



**CLEAN ENERGY RESEARCH AND DEPLOYMENT INITIATIVE
ASSESSMENT REPORT ON
CLEANER COAL TECHNOLOGY**

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February 25, 2010

This report is made possible by the support of the American people through the United States Agency for International Development (USAID). The contents of this report are the sole responsibility of the author and do not necessarily reflect the views of USAID, USDOE's National Energy Technology Laboratory, or any agency of the United States Government.

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Executive Summary

The United States and India recently signed a Memorandum of Understanding (MOU) to Enhance Cooperation on Energy Security, Energy Efficiency, Clean Energy, and Climate Change, and launched a new effort for collaboration. This new effort will be implemented under the new Clean Energy Research and Deployment Initiative (CERDI). Guided by the strategic intent and direction of the MOU, CERDI will build upon the India Mission of the U.S. Agency for International Development's (USAID/India's) bilateral energy programs, notably the Greenhouse Gas Pollution Prevention (GEP) Project and the Energy Conservation and Commercialization (ECO) Program, as well as efforts of the Working Groups under the U.S.-India Energy Dialogue with the assistance of several U.S. government agencies and their partners.

CERDI, which includes both research and deployment components, will promote innovation and collaboration in the deployment of clean energy technologies in three priority areas:

- 1) Energy efficiency in energy-intensive industry, in built environment, and in utilities through smart grids;
- 2) Accelerated deployment and scale-up of grid-interactive and decentralized renewable energy technologies, and
- 3) Market-driven cleaner coal technology demonstration projects and deployment strategies with an emphasis on those technologies and best practices that have the maximum GHG reduction potential and those that can be sustained by technical expertise and support within the country.

USAID/India is leading the deployment initiative of CERDI given the mission's experience in working with the Indian energy sector and business environment.

This report, which was prepared by federal and contractor staff at the U.S. Department of Energy's (USDOE's) National Energy Technology Laboratory (NETL), supports development of the cleaner coal component of the CERDI Deployment Center. This report assesses the potential for greenhouse gas (GHG) emissions reduction from existing coal-fired power plants in India, building upon the USAID ongoing and other related programs, and cleaner coal technology research, development, and deployment (RD&D) opportunities. It reviews USAID/India's and NETL's involvement in clean coal activities in India dating back to 1983. The major technical achievements under USAID's programs, especially the ongoing GEP Project, are highlighted focusing on the millions of tons of avoided CO₂ emissions and lessons learned to date along with identification of support needed, and concepts that have been discussed for the way forward. Inputs obtained from various stakeholders, including the Government of India's (GoI's) nodal ministries for power and coal, and other key stakeholders in power utilities and industry associations – obtained in part through face-to-face and telephone meetings during January 18-29, 2010, in India – are summarized in Appendix A.

The Indian power sector is growing at a rapid pace and coal is, and will continue to be, the primary energy source for the Indian power sector that underpins the country's economic

development. About 68% of India's current power generation is from coal and that share is expected to remain in the same range for many years. A significant percentage of India's existing coal-fired power plants are aging and are no longer very efficient and reliable, especially those operated by state utilities. In recent years, India power generators have focused on increasing plant load factors (PLF, or capacity factors) to increase electricity output, but often at the expense of plant efficiency. While the national average PLF for stations in central sector (i.e., NTPC) has approached 90%, which is world class, the average PLF of state-operated plants is about 70%, and private utility plants is 85%. However, many individual plants, especially those operated by state utilities, are below 55% and below 30% in some cases (Appendix B). The Central Electricity Authority (CEA), the technical arm of the Ministry of Power (MoP), reports that the national average generation efficiency has remained constant at about 32% for at least the past 5 years (Appendix B). This is despite retiring a number of old, small, units and building many new, larger, more efficient units, which should have improved overall generation efficiency. Heat rates (i.e., fuel consumption per unit of electricity generated) higher than 3,000 kcal/kWh (i.e., efficiencies lower than about 28%) are common among the older, especially smaller (100-200 megawatt, MW) units operated by many Indian state utilities. Plant reliability and efficiency suffer as a result of (1) the high-ash content of most Indian coals, which often exceeds 45%, and overall poor coal quality, (2) limited maintenance of equipment, (3) absence of incentives to maintain or improve efficiency and reliability, (4) inadequate operating budgets, and (5) limited knowledge and experience on state-of-the-art operating and maintenance (O&M) practices, which adversely impacts both plant efficiency and reliability. The inability to sustain plant performance and reliability is a serious issue for these old plants. Lack of attention to proper O&M can result in rapid deterioration of plant efficiency, reliability, and maximum sustainable output (MWs) and increased fuel consumption and CO₂ emissions from the onset of plant commissioning.

There are three ways of lowering CO₂ emissions from coal-based power plants: (1) increasing efficiency of existing plants; (2) using more efficient clean coal technologies; or (3) switching to less carbon-intensive fuels (natural gas and biomass) other than coal. India is pursuing all of these options, but option #1, increasing the efficiency of existing plants, can have the greatest near-term impact owing to the large existing inventory of coal-fired power plants. Future power plants will have to use advanced clean coal technologies, including carbon capture storage (CCS), if India is to significantly reduce its emissions of CO₂.

The GoI has embarked upon an ambitious plan to add 78 gigawatts (GWs) of new generating capacity during the country's 11th Five Year Plan (April 2007-March 2012) and 94 MW during the 12th Five Year Plan. The private sector's share of this new capacity is expected to be nearly 40 GW. There is a need to use better O&M practices in these new plants or else it will be a waste of the country's limited investment capital. In view of the high investment requirement for greenfield power plants, along with natural resource constraints and environmental concerns, optimal utilization of the country's existing generating capacity has been given a top priority under MoP's Life Extension (LE) and Renovation and Modernization (R&M) Program. A large potential exists to increase generation and improve efficiency through Energy Efficient R&M (EE R&M).

On average, most Indian coal-fired power plants operate at heat rate higher than their designed value. A CEA study of the heat rate of 53 coal-fired power plants, constituting a total capacity of 37,830 MW – about half of India’s current coal generating capacity – shows that station heat rates are about 13.7% higher than their design values on average. This study indicated that an average improvement of 300 kcal/kWh is achievable through improved O&M practices and plant R&M. Higher operating heat rate leads to increased power generation costs, faster depletion of natural resources (coal), higher emissions of conventional pollutants (SO₂, NO_x, and particulates), and increased CO₂ emissions.

CEA, in consultation with the state utilities, prepared a National Perspective Plan for R&M and LE, which covers up to 2017, for existing 200-210 MW and some 500-MW coal-fired plants that are more than 15 years old. In the plan, 125 existing units (23,850 MW) for LE and 99 units (23,936 MW) for R&M – about two-thirds of India’s entire existing coal fleet – have been designated for improvement during the 11th and 12th Five Year Plans. The plan indicated that the operating capacity of these units could be increased by 4 to 8% and their efficiency improved by 8 to 10%. If achieved, coal consumption in these units could be reduced by up to 15 million tonnes (metric tons, or 16.5 million short tons) annually, which is equivalent to reducing almost 20 million tonnes (22 million short tons) of CO₂ emissions annually, and hundreds of megawatts of power generation capacity restored. The technology-intensive R&M for efficiency improvement needed in these projects is beyond restoration of original generation capacity, life extension, and improved availability. It would enable these units to operate at higher outputs with lower required fuel input and CO₂ emissions. Additional background information on Indian’s power sector is provided in Appendix B.

Several EE R&M projects have already been implemented under cooperative programs with Germany, Japan, and the World Bank. For example, the Japanese government, through Japan’s International Cooperation Agency (JICA), is supporting NTPC on capacity building activities in this area. Other related ongoing initiatives, in which the United States is leading or is involved, such as the power plant peer reviews being conducted by the Power Generation & Transmission (PG&T) Task Force of the Asia Pacific Partnership on Clean Development & Climate (APP), are also making some contributions to improved O&M practices in Indian power stations. Other new initiatives involving the United States, such as delineated in the High-Efficiency, Low-Emissions (HELE) Coal Technologies Action Plan under the Major Economies Forum, have identified similar needs, but have not yet developed work plans or secured resources. Additional information on these initiatives is provided in Appendix C.

Some aspects of the needed policy and regulatory framework to support the adoption of cleaner coal technologies are in place through the Integrated Energy Policy and 2009 Electricity Act, and the National Mission for Enhanced Efficiency (NMEE) of 2009. The latter is an effort to create a market for energy efficiency estimated to be US\$16.5 billion in India. The flagship of NMEE is its “Perform, Achieve and Trade (PAT)” initiative, which is a market-based mechanism to incentivize energy efficiency in nine energy-intensive industrial sectors. This includes

requiring power generation plants to reduce their specific energy consumption by improving overall plant efficiency. Additional information on relevant Gol is provided in Appendix D.

Since 1982, USAID/India has sought to promote and demonstrate better coal utilization technologies and practices in India. In support of USAID/India, USDOE/NETL has provided technical and management support to various coal R&D institutions in India to identify and demonstrate clean coal power technologies, and has worked closely with Bharat Heavy Electricals, Ltd. (BHEL), NTPC Ltd. (formerly, National Thermal Power Corporation; 89% Gol owned under MoP), Power Finance Corporation (PFC), and various Indian R&D institutions, including the Central Fuel Research Institute (CFRI), Council of Scientific & Industrial Research's (CSIR's) Regional Research Laboratory (RRL), and the Tata Energy Research Institute (TERI, now The Energy and Resources Institute). Changing the "O&M culture" in the Indian power plants that have benefited from the clean coal technology programs initiated by USAID/India and NETL is showing signs of moving the stagnation in power plant efficiency and reliability. At the same time, technological developments coupled with new instrumentation, diagnostics, and software have made significant efficiency improvements possible in underperforming plants. Each project implemented through USAID/India's Programs has assisted India by transferring needed U.S. power plant technology and best practices for improved operational efficiency, maintenance, and environmental performance and, at the same time, helped to build business relationships between the Indian and U.S. power sectors.

Actions under the USAID's GEP Project, supported by parallel efforts under the APP PG&T Task Force, to improve power plant's O&M culture and operational efficiency and other related coal activities have resulted in significant CO₂ emissions avoidance. **Starting in April 1996 through March 2010, an estimated total of approximately 101 million tonnes (111 million short tons) of CO₂ emissions have been avoided through power plant performance optimization and efficiency improvements and the use of washed coal.** Testimony to the success of these projects is found in several major international climate and business quality awards that have been bestowed on NTPC's Center for Power Efficiency and Environmental Protection (CenPEEP) for its accomplishments in reducing GHG emissions in power generation through efficiency improvements. An enormous body of cumulative experience and strong linkages has been generated among USAID/India and its U.S. partners with the Indian government and non-governmental entities and various Indian state governments, state utilities, research organizations, private sector companies, and educational institutions. These linkages provide a strong base from which to establish commercial partnerships and to catalyze development and deployment of cleaner coal technologies under CERDI.

