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US-India Cooperation on Clean Coal

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Abstract

One of the essential elements in the US-India bilateral relationship on energy has been cooperation on the use of coal in a clean manner. Supported by the United States Agency for International Development (USAID), the Department of Energy (DOE), laboratories, and utilities in the United States, the core of clean coal activities in India over the past several decades has been to introduce, demonstrate, and commercialize new technologies and practices to promote better utilization of coal in order to lower greenhouse gas and other pollutant emissions while promoting energy security. Starting in the mid-1980s, the US team, in partnership with the Indian Ministry of Power, NTPC (previously, the National Thermal Power Corporation, India's largest state-owned utility), and several state utilities, has worked to improve the operations and performance of India's power plants. These have included coal beneficiation, heat rate improvement, optimal blending techniques, and the introduction of best Operations and Maintenance (O&M) practices. The DOE/USAID support for India's research on advanced gasification of coal technology was also a part of the clean coal activities, which built capacity and demonstrated results, but awaits deployment. USAID's clean coal projects in India were designed to reconcile three key aspects, namely, the abundance of coal, need for energy, and sustainable energy utilization.

Keywords: India, United States, NTPC, heat rate, power plant, plant efficiency, clean coal, coal gasification, carbon capture and sequestration, PACE

20 July 2020

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US-India Cooperation on Clean Coal

Introduction

India and the United States share long-standing and vibrant cooperation on clean coal technologies and practices, supported by the governmental agencies, research laboratories, academic intuitions, power utilities, and energy industries of both countries. Clean coal technologies and methods enable power plants to burn coal but emit far less carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions, as well as pollutants, such as nitrogen oxides (NOx), sulfur dioxide (SO_2), and particulate matter (PM). When the two nations started to engage in clean coal activities in the early 1980s, coal was the chief source of energy for power generation worldwide, not least in India and the United States. However, both nations recognized the several challenges emerging from coal utilization.

Since the beginning, the US Department of Energy's (DOE) National Energy Technology Laboratory (NETL), and its predecessor organizations, supported the implementation of several of the United States Agency for International Development (USAID)'s energy and environment initiatives to advance the cleaner use of coal in India. The US government, through several bilateral and multilateral processes with the Government of India (GOI), including the US-India Strategic Energy Dialogue, the Asia-Pacific Partnership on Clean Development and Climate, Partnership for Advancement of Clean Energy (PACE), and US-India Strategic Energy Partnership (SEP), have sought to promote better coal utilization. Clean coal programs and activities were designed to address India's energy security needs and sustainable energy use while utilizing the technical expertise, technologies, and best practices from the United States.

India ranks third in global coal production, producing about 730 million metric tons (mt) of coal during India's April 2018-March 2019 financial year, the majority of which, approximately 85 percent, was used for thermal power generation. Coal is the dominant source of electricity in India and currently accounts for 72 percent of the supply and 55 percent of total installed capacity, which implies that the coal-fired generation runs at a higher utilization rate than any other source of electricity. India's 2017 draft national energy policy expects coal-fired capacity to grow between 330 and 441 gigawatts (GW) by 2040, which translates into thermal coal demand of between 1.1 and 1.4 billion tons. This demand, when combined with the growth in demand from coal-consuming industrial sectors, like steel, proves that coal will retain a significant part of India's primary energy consumption mix in the next couple of decades.

Coal is plentiful and affordable, and many developing economies, like India and China, which have large reserves. prefer low-cost domestic fuel sources. Coal, whose supply is usually highly reliable, makes for a particularly good baseload fuel. Because coal plants had been an economical option to generate electricity until about ten years ago, they were relied upon to generate about half the supply in the US. That has changed dramatically with the availability of plentiful cheap natural gas from shale resources and the falling cost of wind and solar technologies. Nonetheless, global concern about climate change and greenhouse gas emissions from coal-fired power generation necessitates the use of cleaner coal and clean coal technologies by countries such as India, which has one of the most carbon-intensive electricity systems in the world. India's coal-based thermal power plants also use high-ash indigenous coal that compounds the problem of GHG s and other emissions.

US-India clean coal engagement began in the early 1980s and continues to this date. Through a suite of initiatives undertaken by USAID and DOE, implemented between 1982 and 2010, Indian utilities were introduced to a wide and developing range of clean coal technologies and best practices. These projects, carried out by the USAID team in partnership with Indian power plants, led to the improvement of their operational efficiency and environmental performance. Efficiency in power generation means that less fuel is used to produce the same amount of electricity. According to the International Energy Agency (IEA), a one-percentage-point improvement in the efficiency of a conventional pulverized coal (PC) plant results in a 2-3 percent reduction in CO_2 emissions.

US-India clean coal engagement has continued under the aegis of the India-US Partnership on Clean Energy (PACE). Launched in 2009, the PACE activities were in the areas of energy research (PACE-R), deployment (PACE-D), and access (PEACE). In July 2012, USAID launched the PACE-D technical assistance (TA) program, a six-year plan to deploy projects relating to energy efficiency, renewable energy, and clean energy finance. The activities under the Clean Fossil component, one of the key modules of the PACE-D TA – started in August 2012 and closed in October 2014 – built upon USAID's clean coal work through the past three decades. During this period, USAID and several US state agencies and energy research laboratories assisted NTPC and several state utilities with improving their supply-side efficiency by introducing advanced technologies and management practices.

