plants. As things stand, the possibilities for monitoring and enforcing are limited owing to the diminished capacity of the regulatory body. Capacity building here would repay the expenditure in terms of improved air quality and measures to encourage the building of HELE units. Capacity building is also required in the more general area of plant operation and maintenance to ensure that a trained workforce exists to build and maintain the more demanding HELE plants.

New capacity has to be paid for and with India's growing prosperity there is now relatively little need to access loans from the international financing institutions. Internal sources of liquidity and commercially-based international finance are the most likely funding routes for new coal-based power plant and there are interesting developments with the latter in the example of Japanese-backed loans for HELE technologies. India's natural source of funds for new developments, the revenue from electricity sales is beset with difficulties arising from lack of payment and historic debts. These issues are being dealt with by restructuring the distribution companies and their balance sheets, but it will take time before they are more commercially active. In the meantime, and perhaps in addition, there might be opportunities in investigating an expansion of the role of the coal levy that contributes to the Clean Environment Cess (formerly known as the National Clean Energy Cess) to include clean coal technologies such as HELE.

The slowdown in economic growth that is affecting the world includes India and has led to a number of new power plant plans being mothballed for fear of them becoming stranded assets. Indeed, the Indian government has encouraged a three-year hiatus until conditions improve. This might also be considered an opportunity to reflect and review policy on the choice of technology for new coal-fired plants, and ways of funding them.

Finally, India and its institutions have been described as 'vast, interrelated, and complex' and this is certainly borne out when considering some of the complexities of the electricity generation and distribution sector and the interactions between national and state governments. It is to be hoped that the modernising reforms currently being enacted by the government are successful in delivering clean efficient power to India's people, now and for tomorrow.

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