There is strong consensus among all Indian power sector stakeholders that not only continuing, but expanding, USAID/India's ongoing power plant efficiency improvement and GHG emissions reduction program to include more Indian utilities (state and private) is very much needed and will yield substantial reductions CO₂ emissions from India's power sector – the largest source of CO₂ emissions in India. While the plant-by-plant approach adopted under the GEP Project in working with NTPC and selected state utility power plants has been highly successful, it has limitations from both resources and logistics issues. It is believed that a better approach is to

develop a “model plant,” where new clean coal technologies and best practices that have the greatest impact on plant efficiency could be demonstrated. This model plant could serve as a technology induction, testing, and training center against which all other Indian coal-fired power plants could be benchmarked.

The need to create a pool of service providers for Indian utilities has also been strongly endorsed. Absence of reliable service companies is already being felt by the major utilities, who have historically relied on Bharat Heavy Electrical Limited (BHEL), the dominant original equipment manufacturer (OEM) in India, to provide all needed technical services. BHEL is stretched to the limit in supplying new power plants to meeting the country’s rapidly growing demand for power, and foreign OEMs, such as Alstom and Siemens, who have recently entered the sector, are concentrating mainly on large capital equipment projects. Local providers at the middle-to-lower end of the spectrum for performance improvement, troubleshooting of auxiliary systems, and diagnostic services are very “few and far between”. This leaves power plants with few options to acquire the needed equipment, instrumentation, and knowhow to address their problems. Creating a network of highly skilled engineers and technicians and technology suppliers through joint ventures with U.S. service providers and technology supplier will benefit the Indian power sector immensely.

In July 2008, India released its first National Action Plan on Climate Change (NAPCC, <http://pmindia.nic.in/Pg01-52.pdf>), which delineated the government’s current and future policies and programs to address climate mitigation and adaptation. The NAPCC addresses the urgent concerns of the country through a directional shift in the country’s development pathway, including enhancement of current and planned programs. The Plan states that India is determined that its per capita greenhouse gas emissions “will at no point exceed that of developed countries even as we pursue our development objectives.” To achieve this, India intends to develop and use new technologies, and focus on promoting understanding of climate change, adaptation and mitigation, energy efficiency, and natural resource conservation. The plan identified eight core “national missions” running through 2017 and directed relevant Ministries to submit detailed implementation plans to the Prime Minister’s Council on Climate Change by December 2008. In addition, the Plan also addressed other initiatives including “GHG Mitigation in Power Generation,” with specific recommendations on more efficient, cleaner coal-based power generation technologies. Specifically, the Plan stated:

“Since coal-based power generation will continue to play a major role in the next 30-50 years, it would be useful, wherever cost effective and otherwise suitable, to adopt supercritical boilers, which is a proven technology, in the immediate future, and ultra-supercritical boilers when their commercial viability under Indian conditions is established.” Supercritical and ultra-supercritical plants can achieve efficiencies about 40% and 45%, respectively, compared to conventional subcritical plants at about 35%, and hence emit 15-30% less CO₂.

“Demonstration of plants for integrated gasification combined cycle (IGCC) using high-ash, low-sulphur Indian coal needs to be pursued, while recognizing constraints such as high costs and availability of superior imported coal.” IGCC has the potential to be more efficient than

conventional power generation, especially through hybrid systems, and offers an attractive option to separate a concentrated stream of CO₂ for sequestration via storage in geologic formations, which would allow coal use with near-zero emissions of CO₂.

In 2004, India's Planning Commission formed an Expert Committee on Integrated Energy Policy, which was charged with preparing integrated energy policy for India linked with sustainable development that covers all sources of energy and addresses all aspects including energy security, access and availability, affordability and pricing, efficiency and environment. Their 2005 study (<http://planningcommission.nic.in/reports/genrep/intengpol.pdf>) indicated that the country meets was meeting about 30% of its energy needs through imports. With the increasing share of fossil fuels in the energy supply/use, the share of imported energy was likely to increase. The report posits that India faces formidable challenges in meeting its energy needs and providing adequate energy of the desired quality in various forms to users in a sustainable manner and at reasonable costs. It indicated that India needed to sustain an economic growth rate of 8-10% to eradicate poverty and meet its economic and human development goals. Such economic growth would require a substantial increase in energy consumption while ensuring access to clean, convenient, and reliable energy for all. To deliver sustained growth of 8% through 2031, India would need to grow its primary energy supply by at least 3 to 4 times and electricity supply by at least 5 to 7 times of consumption at that time. By 2031-32, power generation capacity would have to increase to 778,095 MW and annual coal requirement would exceed 2 billion tonnes, unless significant measures to increase power generation from renewable energy sources and to increase both demand and supply efficiency were undertaken. The report states "Meeting this vision would require that India pursues all available fuel options and forms of energy, both conventional and non-conventional, as well as new and emerging technologies and energy sources. Coal shall remain India's most important energy source till 2031-32 and possibly beyond. India will need to take a lead in seeking clean coal technologies...."

Moving forward, two concepts for wider scale replication of the low-cost power plant efficiency improvement activities, which have been under consideration for the past year and should be supported under CERDI's deployment initiative, are (a) creation of a service provider network, and (b) development of model coal-fired power plant. The GoI and the Indian power generation sector have expressed strong support for these replication concepts, indicating that they are likely to be successful at expanding upon the ongoing work, which has already avoided millions of tonnes of CO₂ emissions.

KEY FINDINGS

- *Over the past 14 years, USAID's coal-related programs have addressed many of the Indian coal and power sector's important problems. In particular, the GEP Project has gained a deep knowledge of the problems facing India's coal power sector and has developed an extensive network of relationships between the governments and industry of the United States and India.*
- *Support provided through USAID/India's GEP Project and the APP PG&T Task Force has nurtured India's basic ability to meet its own needs and "opened the eyes and minds" of Indian power plant operators by educating them on how the interrelationships between a number of power plant systems has impeded optimum plant performance for decades. This has been accomplished through extensive hands-on training in both the United States and India.*
- *Through technical support provided by DOE's National Energy Technology Laboratory and U.S. experts and technology suppliers, in partnership with Indian coal and power sector firms, more than 100 million tonnes of CO₂ emissions have been avoided to date.*
- *Based upon the successes of the ongoing U.S. government-supported power plant efficiency improvement activities under USAID/India's GEP Project and the APP PG&T Task Force, replication of similar low-cost power plant efficiency improvement activities throughout India is clearly doable.*
- *Two concepts for wider scale replication of the low-cost power plant efficiency improvement activities, which have been under consideration for the past year and should be supported under CERDI's deployment initiative, are (a) creation of a service provider network, and (b) development of model coal-fired power plant.*
- *The GoI and the Indian power generation sector have expressed strong support for these replication concepts, indicating that they are likely to be successful at expanding upon the ongoing work, which has already avoided millions of tonnes of CO₂ emissions.*
- *This replication, which can only be accomplished with additional funding, could achieve tens of millions of tonnes of additional avoided CO₂ emissions annually.*
- *India is just starting investing in more efficient, cleaner coal-based power generation technologies, such as supercritical pulverized-coal systems. India has started building its first supercritical power plants using imported technology and investing in domestic design and manufacturing capabilities. With technical support through CERDI, these new plants should be able to operate near their design parameters and maintain the plant efficiency, reliability, and maximum sustainable output (MWs) and reduce fuel consumption and CO₂ emissions.*
- *India has yet to fully commit to its IGCC technology and has insisted that it isn't ready to consider carbon capture and storage (CCS) technology as a carbon mitigation option for its power sector. Creating partnerships between Indian and U.S. R&D organizations on IGCC and CCS under CERDI is clearly needed if this paradigm is to be shifted.*

1.0 Introduction

Building on the bilateral Energy and Global Climate Change Dialogue, the governments of India and the United States of America entered into a strategic partnership by signing a MOU on November 24, 2009, to enhance cooperation on energy security, energy efficiency, clean energy, and climate change. The partnership intends to focus on increasing collaboration in energy efficiency, renewable energy, and clean energy technologies with co-benefits for reducing the impacts of climate change through the development, deployment, and transfer of transformative and innovative technologies. The key instrument to carry forward the U.S.-India partnership is the new Indo-U.S. Clean Energy Research and Deployment Initiative (CERDI) as announced by U.S. President Barack Obama and India Prime Minister Manmohan Singh. CERDI is comprised of two primary components:

- Research – A Joint Research Center (JRC) to promote clean energy innovation by supporting collaborative research through one or more consortia involving universities, the private sector, and national laboratories in each country as partners.
- Deployment – Cooperative efforts to accelerate deployment of clean energy technologies, focusing in particular on financing and creating an enabling environment.

This assessment report is intended to support the development of the cleaner coal component of the CERDI Deployment Center. The accomplishments of USAID/India's ongoing Greenhouse Gas Pollution Prevention (GEP) Project, which specifically addresses power plant efficiency improvements and GHG emissions reductions from coal-fired power generation, and predecessor clean coal programs, are reviewed focusing not on the specific technical activities, but on the avoided CO₂ emissions. As part of the ongoing GEP Project, an implementation strategy for cost-effective and sustainable replication, which has been proposed by NETL to USAID, is also reviewed. In addition, activities under the cleaner coal component of CERDI will leverage other ongoing bilateral, multinational, and the Gol's current programs.