Through the Power & Energy Efficiency Pillar of the SEP inaugurated in April 2018, DOE is funding Electric Power Research Institute (EPRI) and working with NTPC to develop a coal power plant flexibility toolkit to identify and prioritize critical plant design and operational issues during flexible operations. Coal-fired power plants built and operated as baseload systems, can be 'cycled' i.e. remodelled and retrofitted to operate as load-following and ramping systems, to support variable power generated from renewable capacity, such as solar and wind plants, as well as stabilize the grid frequency. USAID is also funding Deloitte/Intertek to work with NTPC and other state utilities on coal power plant flexibility to address the variance and intermittency of RE generation in a large multi-year Greening the Grid (GTG)-Renewable Integration and Sustainable Energy (RISE) project. The work relates to economics of cycling (including cycling start costs, load following & ramping costs, operations & maintenance costs, and environmental impacts); regulatory provisions; operational practices; compensation for coal plant's flex services; and digitization to support the entire commercial operations and maintenance strategy.

The Indian government, through policy interventions, is incentivizing the production and utilization of renewable and natural gas in the energy mix to curb emissions and meet the Paris Agreement's long-term temperature goal. However, reducing large-scale emissions from Indian coal power generation facilities would be difficult to achieve because many will remain commercially competitive and/or other generating options are not yet available.

The availability of low-cost shale gas in the United States has shifted dependence away from coal-fired generation. Coupled with the competition from renewables and rising concern over coal's impact on global warming, the US coal sector has been in steep decline over the past decade. While the United States has achieved notable reductions in CO_2 emissions led by its power sector, many of its coal-fired facilities will continue to operate till 2040. In recent years, the US government has provided significant research, development, and deployment support to advanced coal power generation, including high-efficiency, low-emission (HELE) technologies, and carbon, capture, utilization, and storage (CCUS) technologies, which prevent the release of CO_2 generated through conventional thermal power generation and industrial processes to the atmosphere through carbon capture processes. The greenhouse gas is then stored in underground formations, such as depleted oil and gas reservoirs, unmineable coal seams, deep saline formations, and possibly deep ocean. These 'frontier technologies' offer a promising new prospect for a future Indo-US partnership on clean coal.

Clean Coal Program and PACE: Projects and Processes

USAID's Clean Coal Program and Cleaner Fossil Component of the PACE initiative, included research and development (R&D), training, and commercial energy research. The following sections detail the technologies and best practices, which were demonstrated, deployed, and commercialized during the execution of the clean coal and cleaner fossil projects.

AERD: IGCC Clean Coal Technology

The Alternative Energy Research and Development Project (AERD, Phases I & II, 1982-1992), was designed to help India develop combustion technologies compatible with high ash coal and related test facilities to enable cleaner power generation while reducing pollution. It was sponsored under the coal component of the AERD project of USAID, the other component being biomass. The NETL and Oak Ridge National Laboratory (ORNL) provided technical support to Bharat Heavy Electricals, Ltd. (BHEL) and the Tata Energy Research Institute (TERI, now The Energy Research Institute), the collaborating Indian institutions.

In the area of conventional pulverized coal combustion, the AERD project assisted select Indian utilities in developing pollution control strategies for reduction of NO_x and SO_x emissions from coal-fired plants. Because of the inferior quality of Indian coal due to high ash content, the material degradation in power plants is a common phenomenon, affecting plant reliability and expenditure. The EPRI and North American Electric Reliability Council (now, North American Electric Reliability Corporation) provided BHEL with diagnostic techniques, practices and methodologies to perform Remaining Life Assessment (RLA) of critical power plant system components .[1] RLA involved a comprehensive review of the power plant's operational history and failures, evaluation and verification of root cause of deterioration, evaluation of potential solutions, and identification of upgrade options, enabling renovation and modernization (R&M) to improve their efficiency, availability and reliability. Following the initial demonstration, RLA best practices were widely adopted in India.[2] This area was a high priority in the Indian power sector, as R&M activities of power plants were a major part of the proposed capacity addition.

Beginning in the mid-1980s, USAID assisted BHEL with establishing two state-of-the-art, pilot-scale facilities for fluidized bed and pulverized coal combustion at BHEL's R&D facility in Trichy, and assisting with its research on integrated coal gasification combined cycle (IGCC) technology development.[3] In IGCC technology, a series of processes convert coal into clean-burning, synthetic gas (syngas), which is stripped of pollutants and impurities and then fired into a gas turbine to produce power, with heat recovery from gasification providing steam to produce more electricity. Gasification of coal can be a clean method to utilize coal, while generating power using combined cycle technology at high efficiency with the ability to capture CO_2 prior to combustion.