2.0 India's Coal & Power Sector Background

India has significant coal resources, with estimated reserves of over 264 billion tonnes up to a depth of 1200 meters as of January 4, 2008 (www.coal.nic.in/induction08.pdf). India's coal reserves provide a secure economic resource for generation of electricity and meeting the energy demands of the steel, cement, and manufacturing industries. MoP's "Blueprint for the Power Sector" describes the problems and issues hampering the growth of the power sector, and the government's ambitious plan to supply "Power on Demand" to all Indian citizens by 2012. Mainly, they are:

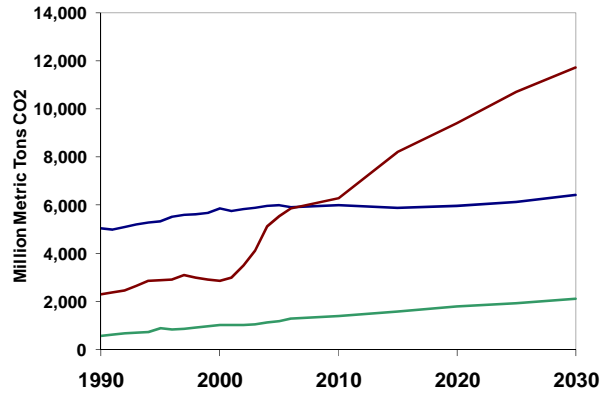
- Higher demand than power generating capacity
- Lack of optimum utilization of existing power generation capacity
- Environmentally sustainable power development
- Upgrading technical efficiency and skill levels and reorientation
- Awareness campaign and consensus building

To meet increasing demand for electricity and to bridge the significant gap between supply and demand, India plans to double its current installed capacity by 2020. The cost of this capacity addition and the associated transmission and distribution systems has been estimated at US\$160 billion. This enormous undertaking will require expertise and skills in the areas of benchmarking, adoption/adaptation of proven technologies, efficient planning and implementation strategies from concept to project execution, training and skill enhancement, consultancy services, research and development, and information management and dissemination. The blueprint also notes, apart from the massive resource mobilization needed to double generating capacity, that the task of identifying “techno-economically viable and environmentally sustainable” projects is a daunting challenge. To meet these challenges, there is an overriding need to provide expertise on a broad range of technology and policy issues for the relevant Ministries (Coal, Power, and Environment & Forests) and all power generators in the central, state, and private sectors.

2.1 CO₂ Emissions

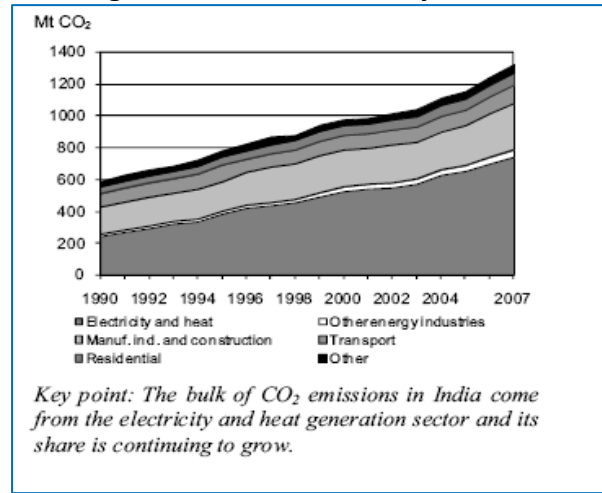
India emits nearly 5% of global CO₂ emissions, and its emissions continue to grow as the country’s standard of living increases. While India’s CO₂ emissions are increasing much slower than China’s, its emissions more than doubled between 1990 and 2007. DOE/Energy Information Administration’s International Energy Outlook projects that India’s CO₂ emissions will more than double again between 2007 and 2030, increasing by an average of 4.1% per year (Figure 1). The largest share of these emissions will continue to be produced by the electricity and heat sector, which represented 56% of CO₂ in 2007, up from 42% in 1990. The transport sector, which was only 9% of CO₂ emissions in 2007, is growing relatively slowly compared to other sectors of the economy (Figure 2). Of the BRICS countries (Brazil, Russia, India, China, and South Africa), India has the lowest CO₂ emissions per capita (1.2 t CO₂ in 2007), about one fourth that of the world average owing its relatively low electrification rate. However, India’s power and industrial sectors rely extensively on coal and it has significant scope to improve its efficiency. Moreover, due to the recent large increases in emissions, mainly from power generation, India’s CO₂ emissions per capita is more than 1.5 times of its 1990 level of 0.8 and will continue to grow. While India’s per capita emissions in 2030 are projected to be well below those of the OECD member countries today (Figure 3), the country’s natural resources will be further stressed and emissions of CO₂ per unit of GDP will remain high if additional actions are not taken. India improved the efficiency of its economy and reduced its emissions of CO₂ per unit of GDP by 21% between 1990 and 2007 (www.iea.org/co2highlights/co2highlights.pdf), however, all sectors still have a lot of scope for improvement.

Figure 1: Total CO₂ Emissions from Energy Consumption: United States, China, India (1990 – 2030)



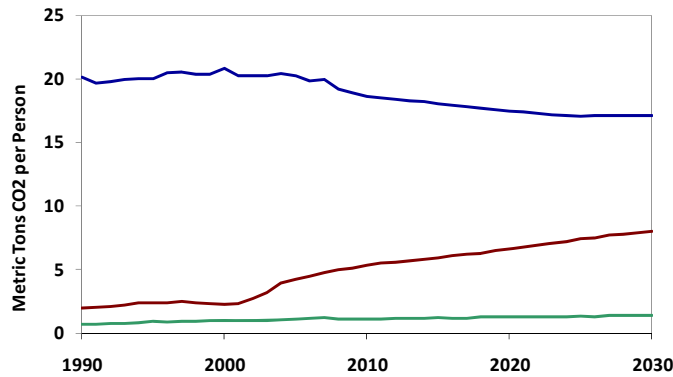
Source: Historical Data, USDOE/EIA, International Energy Statistics, Forecast Data, USDOE/EIA, International Energy Outlook 2009.

Figure 2: CO₂ Emissions by Sector



Source: International Energy Agency Statistics 2009 Edition; CO₂ Emissions from Fuel Combustion

Figure 3: Total CO₂ Emissions per Capita from Energy Consumption: United States, China, India (1990 – 2030)



Source: Historical Data (1990-2007): U.S. Energy Information Administration, International Energy Statistics Portal; Projected Data (2008-2030): U.S. Energy Information Administration, International Energy Outlook 2009.

Other key India CO₂ emissions statistics:

- India's CO₂ emissions in 2007 were 1,324 million tonnes according to the International Energy Agency (IEA) (<http://www.iea.org/co2highlights/co2highlights.pdf>)
- CO₂ emissions from coal use in India were 895 million tonnes in 2007 according to the IEA. (<http://www.iea.org/co2highlights/co2highlights.pdf>)
- India's CO₂ emissions from coal combustion are projected to total 1.3 billion tonnes in 2030, accounting for more than 7 percent of the world total (USDOE/EIA International Energy Outlook 2009, <http://www.eia.doe.gov/oiaf/ieo/index.html>)
- India's CO₂ emissions per capita increase from 1.1 tonnes per person in 2006 to 1.4 metric tons per person in 2030 (USDOE/EIA International Energy Outlook 2009, <http://www.eia.doe.gov/oiaf/ieo/index.html>)

2.2 India Power Sector

With high rates of economic growth and over 15 percent of the world's population, India has become a significant consumer of energy resources. Electricity production in India totaled 904,477 GWh in fiscal year 2007-2008 (CEA, All India Electric Statistics, 2009). In 2007, 68% of electricity came from coal, another 8% from natural gas, and 4% from oil (Appendix B). The share of fossil fuels in India's total generation mix grew from 73% in 1990 to 85% in 2002. Since then, the share of fossil fuels has declined, falling to 81% in 2007. Although electricity produced from hydro increased during this period, its share fell from 25% in 1990 to 15% in 2007. India had an installed capacity of 13 GW of renewable energy sources on 31 August 2009. With an installed wind capacity of 10 GW in July 2009, India has the fifth largest installed capacity of wind power in the world. Under its National Action Plan on Climate Change, India plans to install 20 GW of solar power by 2020.

In 2004, the Planning Commission formed an Expert Committee on Integrated Energy Policy, which was charged with preparing integrated energy policy for India linked with sustainable development that covers all sources of energy and addresses all aspects including energy security, access and availability, affordability and pricing, efficiency and environment. Their 2005 study (<http://planningcommission.nic.in/reports/genrep/intengpol.pdf>) indicated that the country meets was meeting about 30% of its energy needs through imports. With the increasing share of fossil fuels in the energy supply/use, the share of imported energy was likely to increase. The report posits that India faces a challenge in meeting its energy needs and providing adequate energy of the desired quality in various forms to users in a sustainable manner and at reasonable costs. It indicated that India needed to sustain an economic growth rate of 8-10% to eradicate poverty and meet its economic and human development goals. Such economic growth would require a substantial increase in energy consumption while ensuring access to clean, convenient, and reliable energy for all. To deliver sustained growth of 8% through 2031, India would need to grow its primary energy supply by at least 3 to 4 times and electricity supply by at least 5 to 7 times of consumption at that time. By 2031-32, power generation capacity would have to increase to 778,095 MW and annual coal requirement would exceed 2 billion tonnes, unless significant measures to increase power generation from alternative (e.g., renewable or nuclear) energy sources and to increase both demand and

supply efficiency were undertaken. The report states “Meeting this vision would require that India pursues all available fuel options and forms of energy, both conventional and non-conventional, as well as new and emerging technologies and energy sources. Coal shall remain India’s most important energy source till 2031-32 and possibly beyond. India will need to take a lead in seeking clean coal technologies....”

Additional charts and tables on India power sector including CO₂ emissions, installed capacity by fuel and by sector, plant load factors, and thermal efficiencies are presented in Appendix B.

2.3 Indian Power Sector Performance

A significant percentage of India’s existing coal-fired power plants are aging and operate at much higher heat rate than designed, especially those operated by state utilities. In recent years, India power generators have focused on increasing plant load factors (PLF, or capacity factors) to increase electricity output, often at the expense of plant efficiency. While the national average PLF for stations in central sector (i.e., NTPC) has approached 90%, which is world class, the average PLF of state-operated plants is about 70%, and private utility plants is 85%. However, many individual plants, especially those operated by state utilities, are below 55% and below 30% in some cases (Appendix B).

A large potential exists to increase generation and improve efficiency through Energy Efficient R&M. On average, most Indian coal-fired power plants operate at heat rates higher than their designed rate. A recent Central Electricity Authority (CEA) study of 53 power plants, constituting a total capacity of 37,830 MW, which is about half of India’s total coal-fired capacity, shows that their heat rates are about 13.7% higher than their design values. The weighted average design heat rate is 2,377 kcal/kWh (about 36%), whereas their weighted actual heat rate is 2,703 kcal/kWh (31.8%). This clearly indicates that an average performance improvement on the order of 300 kcal/kWh is achievable. Higher operating heat rate leads to increased power generation costs, faster depletion of natural resources (coal), higher emissions of conventional pollutants, such as SO₂, NO_x, and particulates, and increased CO₂ emissions.

Also, CEA, in consultation with the state utilities, prepared a National Perspective Plan for R&M and LE, which covers up to 2017, for existing 200-210 MW and some 500-MW coal-fired plants that more than 15 years old. In the plan, 53 units (7,318 MW) for LE and 76 units (18,965 MW) for R&M were identified in the 11th Five Year Plan and an additional 72 units (16,532 MW) for LE and 23 units (4,971 MW) for R&M in the 12th Five Year Plan. If successful, coal consumption in these units could be reduced by up to 15 million tonnes annually, which is equivalent to reducing almost 20 million tonnes of CO₂ emissions annually. The technology-intensive R&M for efficiency improvement needed in these projects is beyond restoration of original generation capacity, life extension, and improved availability. It would enable these units to operate at higher outputs with lower required fuel input and less GHG emissions.