USAID supported BHEL's pioneering 6.2-megawatt (MW) IGCC pilot facility at Trichy, Tamil Nadu, including procurement of diagnostic hardware from US vendors. With technical assistance from NETL on the gasifier design and overall process, the Trichy plant successfully demonstrated combined-cycle power generation using high-ash indigenous coal, by supplying 400,000 kilowatt-hours (kWh) of power to Tamil

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[1]R.P. Krishnan (October 5, 1990), *Report of Foreign Travel to India*, Development Staff Member, Engineering Technology Division, Oak Ridge National Laboratory, Oakridge, Tennesse.

[2]USAID, USDOE, and NETL, *USAID-USDOE/NETL Cooperation on Clean Energy and Environment: A Legacy of Partnership and Accomplishment*, June 2013.

[3]Ibid.

Nadu Electricity Board (TNEB).[4] With insights gained from training at US IGCC facilities, BHEL's engineers succeeded in improving their gasification unit to generate power in the IGCC mode in 1998. The $3.2-million demonstration plant, commissioned in 1989, was Asia's first and the world's second coal-based IGCC plant at any scale.[5] It was generated a wealth of data on basic processes, design, and engineering that is valuable for a scale-up commercial plant.

On September 11, 2000, DOE, USAID, India's Ministry of Power, and the NTPC signed a Protocol of Intent to conduct a detailed technical and economic feasibility study for setting up a commercial-scale IGCC demonstration plant in India.[6] It followed the signing of a Joint Statement on Cooperation in Energy and Environment on March 2000,[7] during US President Bill Clinton's visit to India that articulated the desire of both countries to increase their energy and environment cooperation.

In 2002, USAID, in partnership with the NTPC, sponsored a $2.5-million IGCC feasibility study under NETL's technical supervision as part of the technology demonstration activity of the Greenhouse Gas Pollution Prevention Program (GEP) project. The study, completed in 2006, recommended a demonstration project of 100-MW utilizing 'pressurized fluidized bed gasification' (PFBG) technology. The US-based Gas Technology Institute's version of PFBG technology, called *U*-GAS®, was identified as most suitable.[8] While the PFBG technology improvised by BHEL for high-ash domestic coal had potential, the study concluded it was untested at a scale large enough to be viable for a full-scale demonstration. However, the study did not find favor with the Indian government due to a preference for indigenous technology. Moreover, there was no plan either with the NTPC or BHEL to finance a commercial facility.

To date, there is no progress on the development of a commercial-scale IGCC facility in India, despite the research experience and data available locally. Two factors are likely the cause of the lack of a dedicated initiative. First, the significant capital investment required to set up an IGCC plant, which can cost considerably more than an equivalent conventional coal plant, weighs heavily on the stakeholders. Secondly, NTPC and BHEL,[9] two public sector behemoths of considerable significance to the project, have clashed over who would own the intellectual property of plant engineering. Since it is clear that India is not ready to shoulder the burden of a large-scale IGCC project fully, it has been recently suggested[10] that India would do

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[4]"India developing eco-friendly 100 MW IGCC plant," *The Electricity Forum* (Geneva, New York), undated, https://www.electricityforum.com/news-archive/oct09/IndiadevelopingIGCCplant

[5]Scott M. Smouse et al. (February 25, 2010), *Clean Energy Research And Deployment Initiative Assessment Report On Cleaner Coal Technology*, USAID&NETL, February 25, 2010, p. 26, www.climatelinks.org

[6]Gene H. Knight (April 2001), *Clean Coal Technology Demonstration Program: Program Update 2000*, US Department of Energy, Washington, DC.

[7]*Joint Statement on Cooperation In Energy And Environment Between India and the United States*, Ministry of External Affairs, Government of India, March 22, 2000, http://www.mea.gov.in/Portal/LegalTreatiesDoc/US00B0972.pdf

[8]P. Jayaram Reddy (2014), *Clean Coal technologies for power Generation*, London: CRC Press, p. 273; see also "USAID to sponsor $2.5 m-study on use of IGCC technology," *The Hindu Business Line*, December 01, 2000, https://www.thehindubusinessline.com/todays-paper/tp-others/article29082113.ece

[9]M. Ramesh, "BHEL-NTPC joint venture for power project in the offing," *The Hindu Business Line*, April 09, 2013, https://www.thehindubusinessline.com/companies/BHEL-NTPC-joint-venture-for-power-project-in-the-offing/article20600077.ece

[10]Jaideep Mishra, "Take US-India energy cooperation to the next level," *Economic Times*, February 20, 2020,

well to negotiate a buyout of its IGCC technology for others to potentially take forward.

Since then, senior DOE leadership participated in discussion on coal gasification, through a workshop held in December 2018 with NITI Aayog. This event focused more on the opportunity to gasify coal to produce syngas to make various chemicals, such as methanol, along with plastics and fertilizers, than IGCC. India should derive significant benefits in this approach to reducing its current huge fuel import bill for petroleum and LNG by basing a new industry on domestic coal. CCUS can also be considered if the gasification plant is situated near depleted oil fields by capturing CO_2 for use in Enhanced Oil Recovery (EOR), or converting the CO_2 into various valuable products.