Efficiency improvement in existing power plants represents the greatest near-term opportunity in the Indian power sector to conserve fuel and achieve significant reductions of CO₂ emissions. A small reduction of 25 kcal/kWh in heat rate (i.e., approximately, 0.3% absolute, or 1%

relative) in a large utility with a total capacity of 25,000 MW, burning a typical Indian high-ash (>40%) coal with a calorific value of 3,500 kcal/kg in a plant with a typical PLF of 83% will reduce the utility's coal consumption by approximately 1.3 million tons and CO₂ emissions by 1.6 million tons annually. Achieving a 25 kcal/kWh improvement, which is possible through simple changes in operational set points determined after combustion optimization testing, requires little or no capital investment. Once the set points are determined, performance improvements achieved can be sustained through periodic testing, which can be done either by trained plant staff or qualified combustion optimization service providers.

While many of NTPC's plants are less than 20 years old, many state utility/SEB plants average more than 30 years in age with limited maintenance and upkeep due to lack of resources. Consequently, many of these plants are no longer in a good shape. Some are now being restored under GoI and other internationally financed R&M programs. A decision has also been made by the GoI to retire around 3,000 MW of existing old generating capacity supplied by 110-MW units and below, primarily due to their poor operating efficiency (less than 20%). The lost capacity will be restored by building larger 210 and 500 MW units, which have become the standard capacity of most coal-fired units being built in India today.

State utility/SEB plants in the country have the greatest potential for efficiency improvement. On average, these plants operate at 3 to 6% below their design efficiency, owing largely to constraints in critical equipment, want of proper instrumentation, poor quality coal, and limited availability of poorly trained manpower. The goal of GoI and a number of other bilateral and multilateral programs is to turn around the performance of state utility/SEB power plants.

The first demonstration of heat rate monitoring and improvement was conducted during 1996-98 at NTPC's Dadri plant under the USAID-GEP Project. Through an interagency agreement with NETL, the Tennessee Valley Authority (TVA) conducted the efficiency tests and helped train the NTPC-CenPEEP and NTPC Dadri plant personnel. USAID supplied a complete set of diagnostic test equipment per TVA specifications. Subsequently, two additional NTPC plants (Singrauli and Rihand) and two State Electricity Board (SEB) plants (Gujarat State Electricity Board's Wanakbori plant and Maharashtra State Electricity Board's Koradi plant) were also included for efficiency improvement. In all, the demonstration of efficiency improvement and transfer of best practices were completed in five Indian power plants by 2000. TVA and CenPEEP prepared comprehensive Heat Rate Improvement Guidelines document complete with test procedures and calculations for Indian coal-fired power plants. The guidelines were distributed by CenPEEP to all state utilities. CenPEEP and NTPC plant engineers were also trained in TVA plants and workshops on best practices were also provided to CenPEEP and NTPC plant personnel. Subsequently two regional CenPEEPs – one in the Eastern Region at NTPC's headquarters in Patna, and one in the Northern Region at Lucknow – were established to meet the needs of NTPC stations in these regions. USAID assistance was limited to providing the test equipment for these centers and technical assistance during the initial operation of the centers. Building on the successes garnered through its network of CenPEEPs, NTPC established an Efficiency Monitoring System throughout its power plant fleet, which has led to some of the NTPC plants being among the top performing coal-fired power plants in the world.

Power plant efficiency improvement activities are also being supported under the Asia Pacific Partnership on Clean Development and Climate (APP), funded by DOE and USAID/India. Under this program, two state utility power plants, Punjab State Electricity Board's (PSEB) Ropar plant and West Bengal Power Development Corporation Limited's (WBPDCL) Kolaghat plant were selected. One 200-MW coal-fired unit was identified in each of the two stations for performance improvement. These efforts led to a 2-3 % boiler efficiency improvement in both power plants and a set of recommendations for further improvement and maintenance of the gains achieved in the units was developed. Both plants have six nearly identical units, which the utilities are now improving on their own based on the knowledge and instrumentation/equipment provided through the APP program. Another 200-MW unit at Tamil Nadu Electricity Board's (TNEB) Tuticorin Thermal Power Station (TTPS) is also being provided similar performance improvement assistance.

Key Findings

- *India currently relies on coal for more than 2/3 of its electricity. Coal will likely continue to underpin India's economic development for many years in the future. While India has significant coal reserves, it is increasingly turning to imported coal, from Australia, Indonesia, and other countries, to meet its energy requirements for power generation, owing to difficult mining logistics, overloaded transportation infrastructure, and high infrastructure financing costs.*
- *A significant percentage of India's existing coal-fired power plants are aging and no longer very efficient or reliable, especially those operated by state utilities. There exists a large potential to increase generation and improve efficiency through Energy Efficient R&M.*
- *State utility/SEB plants in the country have the greatest potential for efficiency improvement. On average, these plants operate at 3 to 6% below their design efficiency, owing largely to limitations in critical equipment, need for proper instrumentation, below average coal quality, and need for trained manpower.*
- *A small reduction of 25 kcal/kWh in heat rate (i.e., approximately 1% relative improvement) in a large utility with a total capacity of 25,000 MW, burning a typical Indian high-ash coal in a typical plant with a plant load factor of 83% will reduce the utility's coal consumption by approximately 1.3 million tons and CO₂ emissions by 1.6 million tons annually. This is achievable through simple changes in operational set points determined after combustion optimization testing, requiring little or no capital investment.*

3.0 U.S.-Indo Cooperation Related to Clean Coal

Cooperation between the United States and India on clean coal-related technologies occurs through:

- U.S.-India Energy Dialogue
 - Power & Energy Efficiency Working Group
 - Coal Working Group
- USAID Programs with the GoI

3.1 U.S.-India Energy Dialogue

The U.S.-India Energy Dialogue is part of the Energy and Climate Change Pillar of the U.S.-India Strategic Dialogue. It consists of five working groups: (i) the Civil Nuclear Working Group; (ii) the New Technology and Renewable Energy Working Group; (iii) the Power and Energy Efficiency Working Group; (iv) the Coal Working Group; and, (v) the Oil and Gas Working Group. The Power and Energy Efficiency Working Group is co-chaired on the U.S. side by DOE and USAID, and on the Indian side by MoP. The Power and Energy Efficiency Working Group has undertaken work in a number of areas, including:

- cooperation between NETL and USAID, and MoP, CEA, NTPC, and several state utilities to improve the efficiency of existing coal-fired power plants in India (joint efforts to date have resulted in the savings of millions of tons of coal and millions of tons of CO₂)
- creation of an Integrated Gasification Combined Cycle (IGCC) Task Force, focused on involving major IGCC technology providers in a joint IGCC pre-feasibility study
- work on building and industrial energy efficiency, including promoting Energy Saving Companies (ESCOs) and energy audits, and broad use of state-of-the art building energy simulation models and tools

The Coal Working Group has focused on coal mining-related issues, including coal preparation/beneficiation, including dry coal cleaning; coal bed and coal mine methane (CBM and CMM); utilization of waste coal from cleaning operation, including combustion using advanced boiler technologies; and coal mine safety. Although these areas offer some potential for GHG reduction, especially CBM and CMM utilization, and resource conservation, they have not been a major focus of NETL and USAID cooperation with India, and are not addressed in this assessment report.

3.2 USAID Programs with the GoI

Several events leading up to the early 1980s gave rise to USAID's energy program activities in India. In the 1960s, India faced severe national food crises, and was heavily dependent on foreign assistance to meet its food needs. There was a growing commitment across the Indian government and the world community to agricultural development and food security for India. During the late 1960s and into the 1970s, USAID worked with India's Rural Electrification Corporation (REC) to form rural cooperatives and build over a dozen thermal and hydroelectric

power plants. USAID used congressionally authorized resources (PL 480) to invest in grid expansion and provided US\$175 million for rural electrification to help India meet its food production needs. Those investments were expanded during the 1980s as REC extended rural electrification under the Minimum Needs Program for particularly underdeveloped areas. A large number of rural areas received power for the first time. At the macro-level, investments in power, irrigation, and rural roads helped to lay the foundation for India’s Green Revolution and set it firmly on the path to self-sufficiency in domestic food production. In addition, oil embargo of the mid-1970s left India facing serious oil shortages (nearly 60% of the oil used in the country was imported) and on the search for alternate sources of energy.

Bilateral cooperation between the United States, supported by USAID, and India in the area of clean coal technologies began in 1982. The overall goal of USAID’s Indo-U.S. Clean Coal Technologies Program has been to strengthen the capacity of India’s scientific laboratories, power plant equipment manufacturers, and coal-fired utilities to develop, deploy, and commercialize new technologies aimed at utilizing high-ash Indian coal efficiently. This objective was later expanded in the early 1990s to address the need to mitigate GHG emissions from Indian power plants. Since 1982, the U.S. Department of Energy’s (DOE) National Energy Technology Laboratory (NETL), and its predecessor organizations, supported implementation of significant elements of several USAID/India energy and environment programs. This has been accomplished through a series of interagency agreements (i.e., Participating Agency Services Agreements, PASAs) between USAID/India and NETL. Table 1 shows the focus and timeframe of USAID’s program that NETL supported.

Table 1: USAID Cleaner Coal Programs

Program/Project	Focus	Term
Alternative Energy Research & Development (AERD Phases I & II)	Pilot Plant Support	1982 - 1992
Energy Management Consultation and Training Program (EMCAT)	Plant Study	1993 - 1995
Program for Accelerating Commercial Energy Research (PACER)	Demo Plant	1993 - 1997
Indo-U.S. Coal Preparation Program	Demo Plant Support	1994 - 1996
Greenhouse Gas Pollution Prevention (GEP) Project	Training and Demos	1995 - 2002
GEP – Climate Change Supplement I	Training and Demos	2000 - 2005
GEP – Climate Change Supplement II	Training and Demos	2003 - 2010

Alternative Energy Research and Development Program (AERD) – This two-phase program was designed to help India develop combustion technologies and related test facilities to use its indigenous high-ash coal and biomass resources cleanly for electric power generation while reducing GHG generation.

Energy Management Consultation and Training Program (EMCAT) – This program was designed to improve the availability, reliability, and efficient use of energy in India through improved management, policy reforms, and public awareness, and included efforts to assess and evaluate the conditions of Indian thermal power plants and identify measures for extending their useful life.