PACER and Indo-US Coal Preparation Program: Coal Beneficiation and Washing

The four-year (1993-1997) USAID's Program for Acceleration of Commercial Energy Research (PACER) and the US Asian Environmental Partnership's (USAEPA's) Indo-US Coal Preparation Program (1994-1996)[11] were designed to support new commercial initiatives in the areas of renewable energy, energy efficiency, and clean coal technologies and processes through Participating Agency Service Agreements (PASAs) with the DOE. Among the many activities were efforts to advance coal beneficiation and washing before its utilization in the thermal power plants.

Coal beneficiation, or washing, is a physical process by which the quality of raw coal is improved by either separating the extraneous mineral matter from the mined coal or reducing the minerals associated with the organic coal, or both, through a range of methods and technologies. When coal undergoes cleaning, it improves the overall thermal efficiency of a power plant by improving combustion, reducing auxiliary power consumption, and ash disposal costs. Operating at higher efficiency reduces coal consumption and resulting CO_2 emissions, as well as reducing conventional pollutants. Also, due to lower ash content, wear and tear of the power plant equipment is reduced, leading to lower O&M costs and significant savings.

While the washing technology was deployed in India for industrial coking coal, beneficiation of thermal coal was not considered a cost-effective practice in power generation. However, as several studies revealed the beneficial results of coal washing on the efficiency of thermal power plants in India, the technology began to be more acceptable. One such economic and engineering analyses of coal from the Dipka Mines in Korba coalfield, Chhattisgarh, was made by NETL under PACER. Based on the flowsheet developed, the Dipka coal was beneficiated at the Central Fuel Research Institute's (CFRI's) pilot-plant in Dhanbad (India). The beneficial results of coal washing were documented, which was hoped to help open the Indian coal preparation market to US companies and technologies.[12] However, in general, adoption of coal washing was delayed for years until regulations were changed and resources became available.

Subsequently, BSES (Bombay Suburban Electric Supply Limited), a vertically integrated private utility, approached USAID to assist with a coal washery under the PACER program, for its 500-MW Thermal Power

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https://economictimes.indiatimes.com/industry/energy/power/view-take-us-india-energy-cooperation-to-the-next-level/articleshow/74344492.cms?from=mdr

[11]US Office of Fossil Energy, *Coal & Power Systems Strategic Plan & Multi-year Program Plans*, Pennsylvania: DIANE Publishing, 1999, p. 86.

[12]S. Gollakota, N. Rao, A. Duerbrouck, and G. Staas, "Characterization and preparation of Dipka coal from Korba coalfield in India," (Abstract), Office of Scientific and Technical Information, US Department of Energy, https://www.osti.gov/biblio/349187-characterization-preparation-dipka-coal-from-korba-coalfield-india; US Office of Fossil Energy (1999).

Plant at Dahanu. Coal at the plant was linked to Dipka mines located about 1400 kilometers (km) away.[13] The Ministry of Coal approved BSES' proposal, and it was financed by part of USAID's $20-million grant to the Industrial Credit and Investment Corporation of India Bank, to develop market-driven energy technologies.[14]

India's first non-coking coal commercial washery was established in Bilaspur, Chhattisgarh, in 1998. The ST-BSES Coal Washeries Limited (Bilaspur Washery) – a joint venture of privately-owned BSES and two US firms, Spectrum technologies (ST) and CLI Corporation – was set up in the Dipka with a capacity of 2.5 million-ton-per-annum (mtpa).[15] The USAEP's project supported deployment of an advanced coal-cleaning circuit based on US technology.[16]

The Bilaspur coal washery showed how washed coal (with less than 30 percent ash) improved the Dahanu's power plant's generation capacity by 16 percent, cost of per unit power generation by approximately 10 percent, and ash generation by 8.5 percent among other improvements in operational efficiency. These performance improvements also implied a substantial reduction in CO_2 emissions. The net gain between additional units of power sold and additional cost of generation (in which cost of washing was added) was a savings of $26.73 million of total generated power.[17]

The Indian government, which had taken a keen interest in USAID's coal beneficiation project, promulgated its first order on the use of washed coal in Indian power plants. In June 1998, the Ministry of Environment & Forests (MOEF), GOI, notified that power plants located beyond 1000 km from coal mine pit-head and in critically polluted areas, urban areas and in ecologically sensitive areas, would have to use beneficiated/blended coal as of June 2001. The ash content should be no more than 34 percent.

A decade later, the MOEF in its January 2014 notification stipulated that a stand-alone thermal power plant (of any capacity), or a captive thermal power plant of installed capacity of 100 MW or above, located between 750-1000 km and 500 -749 km from pit-heads, must utilize beneficiated coal as of 1 January 2015 and 5 June 2016, respectively. A noteworthy aspect of the stipulation is that power plants "shall be supplied with" beneficiated coal with ash content not exceeding 34 percent, meaning the obligation to meet these targets also rests with the coal supplier.[18] Further, the notification mandates all new opencast projects with capacity of 2.5 mtpa and above and not linked to pit-head power stations, should be designed with integrated washeries.

[13]R.V. Shahi, *Indian Power Sector: Challenge and Response*, New Delhi, *Coal & Power Systems Strategic Plan*.: Excel Books, pp. 340-341.

[14]Robert Beckman (September 1991), "Technology projects target Indian firms," *Front Lines* (USAID), Volume 31, Issue 8, p. 13; R. K. Sachdev and Malti Goel (1997), "A Critical Evaluation of Clean Coal Industry as a Source of energy in India," in Pradeep Chaturvedi (ed.), *Sustainable Energy Supply in Asia*, New Delhi: Concept Publishing Company, p. 157.

[15]Mrinal Biswas, "ST-BSES Bags MP Washery," *Business Standard*, February 26, 2013, https://www.business-standard.com/article/specials/st-bses-bags-mp-washery-197080101117_1.html

[16]US Department of Energy, Office of Fossil Energy (1999), *Coal & Power Systems Strategic Plan*, p. 86.

[17]Craig D. Zamuda and Mark A. Sharpe (August 22-24, 2007), "A Case for Enhanced Use of Clean Coal in India: An Essential Step towards Energy Security and Environmental Protection," Presentation at the *Workshop on Coal Beneficiation and Utilization of Rejects*, Ranchi, India.

[18]*Notification GSR 02 (E), dated January 02, 2014 in respect of use of washed, blended or beneficiated coal in Thermal Power Plants*, Ministry of Environment and Forests, February 4, 2014, http://www.indiaenvironmentportal.org.in/files/file/beneficiated%20coal.PDF

This significant change in policy finds its roots in across-the-board benefits – environmental, public health, plant efficiency, and electricity costs – of employing cleaner coal technology and practices.

There is currently around 185 mtpa coal washing capacity in India across 60 operating washeries.[19] The integration of coal washing into the regular operating practices in a coal-fired generation plants will further augment the thermal efficiency of supercritical (SC) power plants, slated for India's future capacity build-up. Also, if India builds an IGCC power plant, it will benefit in terms of overall thermal efficiency from a steady supply of beneficiated coal.

The Coal Working Group, created in 2005 under the Indo-US Strategic Energy Dialogue, played an important role in clean coal engagement. Accomplishments include promoting the use of coal washeries and advanced coal beneficiation techniques in India through technical exchange visits, workshops, transfer of information, and utilization of waste coal from cleaning operation.

GEP: Efficiency Improvement and Emission Control

In 1994, the United States and India signed a protocol of intent, pledging to support the execution of activities under USAID's Greenhouse Gas Pollution Prevention (GEP) clean coal project. Under its two components, Efficient Coal Conversion (ECC) and Efficient Power Generation (EPG),[20] the GEP project, one of the longest-running USAID environmental programs in India (1994-2010), focused on the issues of power plant efficiency improvement and GHG emissions reductions from India's coal-fired power generation.

The main activity under the ECC component was the establishment of the Centre for Power Efficiency and Environmental Protection (CenPEEP) by NTPC in partnership with USAID and NETL. As a self-sustaining institution, the CenPEEP was designed to provide technical support to coal-fired power plants throughout the country and serve as a knowledge think tank for the Indian power sector. Inaugurated by US Energy Secretary in 1994, the CenPEEP functions as a resource center for acquisition, demonstration, and transmission of advanced technologies, best power sector practices and operating efficiency procedures, and knowledge related to environmental protection for improving the operating performance of coal-fired utilities in India.[21] Two CenPEEP regional offices were established in Lucknow, Uttar Pradesh, and Patna, Bihar, to assist the power plants of the State Electricity Boards.

The work under GEP-CCS EPG Component addressed the issues of operational efficiency and environmental performance of India's coal-fired plants, through the improvement of their heat rates. Heat rate is a measure of how efficiently a fossil-fuelled power plant converts the chemical energy in the fuel into electrical energy. Improvement in heat rate implies lower fuel consumption and, therefore, lower CO_2 emissions. Through an interagency agreement with NETL, the United States' Tennessee Valley Authority (TVA), carried out tests and training at the NTPC's coal-fired power plants and the state utilities, on heat rate monitoring and efficiency improvement.

One of the first such heat rate 'demonstration, monitoring and improvement' exercises was at the NTPC's

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[19] "Coal Beneficiation," *Powerline* (Delhi), July 2017, https://powerline.net.in/2017/07/09/coal-beneficiation/

[20] Neale MacMillan, Matthew Addison, and Vivek Asthana (September 2011) *Evaluation of Greenhouse Gas Pollution Prevention Program*. Social Impact, Inc.: Arlington, VA; Smouse et al. (February 25, 2010), *Clean Energy Research And Deployment*.

[21] *Centre for Power Efficiency & Environmental Protection (CenPEEP)*, NTPC, https://www.ntpc.co.in/en/environment/cenpeep

Dadri plant. Subsequently, at least 30 state utility plants/SEBs were included in the efficiency improvement program. The CenPEEP and NTPC plant engineers received training in TVA plants and assistance through technical workshops on clean and cost-effective energy practices. With the introduction of the practice of conducting performance audits in power plants, several NTPC and state utilities' stations were able to identify heat rate improvement potential even at their best-run stations. Through the introduction of the Best Overhauling Practices Manual, the utilities were able to make significant savings on their O&M costs. The power plant efficiency improvement activities were also funded by the DOE and USAID in India under the Asia Pacific Partnership on Clean Development and Climate (APP),[22] engaging the state utilities of West Bengal, Punjab, and Tamil Nadu in heat rate improvement assistance and related technologies.