Program for Accelerating Commercial Energy Research (PACER) – This program was designed to promote the development of new or innovative products or processes relevant to the Indian energy sector. The coal conversion technology component focused on supporting the development of pressurized fluidized bed coal gasification with a combined cycle power plant, and a demonstration plant for the beneficiation of high-ash Indian coals in the first commercial washery in India in the private sector for steam coal. The cleaned coal from the Bilaspur washery has allowed more efficient operation of Reliance’s Dahanu power plant, resulting in substantial CO₂ emission reductions.

Indo-U.S. Coal Preparation Program – This interagency public/private partnership program was designed to demonstrate within India the commercial feasibility and economic and environmental benefits from using beneficiated or washed coal in power plants.

Greenhouse Gas Pollution Prevention (GEP) Project – The GEP Project agreement was signed between the Governments of India and the United States through USAID/India on April 10, 1995. This project has two components: (a) Efficient Coal Conversion, which focused on technology demonstration, training and outreach to improve the performance of existing coal-fired power plants, thereby reducing CO₂ emissions, and (b) Alternative Bagasse Cogeneration, whose intent was to demonstrate the year-round use of bagasse (crushed sugarcane waste) or other biomass fuels for efficient cogeneration in the Indian sugar industry. The accomplishments achieved under the GEP Project – and its extension, the Global Climate Supplement – are a main focus of this assessment report.

When the agreement was signed, India’s economic reform process was at a critical point as there was a shortfall in the supply of reliable electric power. Indian power plants were not as efficient as world standards and were fueled by low-calorific value, high-ash coals. For India to continue to grow, it was necessary to augment its electric generation capacity. However, India was already the fifth largest and second fastest growing GHG source in the world. Decisions about the selection of non-polluting capital equipment and the improvement of the efficiency of existing thermal plants were viewed as key elements to sustaining India’s economic growth and protecting its environment. The GEP Project was designed to provide the knowhow and tools needed to ensure that such decisions would improve the Indian standard of living and protect the environment.

GEP Project Efficient – Coal Conversion (ECC) Component The GEP ECC Component aimed to establish a self-sustaining institution for technical support to improve efficiency in the thermal power sector in India and conduct a study on advanced coal conversion technologies suitable for India. Under the ECC component, the Center for Power Efficiency & Environmental Protection (CenPEEP) was established in 1994 by NTPC in partnership with USAID/India and NETL. CenPEEP serves as the national resource center for acquiring, demonstrating, and disseminating technologies and best practices for the improvement of power plant operating efficiency, availability, and environmental performance in coal-fired power plants. NETL has supported CenPEEP’s growth and expansion to two regional centers in Patna and Lucknow, and

now works closely with CenPEEP in implementing both GEP and APP project activities throughout India.

GEP Project Climate Change Supplement – Efficient Power Generation Component – The GEP-Climate Change Supplement’s (GEP-CCS) Efficient Power Generation (EPG) Component was launched to expand upon the success of GEP-ECC. Two new elements – fostering climate change initiatives for sustainable development, and linking urban development and climate change activities – were added. Through the GEP-CCS EPG Component, many activities were conducted with NTPC as the primary partner to improve their power plants and several state utility plants. NETL provided technical assistance and training to NTPC and to coal-based power plants of state utilities through CenPEEP, which resulted in a significant reduction of GHG emissions while saving many millions of dollars in reduced operating and maintenance (O&M) and coal costs. For example, *Heat Rate Improvement Guidelines* were prepared and distributed throughout the Indian power sector, and are being routinely used by power stations to improve their performance. More than 300 demonstration exercises have been conducted and replicated in various Indian power stations on a wide range of state-of-the-art technologies and practices (e.g., combustion optimization, condenser optimization, cooling tower performance improvement, and turbine evaluations).

Since 1996, CenPEEP has hosted nearly 50 U.S. expert teams covering about 1,000 person-days and 15 Indian teams have visited more than 20 U.S. power stations and institutes for training. About 110 workshops have been conducted on a broad range of topics, and CenPEEP provided more than 13,000 person-days of technical assistance, training, and outreach to power professionals throughout India through a Comprehensive Performance Optimization Program that addressed (1) power plant efficiency improvement, (2) predictive maintenance and overhauling practices for power plant equipment, (3) environmental monitoring and control, and (4) large-scale fly ash utilization.

For its efforts in promoting climate friendly technologies and reducing GHG emissions, CenPEEP has received the following major domestic and international climate and business excellence awards:

- World Climate Technology Award 2002 by IEA’s Climate Technology Initiative (CTI)
- U.S. Environmental Protection Agency’s Climate Protection Award in 2003
- India’s Council of Power Utilities’ India Power Award 2008 Jury’s Award
- ISAQ International Star Award for Quality in the Gold Category, presented by Business Initiative Directions (BID) in 2009

3.3 GEP Project Sustainable Benefits

- A heat rate improvement of 1-2 percentage points (3.2-6.4% relative) can be achieved in the majority of existing Indian coal-fired power plants simply through sound efficiency monitoring practices, techniques, and systems, and improved plant operational practices with the help of simple diagnostic and testing equipment – all with low investment. A 1% heat rate improvement (equivalent to about 0.33% efficiency) is

equivalent to a reduction in annual reduction of about 4 million tons of coal and over 5 million tons of CO₂ for all Indian coal-fired power plants, with the accrued benefits, including improved reliability, exceeding costs.

- Infrared thermography and acoustic diagnostic techniques were introduced for early detection of equipment problems, and have become accepted practices in many Indian coal-based power plants. The introduction of predictive, condition-based maintenance in NTPC power plants has significantly improved the reliability of power plant equipment.
- Ash resistivity measurement facilities have filled a gap in ash characterization – critical for optimization of electrostatic precipitators, which is essential for Indian power plants.
- An overhauling practices manual for use by power plant professionals throughout India was prepared, which is providing the foundation for plant improvement projects.
- The use of eddy currents for removing the ‘studs’ of steam turbines has been demonstrated and is now being used by local manufacturers.

3.4 CO₂ Emissions Avoided as a Result of USAID’s Coal Programs

Measures instituted under the U.S. Clean Coal activities to improve power plant’s operations and maintenance (O&M) culture or its operational efficiency, have resulted in significant CO₂ emissions avoidance. Table 2 is a snapshot of what has been documented starting in April 1996 and estimated through the end of March 2010.

While rigorous testing wasn’t performed before or after most of the activities conducted owing to technical (e.g., plant availability) and budget limitations, the avoided CO₂ emissions were estimated base on estimated emissions reduction determined through sound engineering experience and judgment by very experienced engineers. The avoided emissions were estimated by assuming that emissions reduction achieved in a reporting period is maintained over subsequent periods. If no additional efficiency improvement measures are taken then the reductions achieved in the preceding period are assumed, which is reasonable based on sound engineering experience. In other words, once a reduction is attained, it is maintained. The state utilities, who were supported early in the GEP Project, have not reported their activities after April 2000; however, it is believed that additional reductions were achieved through incremental improvements in efficiency in additional plants. Therefore, the 101 million tonnes of avoided CO₂ emissions is likely a conservative number. Efforts are being made by USAID, NETL, and NTPC to obtain these data, including asking MoP and CEA to formally request it from the state utilities.

Estimated aggregate CO₂ emissions avoided during October 2006 and September 2009, which were projected to the end of March 2010, are given in Figure 4 and Table 2. It is obvious from the estimates that the potential for CO₂ emissions reduction and subsequent avoidance is the greatest in state utility plants, which are much less efficient than plants operated by NTPC, private utilities, and some captive power plants operated in the industrial sector.

Figure 4: CO₂ Emissions Avoided (in Tonnes) from USAID’s Clean Coal Activities by Participant (April 1996 – 2030)

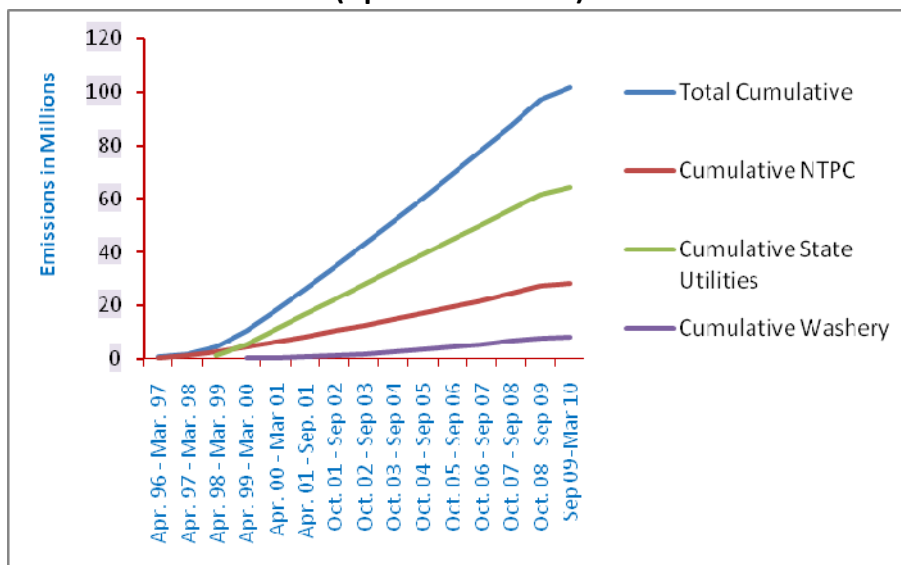


Table 2: CO₂ Emissions Avoided (in Tonnes) from USAID’s Clean Coal Activities by Participant (April 1996 – 2030)

PERIOD	NTPC	CUMULATIVE NTPC	STATE UTILITIES	CUMULATIVE STATE UTILITIES	COAL WASHERY	CUMULATIVE WASHERY	CUMULATIVE TOTAL
Apr. 96 - Mar. 97	349,337	349,337					698,674
Apr. 97 - Mar. 98	853,680	1,203,017					1,552,354
Apr. 98 - Mar. 99	1,493,116	2,696,133	1,409,913	1,409,913			4,455,383
Apr. 99 - Mar. 00	1,808,658	4,504,791	4,229,739	5,639,652	174,390	174,390	10,668,170
Apr. 00 - Mar 01	1,840,222	6,345,013	5,490,430	11,130,082	300,730	475,120	18,299,552
Apr. 01 - Sep. 01	1,912,409	8,257,422	5,490,430	16,620,512	363,900	839,020	26,066,291
Oct. 01 - Sep 02	2,138,368	10,395,790	5,605,430	22,225,942	490,240	1,329,260	34,300,329
Oct. 02 - Sep 03	2,178,368	12,574,158	5,605,430	27,831,372	616,580	1,945,840	42,700,707
Oct. 03 - Sep 04	2,228,368	14,802,526	5,605,430	33,436,802	728,589	2,674,429	51,263,094
Oct. 04 - Sep 05	2,298,368	17,100,894	5,605,430	39,042,232	854,929	3,529,358	60,021,821
Oct. 05 - Sep 06	2,378,368	19,479,262	5,605,430	44,647,662	981,269	4,510,627	68,986,888
Oct. 06 - Sep 07	2,473,368	21,952,630	5,605,430	50,253,092	1,107,609	5,618,236	78,173,295
Oct. 07 - Sep 08	2,571,868	24,524,498	5,605,430	55,858,522	1,107,609	6,725,845	87,458,202
Oct. 08 - Sep 09	2,667,061	27,191,559	5,605,430	61,463,952	1,107,609	7,833,454	96,838,302
Sep 09-Mar 10 (estimated)	1,333,531	28,525,090	2,802,715	64,266,667	553,805	8,387,259	101,528,352

Key Findings

- *Over the past 14 years, USAID's coal-related programs have addressed many of the Indian coal and power sector's most important problems. In particular, the GEP Project has gained a deep knowledge of the most pressing problems facing India's coal power sector and has developed an extensive network of relationships between the governments and industry of the United States and India.*
- *Through technical support provided by DOE's National Energy Technology Laboratory and U.S. power plant experts and technology suppliers, in partnership with NTPC and several state utility power plants under the GEP program, more than 100 million tonnes of CO₂ emissions have been avoided to date.*
- *Based on these accomplishments, wider replication of similar low-cost power plant efficiency improvement activities throughout India is clearly doable.*
- *This replication, which can only be accomplished with additional funding, could achieve tens of millions of tonnes of additional avoided CO₂ emissions annually to add to the cumulative avoided CO₂ emissions to date.*

4.0 U.S.-India Cleaner Coal Technologies R&D Programs

Historically, India has had a modest national effort to research and develop cleaner coal technologies, along with some bilateral and multilateral cooperation with other nations. The Ministry of Coal has supported R&D on improved coal mining and processing technologies since 1976. During the last 2 decades, a number of science & technology (S&T) projects on cleaner coal technologies have been supported by the Council of Scientific & Industrial Research (CSIR). Most activities have focused on the adaption of proven technologies from around the world to Indian conditions (e.g., high-ash coals and high-ambient temperatures) and situations (e.g., manufacturing capabilities and cost structures). Also, most of the cleaner coal R&D conducted by leading universities is directed at basic research, with limited commercial application.

4.1 Supercritical and Ultra-Supercritical Technology Development in India

BHEL, the primary boiler supplier in India, has the capability to manufacture subcritical boilers up to 800 MW. However, based on the challenging targets that have been set for capacity addition during the 11th Five Year Plan, along with Gol's Ultra Mega Power Project concept, BHEL signed an industrial partnership agreement in 2007 with Alstom, a global power systems manufacturer and service provider, for cooperation on once-through boiler and pulverizer technologies. A major objective of this partnership, which will enable BHEL to produce 1,000-MW power plants, is to win business in India's supercritical power plant program to help India efficiently meet its power generation needs. The partnership agreement was constituted by a Technical Assistance Agreement (e.g., license) including all once-through boiler designs and associated high-performance pulverizers and a Business Cooperation Agreement defining the industrial scope of each of the partners for future boilers to be ordered. Alstom will supply engineering and key boiler components, bringing work to its facilities in the United States, Germany, and India. BHEL has also signed a MOU with Siemens for cooperation in the field of advanced power plant technology. BHEL and Siemens will jointly offer and install steam turbines for supercritical power plant projects.

In February 2010, Alstom, and Bharat Forge Ltd., a global leader in manufacturing and metal forming, laid the foundation stone for their new power equipment manufacturing plant at Mundra. The plant will manufacture 300-800 MW subcritical and supercritical equipment with an annual capacity of 5,000 MW. In the future, the JV will also explore possibilities of manufacturing turbines and generators for gas-based plants and nuclear applications.

NTPC is erecting India's first supercritical thermal power station in Sipat, Chhattisgarh. The total approved capacity of Sipat is 2980 MW, which includes three 660-MW supercritical units in Stage I and two 500-MW supercritical units in Stage II. The boilers and auxiliaries for the Stage I units, which are under various stages of implementation, are being supplied by Doosan of Korea. The Stage I project was due to be completed in early 2009, but has been delayed until early 2010.

4.2 IGCC Technology Development in India

BHEL started bench and pilot-scale R&D on coal gasification in the mid-1980s. The first pilot-scale test facility based on fluidized-bed gasification (FBG) was set up at BHEL's Corporate Research Center in Hyderabad. This was designed for 18-tons/hour coal throughput with a pressurized-lock hopper system. Early testing was aimed at running the gasifier to resolve the operational bottlenecks and improve the heat value of the coal gas. A parallel effort funded by CSIR was initiated at its Regional Research Laboratory in Hyderabad to conduct bench-scale research on cold-gas clean up and at BHEL Corporate R&D Center on hot-gas clean-up R&D.

Subsequently, BHEL set up a larger-scale (6.2-MWe) IGCC pilot plant at its R&D Center in Tiruchirapalli (Trichy) in 1985. The facility was commissioned in 1989, with a pressurized fluidized bed gasifier and a 4.0-MW Mitsubishi gas turbine using cold-gas clean up. The gas turbine did not operate as expected because of blade failure from corrosion from the high-sulfur content of the syngas. Thereafter, the gasifier was operated only to obtain process and systems data. BHEL has reported 4000 hours of operation. Later, BHEL increased the coal throughput to 150 tons/day and operating conditions to 13 atmospheres pressure and 1000°C. The gasifier has operated for more than 2000 hours and has provided data for scale up to a 125-MW IGCC plant. In addition to the initial capital investment of Rs 15 Crores (about US\$3 million) for the pilot plant, an additional investment of Rs 18 crores (about US\$4 million) has been made. BHEL's current annual expenditure on IGCC development is about 8 crores (about US\$1.7 million).

GoI has constituted an R&D Committee to bring about synergy between BHEL and the user utility. The committee with members from CSIR, NTPC, and BHEL set targets to be met before taking up the installation of a demonstration project. The working group participated in experiments in BHEL's research facilities, evaluated the data, and reported the results to the R&D Committee. The Committee concluded that the targeted performance has been achieved and scaling up the BHEL design from 6.2 MW to 125 MW was feasible. Subsequently, Andhra Pradesh Generating Company (APGENCO) and BHEL agreed to enter into a MOU to establish a 125-MW IGCC project. The demo plant is proposed to be installed at APGENCO's Vijayawada

Thermal Power Station. The expected cost of the project is around Rs. 950 crores (about US\$2.1 billion) with BHEL contributing Rs. 420 crores (about US\$915 million) for the coal gasifier and gas clean-up system and APGENCO mobilizing Rs. 530 crores (about US\$1.2 billion) for the power block.

Separately, NTPC has proposed building a 100-MW IGCC demonstration plant. The project aims to adapt the IGCC technology to Indian conditions. In the first phase, NTPC would procure and develop the fluidized gasifier and gas clean-up system and other required equipment. Under the second phase, it would procure appropriate combined cycle gas treatment plant and integrate it with the gasifier and gas clean-up system. NTPC is to appoint a reputed consultant to assist in preparation of technical specifications and provide services as the owner's engineers.

4.3 USAID/India Support for IGCC Technology Development in India

Starting in the mid-1980's, NETL provided technical assistance to BHEL through USAID/India's AERD Programs to improve their technology for gasification of Indian coals:

- Technical assistance on design, process integration, gas clean up, coal characterization and process simulation and modeling
- USAID partially funded (US\$3 million) BHEL's IGCC pilot facility in Trichy, including providing equipment, controls, and instrumentation from U.S. vendors
- Visits by BHEL engineers to U.S. IGCC facilities (Tampa, Wabash, and Pinon Pine)

In early 1990's, technical assistance was provided by the former DOE Pittsburgh and Morgantown Energy Technology Centers (PETC and METC, now NETL) on gas clean-up systems and arranged visits by Indian investigators to METC and other gasification research facilities, including the Institute for Gas Technology (IGT) and Westinghouse. In addition, an on-line gas analyzer system and laboratory instrumentation were provided. Under USAID's PACER Program, US\$3.0 million was provided to BHEL to support the scale up of the gasifier, including purchases of equipment, instrumentation, etc. Also, PETC and METC provided technical assistance, valued at about US\$300,000, including review of the gasifier design, support for modeling of the overall gasification process, and studies on ash agglomeration, and coal and char reactivity measurement.

In 2002, USAID funded a US\$2.0-million IGCC feasibility study, which was conducted by Nexant with NETL technical oversight. The Indian partner was NTPC, which had indicated interest in setting up India's first IGCC demonstration plant. This feasibility study:

- evaluated and ranked commercial IGCC technologies that are most suitable for Indian coals;
- compared their economics with the conventional PC-fired and other advanced coal-fired power generation technologies;

- selected the most suitable IGCC technology in terms of techno-economic feasibility and environmental benefits;
- performed a site-specific engineering design and economic analysis for the selected technology for 100-MW capacity;
- determined the benefits with respect to life cycle costs and emissions; and
- established a roadmap for commercialization of coal-based IGCC technology.

BHEL, Lurgi, KRW, Gas Technology Institute (GTI), and other technology suppliers were asked to participate in the project. The final report concluded that the pressurized fluidized bed gasification (PFBG) technology offered by GTI was the technology of choice for typical high-ash Indian coals, based in great part on it having operated at scale on similar coals. The BHEL technology was believed to be promising but unproven at scale, and hence was not ready for full-scale demonstration. The study focused on developing performance and cost data for a full-scale demo plant. However, these recommendations were not accepted owing to a preference for domestic technology. The project did not move forward owing to lack of a viable plan to finance the incremental costs for the IGCC demonstration plant by the Indian government, and interested organizations, including NTPC and BHEL.

Subsequently, the Asian Development Bank (ADB) proposed a US\$2-million Project Preparatory Technical Assistance (PPTA) Project to MoP and NTPC to develop a reference IGCC plant (100-200 MW capacity) for India. The PPTA would have covered gasification technology selection, development of EPC contract documentation, and probable financing mechanism, and would have been executed through an international consultant selected through a proposal process. The ADB indicated it wanted to involve NETL in the PPTA, as an advisor to the selected consultant based on its earlier IGCC study for USAID. However, MoP and NTPC were not ready to undertake a large-scale demonstration project.