In 2000, India's Ministry of Power released the 'Guidelines for Heat Rate Improvement' for implementation in both older and newer subcritical coal-fired power plants, prepared jointly by NETL, TVA, EPRI, and CenPEEP. The guidelines were based on the practices and demonstrations in India through GEP and provided methods and tools, test procedures, and calculation methodologies from the United States.[23] The guidelines document was distributed within NTPC plants and given to state utilities and is being routinely used by power stations to improve their performance.

What the GEP project introduced was tested, proven, and widely accepted practices in the US power plants. Technical interventions and practices, such as i) the use of infrared thermography and acoustic diagnostic techniques for early detection of equipment problems; ii) the practice of predictive, condition-based maintenance in NTPC power plants to improve their reliability; and iii) the introduction of ash resistivity measurement facilities critical for the optimal performance of SO_2 scrubbers[24], could be easily replicated anywhere with minimum capital investment.

These generation efficiency improvements of the GEP program had a significant impact on NTPC's organizational culture, marking a shift in focus from plant load factor (PLF) i.e., increasing electricity generation, to the improvement of power plants' operational efficiency through O&M culture. For example, while the efficiency at NTPC's Dadri plant improved by 1.5 percent, which reduced coal use by 81,000 tons/year, thereby saving $2.4 million/year, and reducing CO_2 emissions by more than 100,000 tons/year.[25] NTPC's annual report for the 2009–2010 fiscal year indicated the company had saved 89.5 million rupees, or 72,747 tons of coal, at its coal-fired power plants.[26]

Moreover, through the GEP, India was able to avoid 99.1 million tons (MT) of CO_2 emissions and reduced coal consumption by 78 million tons, over 16 years of the project through power plant performance

[22]"How thermal plants can be re-energised with help from US agencies," *The Hindu Business Line*, April 12, 2011, https://www.thehindubusinessline.com/economy/How-thermal-plants-can-be-re-energised-with-help-from-US-agencies/article20190990.ece

[23]Neale MacMillan, Matthew Addison, and Vivek Asthana (September 2011), *Evaluation of Greenhouse Gas Pollution Prevention*, p. 55.

[24]Smouse et al. (February 25, 2010), p. 22.

[25]Scott M. Smouse (November 18, 2005), *A 25-Year History of Cooperation with India*, NETL, https://fossil.energy.gov/international/Publications/cwg_nov05_smouse.pdf

[26]Neale MacMillan, Matthew Addison, and Vivek Asthana (September 2011), *Evaluation of Greenhouse Gas Pollution Prevention*, p. 20

optimization and efficiency improvements and the use of washed coal.[27] A set of auxiliary interventions also led to efficiency gains and CO_2 reductions. The Partnership in Excellence (PIE) Programme, launched by the CenPEEP and GEP in August 2005, identified 26 coal-fired power stations for thermal efficiency and performance improvement. In the 2007-2008 fiscal, 13 plants recorded an additional generation of 440 MW.[28] As the maintenance systems were updated, plant load factors improved, additional capacity was realized, and GHGs emissions were avoided.

Building upon its experiences of power plant management under the GEP program, the CenPEEP/NTPC established a computerized efficiency monitoring system across the fleet of its power plants, allowing the whole host of operational parameters to be monitored centrally in real-time. In 2009, the NTPC established NETRA (NTPC Energy Technologies and Research Alliance) for conducting cutting-edge research on climate change, new & renewable energy, efficiency & reliability of thermal power generation, and CO_2 mitigation/fixation. NTPC has also institutionalized the knowledge gained through the GEP program through its Power Management Institute (PMI), which offers training and consultancy to SEBs and other power utilities.

PACE: Benchmarking and Best Practice Manual for SC Technology

One of the first activities under USAID's PACE-D TA Cleaner Fossils (2013-2014) program, which was supported by Nexant with many of the same experts previously used by NETL, was to organize heat rate training workshops in partnership with the NTPC/CenPEEP in March 2013.[29] The Panipat Thermal Power Station (PTPS), Panipat, in Haryana, and Chandrapur Thermal Power Station (CTPS), Chandrapur, in Maharashtra, were selected to demonstrate the importance of periodic audits, training, and deployment of various best practices and benchmarking tasks to audits. Benchmarking is an advanced management technique to evaluate the performance of a power plant unit, which includes key metrics and process for assessment against a set of baseline parameters.

A formal heat rate program for Unit-6 in CTPS and Unit-5 in PTPS was established to serve as the benchmark for the individual plants. This helped to assess and rectify 'low-hanging fruit' – meaning the easily achievable resolution of operational issues that can facilitate the effort towards performance optimization – and site-specific opportunities.[30] The recommendations emerging from the workshop at the PTPS were to serve as the benchmark on how to institute a formal heat rate improvement program for a PC unit.

The TA Program and USAID also facilitated collaboration between American experts and NTPC/CenPEEP to develop a best practice manual for coal units using SC technology. Another goal was to produce a benchmark/baseline document for one SC unit that could be used by other Indian utilities planning SC units. The benchmark/baseline document for a 660-MW SC unit was prepared based on the Sipat Thermal Power Station (STPS), Bilaspur District, Chattisgarh, which is NTPC's first SC plant amongst its many coal-fired power plants. Sipat has a total approved capacity of 2980 MW, which includes three 660-MW SC units in

[27] *Advanced Technologies and Best Practices for Supercritical Thermal Power Plants: Conference Report*, PACE-D Technical Assistance Program, February 2014, http://pace-d.com/wp-content/uploads/2013/11/Clean-Coal-Conference-Report.pdf

[28] NTPC (April 10, 2008), "Major Highlights," Press Release, https://www.ntpc.co.in/sites/default/files/files/Highlights%202007-08.pdf; Colin Handerson (November 2015), Coal-fired power plant efficiency improvement in India, London: IEA Clean Coal Centre, p. 24.

[29] *Workshop on Hear Rate Improvement*, PACE-D TA, March 2013, https://www.pace-d.com/cleaner-fossil-2/

[30] Ibid.

Stage I, and two 500-MW SC units in Stage II.

The goal was to enable the reliability of Sipat's SC boilers to become best in class through understanding baselines, benchmarks, and adaption of best practices to achieve NTPC's 'model plant' status[31] while underpinning future deployment of ultra-supercritical (USC) clean coal technology. Several aspects related to safety, reliability, availability, and efficiency of SC units are addressed in the manual, including experience and case studies from some of the highest performing units worldwide.

Coal Blending

The blending of coal is a process wherein low-grade coals can be mixed with high-grade coal without compromising the thermal performance of the boiler while achieving plant benefits, especially lower fuel costs. Many power stations in India have started importing coal from the international market and blending them with available low-grade coal to improve performance. The blending practices are expected to increase soon, as Indian power plants realize their expansion projects to meet demand. However, blending is not simple, but involves informed decisions about the different types of coals and the standard blending ratios based on the scientific review of their behaviour (combustion, ash deposition, ash collection, etc.) in a specific unit at typical operating conditions.

The Cleaner Fossil component of the PACE-D TA program, in partnership with the NTPC, addressed these issues at the brainstorming session on Optimizing Blend Levels and Selecting Fuel Blend in August 2014.[32] A feasibility study focused on customizing the VISTA™ Fuel Quality Impact Model, EPRI's state-of-the-art computer-based simulation tool, to Indian conditions. Since many plants in India use high-ash domestic coal, the Vista™) Model was able used to quantify the impacts of imported coals concerning performance, emissions, O&M, and logistics.

A simulation of the impact of blended coal on an STPS unit showed that plant performance generally improved with higher blending. For instance, the boiler efficiency and net unit heat rate improved with a blend of South African coal at 40 percent with indigenous Dipka coal, as compared to an Indonesian blend.[33] It was demonstrated that Vista™ model could provide a basis of calculation upon which any utility can conduct economic analyses and make informed fuel decisions, which can be leveraged in annual coal purchasing contracts.

Looking Ahead: Coal Component and Energy Partnership

Through the clean coal activities, Indian utilities have gained deep insight into the most pressing problems facing the coal power sector, especially those related to coal combustion, the efficiency of power plants, plant management techniques, and GHG emissions. Moreover, spurred by the clean coal initiatives, advanced technology and practices are have been adopted by power plants throughout India, saving millions of dollars in reduced O&M and fuel costs.

Taking further steps in clean coal activities, India has adopted SC and USC emissions- mitigating

[31] *Supercritical Technology Best Practice and Benchmarking*, PACE-D TA, March 2013, https://www.pace-d.com/march-18-21-2013-sipat-workshop-on-benchmarking-and-best-practices/

[32] *Optimizing Blend Levels*, PACE-D TA, August 25, 2014, https://www.pace-d.com/august-25-2014-new-delhi-frideas-analytical-tools-optimizing-blend-levels-and-selecting-fuel-blend/

[33] FRIDEAS – Analytical Tools – Optimizing Blend Levels, August 25, 2014, PACE-D TA, https://www.pace-d.com/august-25-2014-new-delhi-frideas-analytical-tools-optimizing-blend-levels-and-selecting-fuel-blend/

technologies for coal-based power. In August 2019, NTPC commissioned the country's first USC unit – the 660-MW unit at the two-unit Khargone Super Thermal Power Station in Madhya Pradesh. The Khargone USC unit is likely to operate at an efficiency of 42 percent compared to 35 percent of the conventional power unit, which will result in a reduction of 3.3 percent CO_2 emissions.[34] While the Khargone unit uses imported technology from Japan, NTPC has signed an MoU with BHEL to set up an 800-MW technology demonstration advanced-USC (AUSC) unit using indigenous technology at the Sipat plant. A plant that employs AUSC technology is five percent more efficient, bringing about 12 percent savings in coal, thus reducing CO_2 emission by about 20 percent.

While some progress demonstrating AUSC materials is being made using a component test loop at NTPC's Dadri station, the DOE-funded AUSC consortium, led by the Energy Industries of Ohio (EIO), has developed high-temperature (760C) alloys over the past decade that are already code certified. EIO has been talking with NTPC about testing these US materials at Dadri for several years and doing detailed techno-economic engineering studies.