Under the flagship Best Practices for Power Generation Project, the American Electric Power Company (AEP) hosted a set of site visits during 30 October – 4 November, 2006. AEP fostered a “hands-on” environment where participants learned from one another, shared information, and collaborated on how best to address the world’s need to generate electricity from coal with less or minimal environmental impacts. One of the session tracks was on IGCC technology in which several Indian engineers from BHEL and NTPC participated.

4.4 CCS Technology Development in India

Currently, India has annual CO₂ emissions of around 1343 Mt with approximately half being emitted from large point sources suitable for CO₂ capture. A GoI initiative to develop up to nine Ultra-Mega Power Projects (UMPP) to meet increased energy demand will add approximately 36,000 MW of installed capacity, with a corresponding increase in CO₂ emissions of approximately 275 million tonnes per year. Considering India’s status as a large emitter of CO₂ from existing coal power generation and with a large expected increase in CO₂ emissions in the near term, it has been suggested that India consider CO₂ capture and storage as a mitigation option.

A 2009 IEA study (<http://co2storage.org/Reports/2008-02.pdf>) assessed CO₂ storage potential in India's saline aquifers and coal, oil, and gas fields at 5 gigatons (GT). However, the geological data needed to estimate the storage potential of India's saline aquifers are sparse and would need to be quantified before India could consider this option. Some of the major conclusions from this study are summarized below.

Storage in deep coal seams is still in the demonstration phase, and, therefore, not ready for full-scale development, but as more demonstration projects become active around the world, there may be scope for a demonstration project to ascertain its relevance to India. There is potential for CO₂ for enhanced oil recovery, both onshore and offshore, but the potential cannot be quantified without further exploration of the oil fields. There may be potential to store CO₂ in India's deep saline aquifers in shallow offshore areas, in Gujarat, Rajasthan, and Assam and possibly in Cachar, Tripura, and Mizoram, although most of the main emission sources are located some distance from potential storage sites (IEA Technical Study Report No. 200/2, May 2008). It is essential that the saline aquifer CO₂ storage potential of India's onshore and offshore sedimentary basins be investigated in more detail. If the saline aquifers are found wanting, export of CO₂ by ship, perhaps to the Middle East, could be an alternative for CCS for India.

DOE's Carbon Sequestration Program is focused on developing technologies to capture, separate, and store CO₂. India could benefit through cooperation with NETL, which could be supported through CERDI.

4.5 Indian CCT R&D Organizations

India's capacity for conducting cutting-edge cleaner coal-related R&D is rather limited compared to China's, from the view of both resources and research facilities. A number of Indian organizations have the beginnings of cleaner coal R&D programs, and some organizations are expanding their existing R&D capabilities, including BHEL and NTPC. Several of these are collaborating with well-known international organizations on preliminary investigative research work on IGCC and CCS technologies. These existing platforms could be expanded under CERDI.

Council of Scientific & Industrial Research (CSIR) – the premier industrial R&D organization in India. With 38 laboratories, CSIR is one of the world's largest publicly funded R&D organizations. CSIR's R&D portfolio embraces essentially all S&T R&D areas.

National Environmental Engineering Research Institute (NEERI) – a constituent of CSIR, with has five regional laboratories, was established in 1958 as the Central Public Health Engineering Research Institute, when the primary environmental concerns was on human health issues (water supply, sewage disposal, diseases, industrial pollution, and communicable/occupational diseases). With increasing worldwide public awareness on the environment on regional to global scale in 1970's, it was renamed as NEERI in 1974, with an expanded mission on research and innovations in environmental science and engineering and solving a range of national environmental problems by S&T intervention. NEERI has about 125 scientists in various core

disciplines of relevance to environmental science and engineering (e.g., environmental engineering, chemical engineering, environmental chemistry, and environmental biology). NEERI's budget in 2005-06 was only Rs. 23.90 Crore, or about US\$5 million, with funding received from the GoI, primarily CSIR and various industrial and foreign sources.

National Geophysical Research Institute (NGRI) – NGRI has a scientific staff of about 200, and focuses on exploration of hydrocarbon and mineral resources; engineering geophysics; assessment and management of groundwater resources and earthquake hazards. NGRI has initiated some projects, including cooperation with the United Kingdom and Norway, on estimation of India's potential to store CO₂ in continental flood basalts and via enhanced oil recovery (EOR). Under APP, NETL attempted to develop a joint project under the Cleaner Fossil Energy Task Force with NGRI and Columbia University to assess the potential to store CO₂ from the planned 100-MW IGCC demonstration project in the state of Andhra Pradesh being developed by APGENCO and BHEL. However, while NGRI was interested, the Ministry of Environment and Forests rejected formal registration of the project on the grounds that India wasn't ready for a CCS project.

Bharat Heavy Electrical Ltd. (BHEL) – BHEL, which has around 40,000 employees, is India's largest developer of power plants, with an installed base of 100 GW worldwide. During fiscal 2008-09, their annual turnover was approximately Rs 27,205 crore (US\$6 billion), which is expected to nearly double by 2012. Nearly Rs 5,405 crore (US\$150 million) – about 20% of the company's total turnover was achieved through commercialization of products and systems developed by its in-house R&D groups. However, historically, BHEL assimilated and updated/adopted state-of-the-art-technologies for the power and industrial equipment sectors acquired from world leaders through licensing and joint ventures rather than developing its own technologies. BHEL has placed increasing emphasis on R&D as a key driver of the company's evolution into the realm of next-generation products and systems. Significantly, during the year, BHEL spent over Rs 650 crore (US\$30 million) on R&D efforts – 40% more than the previous year. During fiscal 2008-09, BHEL spent 2.36% of its total turnover on R&D, which is among the highest in India for manufacturing companies. Formal cooperation between NETL and the BHEL has been discussed, including technical advice with expanding BHEL's R&D capabilities and joint R&D, such as modeling and simulation of advanced power plants and CCS-related technologies, especially oxy-fuel combustion. Initial discussions on formal cooperation have been held, but no decision has been made yet pending identification of specific projects, resource needs, and an appropriate cooperation mechanism.

NTPC Energy Technologies and Research Alliance (NETRA) – NTPC established NETRA to conduct research technology development and scientific services related to electric power generation. 75 acres of land have been purchased by NTPC for NETRA in Greater Noida (UP), of which 25 acres is earmarked for future pilot plant R&D facilities. NETRA's prime thrust areas are climate change, new and renewable energy, efficiency improvement, and clean and economic power generation. NTPC has committed 0.5% of its profit after tax towards R&D and another 0.5 % of its profit after tax towards climate change research. A Research Advisory Committee (RAC) comprising of eminent scientists and experts from India and abroad has been constituted to

steer NETRA for high-end research. An in-house Scientific Advisory Council (SAC) has also been constituted to guide the direction of scientific services and Technology Development. NETRA is involved in collaborative research projects with key national institutes and universities, including R&D research to develop economic technologies for clean coal, new and renewable energy, efficiency and reliability enhancement of thermal power generation, and CO₂ mitigation/fixation.

Formal cooperation between NETL and NETRA was proposed under the U.S.-India Energy Dialogue in 2007. Proposed cooperation included technical advice with setting up and expanding NETRA's R&D capabilities and joint R&D on areas, such as modeling and simulation of advanced power plants, especially IGCC and CCS-related technologies. Initial meetings were held following the 2007 Energy Dialogue Meeting on a new IGCC study including direct involvement of U.S. technology suppliers under the new Joint IGCC Task Force. NETL attempted to arrange a video conference to discuss next steps in late 2007 and early 2008 to discuss next steps; however, MoP and NTPC did not confirm their availability. Further discussions on formal NETL-NETRA cooperation have been held, including during the Assessment Team's visit, but no decision has been made yet pending identification of specific projects, resource needs, and an appropriate cooperation mechanism.

5.0 The Way Forward for India: Recommendations

This is a very dynamic period as major governments of the world are searching for a way forward on clean energy and climate change issues after the Copenhagen Climate Change Conference 2009. In addition, bilateral relationships, such as the one between the governments of the United State and India, are in the process of being redefined. However, across all of this uncertainty, emphasis on cleaner and more efficient energy technologies remains at the forefront of the interactions. USAID is renewing its focus on using development assistance to improve the lives of poor and impoverished peoples and to advance America's goals and values around the world. Initiatives focusing on improving supply side efficiency and in promoting adoption of new high-efficiency power systems will improve the quality of life by increasing access to reliable and responsibly generated electricity.

5.1 Cleaner Coal Technologies Deployment

Deployment of cleaner coal technologies through CERDI should focus on technical assistance from the United States on improving heat rates and other means to optimize the operations of existing coal-fired power plants and to accelerate adoption on advanced clean coal technologies, especially IGCC and CCS. A new phase of work with support from CERDI would assess emerging commercial technologies and promising new technologies with the corresponding skilled workforce development activities. This would be amplified by the service providers' network discussed in Section 5.2 and the model power plant concept in Section 5.3.

5.2 U.S.-India Service Providers Network

With the anticipated growth in thermal power generation in India, and the addition of captive power plants in the steel, cement, aluminum, and other energy-intensive industries, there is an imminent and critical need for service providers to meet the O&M needs of both existing plants and future power plants. The shortage of service providers is already being felt by NTPC, state and private utilities, and companies that operate captive power plants who rely on BHEL, the dominant original equipment manufacturer (OEM) in India, for their technical plant services. BHEL is the only service provider in India for all types of power plant equipment, large and small, and is stretched to the limit. Others, such as Alstom and ABB-Siemens, provide technical services, but they focus mainly on overhauling of major capital components (boiler, turbine-generator, and particulate control equipment) and R&M projects. At the lower end of the service providers' spectrum, such as performance improvement, troubleshooting of auxiliaries, and diagnostic services, there are only a few companies that conduct routine thermal audits for power plants. Their expertise is limited to conducting energy audits of the entire plant and providing a report on the heat losses and health of the peripheral components. Many Indian power plants are not aware of the range of performance improvement technologies, equipment, and systems that are available from developed countries, and are hesitant to modify existing equipment and systems, or change even simple operational practices, without the consent of their OEM. Such high dependence on the OEM and the profound lack of service providers to provide similar services are hampering the ability of Indian utilities to address maintenance problems in their plants on a timely basis.

Many of India's power plants, especially those operated by the state utilities, need to develop skills and tools to do the testing in-house and become familiar with where to procure such services and equipment in India and other countries such as United States. It is highly desirable to create a mechanism to offer key services from the United States that are critically needed for efficiency improvement in Indian power plants.