Besides, as part of the country's clean energy initiatives, the Government of India has announced a National Mission on AUSC technologies for cleaner coal utilization at a total cost of US$238 million and the setting up of two Centres of Excellence on Clean Coal Technologies – one on methanol and the other on dimethyl ether - involving investments of US$5 million each.[35] These molecules can be sourced from coal and have a variety of applications in the chemical and petrochemical industry, power generation, and transportation.

The US-India Strategic Energy Partnership (SEP) launched in April 2018, which has identified cooperation on clean coal technology, including CCUS, for bilateral cooperation, provides a critically need platform to resurrect the previous USAID and DOE efforts and to explore new areas for cooperation. For example, the study on coal gasification and the data available from BHEL's demo IGCC plant at Trichy could be reconsidered for a scaled-up IGCC plant along with production of syngas for industrial applications. The efficient gasification of domestic coal will effectively complement India's LNG imports from the United States, and if CCUS is included, will provide CO_2 for use in enhanced oil recovery (EOR) and/or production of various valuable chemicals and transportation fuels – all of which would reduce India's huge annual fuel import bill.

Beyond the cooperation on now-commercial clean coal technologies, India should also engage the United States on next generation technologies, such as DOE's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative36. This effort will develop the coal power plant of the future that can provide secure, stable, reliable electricity, with near-zero emissions of both conventional pollutants and CO_2. This R&D will underpin coal-fired power plants that are capable off flexible operations to meet the needs of the grid; use innovative and cutting-edge components that improve efficiency and reduce emissions; provide resilient power; are small compared to today's conventional utility-scale coal power plants; and will transform how coal technologies are designed and manufactured. DOE is also sponsoring cutting-edge R&D on A-USC materials, advanced sensors and control systems, and the production of high-value carbon-based

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[34] *NTPC installed capacity is 57,106 MW with two 660 MW units at Tanda & Khargone*, Press Release, October 3, 2019, https://www.ntpc.co.in/en/media/press-releases/details/ntpc-installed-capacity-57106-mw-two-660-mw-units-tanda-khargone

[35] *India announces mounting of a National Mission on advanced ultra-supercritical technologies for cleaner coal utilization, Department of Science and technology*, Government of India, June 12, 2017, https://dst.gov.in/pressrelease/india-announces-mounting-national-mission-advanced-ultra-supercritical-technologies

[36] Coal FIRST, US Department of Energy, Office of Fossil Energy, https://www.energy.gov/fe/coal-first

materials and other products, including rare earth minerals, from coal and CO_2.

While the Indian government has not viewed CCUS as a critical technology in its national energy and climate policy, due to concerns about viability, cost, and safety, it joined the Carbon Sequestration Leadership Forum (CSLF) and Mission Innovation's (MI's) CCUS Initiative. India hasn't been very active in the CSLF, but did organize a MI Carbon Capture and Utilization Challenge workshop during September 2017 to discuss current R&D gaps; the need for national/international collaborations; and short-, mid, and long-term strategies.

In May 2018, Technology Information, Forecasting and Assessment Council (TIFAC) – an Autonomous Body under the Government of India's Department of Science & Technology (DST) – released a report entitled "Carbon Capture Utilization & Storage - A Roadmap for India." Some US experts contributed to development of the roadmap. This roadmap laid out a credible initial pathway for India to follow to advance its own R&D and to develop the needed policy framework for CCUS commercialization and deployment. This roadmap needs to be picked up again by the government and industry for India to guide meaningful R&D collaboration with the US and other leading countries.

Under the India chapter of the Mission Innovation (MI), the DST & Department of Biotechnology (DBT) in July 2018, launched a $6 million *call* for proposals for collaborative R&D with MI member countries in the field of CCUS. The MI is a global initiative of 24 countries and the European Union, including the US, announced on November 30, 2015 – as world leaders met in Paris to make a determined effort to combat climate change – that commits the member countries to accelerate clean energy investment so as to promote innovation, that will create a clean, affordable and sustainable future of the global energy mix. The objective of this call is to identify, prioritize, and deploy breakthrough technologies that will enable India to achieve substantial decarbonisation of its fossil fuel-based economy.

India's DST and DOE have started discussions on R&D cooperation on CCUS, along with advanced clean coal and other clean energy technologies, under the research component of the second phase of the Partnership to Advance Clean Energy (PACE-R). India should re-engage in the CSLF and join the Clean Energy's Ministerial (CEM) CCUS Initiative. These multi-lateral fora can help India gain a deeper knowledge on CCUS technologies, policies, and regulations, by cooperating not only with the United States, but also with other countries. Also, the US leads the world on CCS technologies and has developed an advanced set of policy incentives and infrastructure framework, India would also benefit immensely through cooperation DOE's National Labs and other entities supported by the DOE's Carbon Sequestration Program.

The new SEP's Power & Energy Efficiency Pillar, led by the MoP and DOE's Office of Fossil Energy, and PACE-R program creates the opportunity for the two countries to deepen cooperation on a wide range of next-gen clean coal technologies and CCUS to ensure coal remains a key element of both countries' clean energy strategy.

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