Recognizing this, in 2004, NETL collaborated with the Confederation of Indian Industry (CII) to submit an application to USAID for funding under its Global Development Alliance (GDA) to establish a Clean Coal Business Centre (CCBC) at the CII-Sohrabji Godrej Green Business Centre (GBC) in Hyderabad, India. The intent was to facilitate:

- Establishment in India of a network of indigenous, clean coal technology business service providers through a structured incubation/enterprise launching support system.
- Awareness of this network of indigenous clean coal technology business service providers and their capabilities within the Indian coal-fired power generation community.
- Recognition of the CCBC as the preferred destination in India for small/medium-sized U.S. service firms that seek work in the Indian power sector.
- Development and maintenance of a database of (a) specific clean coal business opportunities in India, (b) available U.S. clean coal technologies, and (c) U.S. clean coal technology business service providers.

- Provision of relevant clean coal business advisory services that could lead to the establishment of Indo/U.S. joint ventures, etc.
- Transition of USAID's successful assistance programs aimed at India's power sector to a self-sustaining, Indian-led organization.

The CCBC was to serve as an information clearinghouse to help India's coal power industry develop and sustain the institutional capacity required for planning and selection of technologies and best practices. The CCBC was to:

- Develop and maintain a database of U.S. equipment vendors and service providers. This database was to be a valuable resource for (1) reducing the time and cost of identifying, evaluating, and selecting equipment and service providers for existing and new capacity additions, (2) improving plant availability by improving outage planning, management, and execution, which reduces breakdowns and the time taken to accomplish all of the required tasks in a planned plant outage, and (3) maintaining plant operating efficiency at design standards.
- Provide training and human resource development through a balanced mix of India and U.S.-based training activities for Indian coal power plant and related environmental personnel.
- Convene and facilitate conferences, workshops, seminars, and symposia that address issues critical to the sustainable expansion of India's coal-fired capacity.
- Support and promote the development of a pool of Indian private sector service providers to meet current and future needs of India's coal power generation sector.
- Acquire, evaluate, make available, and disseminate through hard copy and electronic media the latest market, services, technologies, and R&D information.
- Provide a unique forum and platform to attract existing coal utility service providers and technology vendors in India and support their growth and expansion through association with U.S. partners.

Although the proposal was not funded, the CCBC concept became the foundation for establishment of a Service Providers Network in India. This concept was kicked off by convening the Power Plant Summit 2008 – Service Providers Network Conference (November 6-7, 2008, New Delhi). USAID, NETL, and CII collaborated on planning and convening of this event. At the event, participants were introduced to some of the latest technologies and products and services available to U.S. utilities. Over 150 delegates from the Indian power sector (public and private) attended the 2-day conference. A total of 16 service providers (15 from the United States and 1 from Japan) participated, covering a broad range of plant efficiency and diagnostic and testing improvement technologies and techniques, and O&M best practices, and monitoring systems. The participants agreed that enormous benefits would accrue to the India power sector by establishment of a service provider network. Following the event, two U.S. companies have returned to India to pursue business opportunities.

5.3 “Model” Plant for Cleaner Coal Technology Demonstrations

Going forward, the plant-by-plant approach that has been adopted by USAID and NETL in working with NTPC and several state utilities/SEBs under the GEP Project and APP Program is difficult to sustain, both from a resource and logistics standpoint. All the previous and ongoing work to improve the efficiency of existing Indian coal-fired power plants, which has and is yielding significant CO₂ emissions reduction, was spread by working on individual solutions in individual across India. Quantification of the overall impact on CO₂ emissions reduction, including the accumulative impact of the various strategies, has been difficult to obtain.

At the same time, the opportunity for GHG emissions reduction in the state utility/SEB plants, privately owned power plants, and captive power plants in the industrial sector and throughout the country is significant. The ideal setting to meet the needs of such a large customer base would be a central facility located at a power plant with facilities for training, laboratories, communication and data-links as well as “on-line” demonstration of technologies. The Electric Power Research Institute (EPRI) adopted this approach when it created training and demonstration facilities in the 1980s and 1990s at several power plants to meet the needs of the U.S. power industry. EPRI’s Monitoring & Diagnostic (M&D) Center at Philadelphia Electric Power Company (PEPCO), their Instrumentation and Controls (I&C) Center at TVA’s Kingston plant, and their Heat Rate Improvement Center at Potomac Electric Power Company are a few examples of where collaborative research and technology demonstration projects on behalf of the U.S. electric power industry were conducted. By applying many of the same, as well as new strategies, in a single location, the overall impact, as well as the impact of multiple interacting strategies, can be easily assessed.

The primary objective of a Model Plant in India is to:

- Establish a single facility where power plant efficiency improvement equipment, instrumentation, and best practices can be demonstrated and incorporated into existing plant operations and system maintenance strategies so that their applicability in Indian coal-fired power plants can be validated.
- Establish a single facility that can serve as a training center and disseminate proven power plant efficiency improvement equipment, instrumentation, and best practices throughout India.

The advantage of having all these resources and capabilities at a single plant location is that it will provide practical demonstrations of new technologies under real plant operating conditions. A Technology Transfer Center, located onsite with trained staff would host training workshops and seminars. Utilities can take advantage of the resources available at the center to improve upon their O&M practices as well as troubleshoot new equipment/instruments and solve lingering equipment problems.

One example of a technology demonstrated that has been proposed for the Model Plant is turbine upgrades. There are 53 LMW (Russian) 210-MW units in India that have the old Bowmann design stage in the Low Pressure (LP) turbine. The later LMZ turbines came with a

modified LP turbine without the Bowmann stage, and these machines generate an additional 6-8 MW from the same turbo-generator for the same steam flow. Other advances in tip seals, blade design, etc., have also contributed to better performance (2-3 % decrease in heat rate).

Some of the other technologies and services that can improve plant efficiency that could be considered are:

- Combustion optimization by coal and air flow balancing (used by AEP, Allegheny Power, Xcel Energy, etc.), pulverizer performance assessment and improvement (grindability, fineness, spills, etc.)
- Artificial intelligence-based plant control systems (e.g., Neuco) for intelligent soot blowing systems and overall plant optimization
- Real-time mapping and measurement of combustion (e.g., Zolo Technologies)
- Computational fluid dynamic (CFD) modeling of flue gas duct flows
- Isomembrane sealing of furnace roof and ducts (e.g., High Temperature Technologies)
- Plant performance software, such as ETAPRO™, AWARE™, Targeted Boiler Management™
- High-pressure boiler feed pump reengineering (e.g., HydroAir International)
- Infrared Thermography for Predictive Maintenance
- Acoustic technologies to assess boiler tube rupture, steam leaks in pipes, partial discharge in generator transformers
- Condenser cleaning and troubleshooting
- Steam turbine path audit
- Condition monitoring of high-temperature piping and supports
- Nondestructive evaluation (NDE) of boiler and turbine components
- Damage and remaining life assessment (RLA) of power plant components

The criteria for selection of the model plant will be developed by a committee of utility experts drawn from the Indian and United States, including both public and private sector utilities and consulting companies. To successfully demonstrate power plant heat rate/efficiency improvements, including O&M best practices and other clean coal technologies to achieve GHG emission reductions, selection of right partner for the model plant is critical. The criteria for selecting the suitable plant to develop into the model plant are both complex and somewhat subjective. The selection criteria should include, but not limited, to the following.

- Plant Commitment - A strong commitment to meet project goals from senior management of the participating utility is required up front. Such commitment would include adequate human and capital resources dedicated to the program and periodic mutually agreed upon data collection and analysis to assess progress, quantify improvements made, and to document efficiency gains including emissions reductions. Additional resources, if required, will be determined during the project design phase and will be communicated to the utility.

- Plant Operating Conditions - The designated plant should be operating at its rated capacity and close to the design parameters. The level of instrumentation available and the condition of the critical equipment needed for establishing baseline conditions necessary for full implementation must be acceptable to the expert group. To properly collect and manage the unit operating data prior to and after a technology is applied, it is important that the model plant have properly functioning instrumentation and data collection capabilities. A state-of-the-art data acquisition and handling platform, such as the PI Historian, is desired.
- Plant Vintage - The vintage of the designated plant may be critical in that, depending on the technology at the period of design, the level of impact of a particular new technology will vary. In general, a newer design plant with more recently engineered equipment may benefit less from a particular solution. The technologies deployed at the model plant should have commensurate impact on as many other Indian plants as possible.
- Plant Size and Type - The model plant should be somewhat representative of the overall India fleet. The selection criteria should include unit size, fuel fired, firing configuration and equipment type. The plant size should represent majority of the Indian fleet.
- Accessibility – The selected plant should be easily accessible either by rail, air, or ground to avoid daunting travel logistics.
- Plant Availability - The participating utility management should be willing to make the plant available for initial walk-down and assessment and subsequent periodic testing, evaluation, and training. The frequency and timing will be determined by the utility.

5.4 Cleaner Coal Technologies R&D

In addition to focusing on cleaner coal technology deployment, a number of critical needs should be addressed across the RD&D spectrum through CERDI. In particular, the increasing use of lower quality Indian coals along with blends of domestic and imported coals or other opportunity fuels (petroleum coke, biomass, etc.) is driving a need for increased R&D. This R&D program should focus on applied technologies that can be demonstrated at less than full commercial-scale facilities. These efforts need to be supported by partnerships among top Indian corporate research organizations, such as NTPC's NETRA, other independent research centers, including national labs (e.g., NEERI and NGRI), and leading Indian research universities.

Key Findings

- *Based upon the successes of the ongoing U.S. government-supported power plant efficiency improvement activities under USAID/India's GEP Project and the APP PG&T Task Force, two concepts for wider scale replication that could be supported under CERDI's deployment initiative are (a) creation of a service provider network, and (b) development of model coal-fired power plant.*
- *The GoI and Indian utility sector have expressed strong support for the service provider network and the model coal-fired power plant concepts, indicating that these activities are likely to be successful at expanding upon the ongoing work, which has avoided a total of more than 100 millions of CO₂ to date through low-cost technology demonstration and deployment activities.*
- *Through the ongoing programs, several U.S. companies have entered or expanded their business in the Indian utility market for power plant efficiency improvement technology and services. Significant opportunities exist for U.S. in this market space, which is largely unserved by Indian companies today, if support could be provided under CERDI.*
- *The primary cleaner coal R&D-related activities that could be supported under CERDI are (a) IGCC for high-ash Indian coal and to take advantage of the benefits of polygeneration, and (b) carbon capture, utilization, and storage (CCUS) for existing and new coal-fired power generation.*
- *Cleaner coal R&D cooperation on these areas under CERDI can be achieved by strengthening existing ties between U.S. and Indian universities, national laboratories, and other research organizations in cooperation with private industry to accelerate the transition of R&D results into practical applications.*